# EVALUATING LANDSCAPE CONNECTIVITY AND BOTTLE-NECKS FOR TIGERS (*Panthera tigris tigris*) IN TADOBA ANDHARI LANDSCAPE COMPLEX, MAHARASHTRA, INDIA

**THESIS**

**SUBMITTED TO THE**

**FOREST RESEARCH INSTITUTE (DEEMED TO BE) UNIVERSITY**

**DEHRADUN, UTTARAKHAND**

**FOR**

**THE AWARD OF THE DEGREE OF**

**DOCTOR OF PHILOSOPHY**

**IN FORESTRY**

**(FOREST GEOINFORMATICS)**

FRI

DEHRA DUN


**BY**

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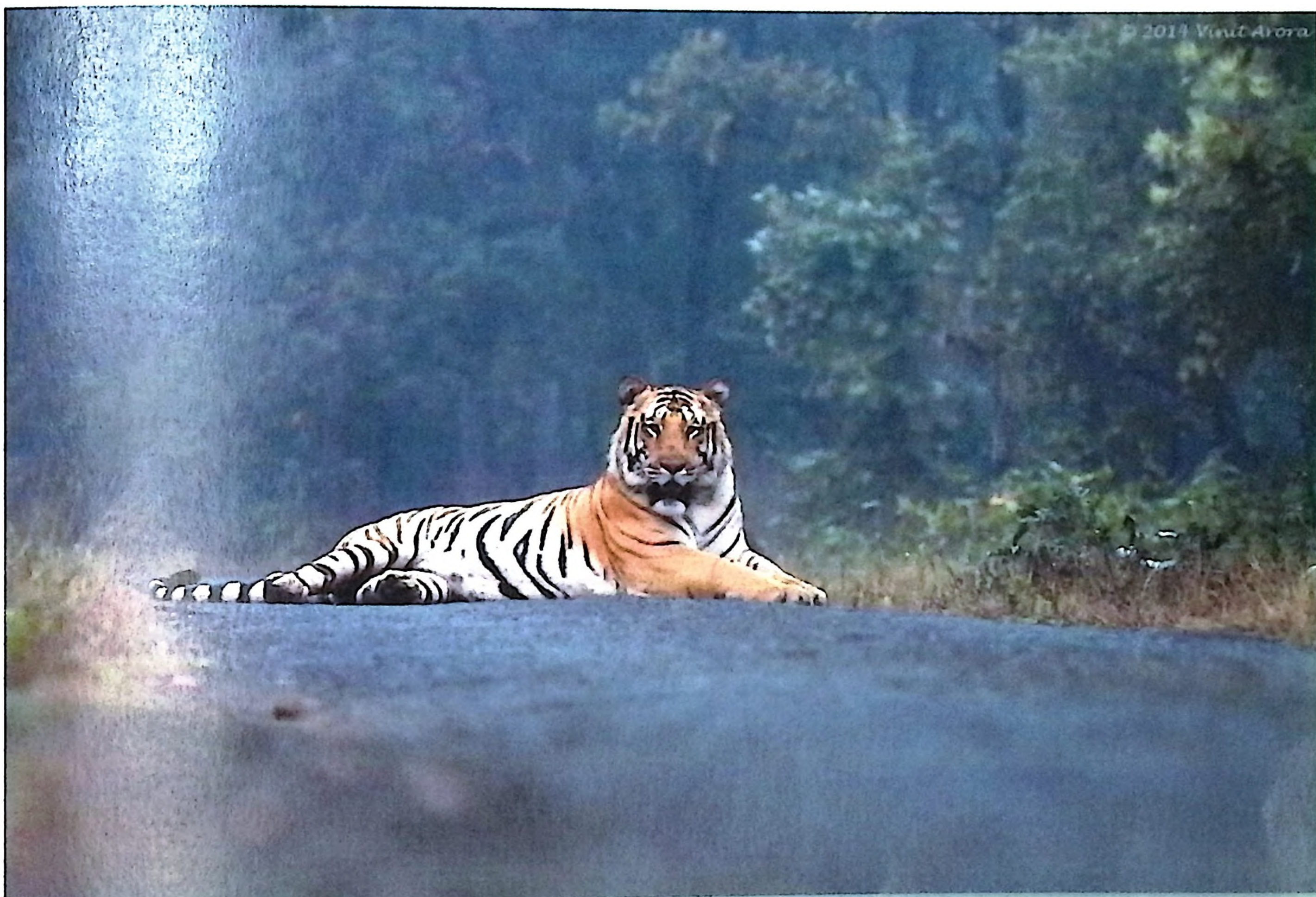
**2018**

(1 thesis Received on 9/4/18)

# *Dedicated to…..*

# *"Jai"*

*T1 (Jai) from Umred Karhandla Wildlife Sanctuary, the first collared tiger of this study.*




*His mysterious disappearance has taught us about the perils that tigers face in a human-dominated landscape, stressing upon the importance of radio-collaring studies to detect such perils.*

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

**Gautam Talukdar, Ph.D.**
Scientist E
Department of Protected Area Network,
Wildlife Management and Conservation Education

## CERTIFICATE

This is to certify that the thesis entitled **"Evaluating Landscape Connectivity and Bottle-necks for Tigers (*Panthera tigris tigris*) in Tadoba Andhari Landscape Complex, Maharashtra, India"**, submitted by **Mr. Indranil Mondal** (Regn. No. 13PHD274) to Forest Research Institute Deemed-to-be University, Dehradun for the award of the degree of **Doctor of Philosophy in Forestry (Forest Geoinformatics)** is a record of bona fide research work carried out by him under my supervision. No part of this thesis has been submitted for any other degree and it fulfills all the requirements laid down in the ordinance of the Forest Research Institute Deemed-to-be University, Dehradun for this purpose.

**Gautam Talukdar**
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Place: Dehradun
Date: 26th February, 2018

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This is to certify that Mr. **Indranil Mondal** enrolment no. **13PHD274** carried out research work under the supervision of **Dr. Gautam Talukdar**, Scientist E and co-supervision of **Dr. Bilal Habib**, Scientist E of Wildlife Institute of India. The topic of the research registered with FRI University was **"Evaluating Landscape Connectivity and Bottle-necks for Tigers (*Panthera tigris tigris*) in Tadoba Andhari Landscape Complex, Maharashtra, India"**. The scholar presented his work in the pre-thesis submission seminar held on **10.11.2017** and the RAC found the work to be satisfactory and approves the work to be presented in the form of thesis for evaluation by examiners for "Award of Ph.D. Degree" by Forest Research Institute Deemed-to-be University, Dehradun.

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## DECLARATION

I hereby declare that the thesis entitled **"Evaluating Landscape Connectivity and Bottle-necks for Tigers (*Panthera tigris tigris*) in Tadoba Andhari Landscape Complex, Maharashtra, India"** submitted by myself **Mr. Indranil Mondal** (Regn. No. 13PHD274) to Forest Research Institute Deemed-to-be University, Dehradun for the award of the degree of **Doctor of Philosophy in Forestry (Forest Geoinformatics)** is a record of original research work carried out by me under the supervision of Dr. Gautam Talukdar and Dr. Bilal Habib, Wildlife Institute of India, Dehradun and has not formed the basis for the award of any other degree or diploma. I also declare that the thesis embodies my own work, observations and analysis and in that respect the investigation appears to advance knowledge in the subject.

**Indranil Mondal**

Place: Dehradun
Date: 26th February, 2018

Countersigned:

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**Dr. Bilal Habib, Scientist E**
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**Sub:- Registration for Doctor of Philosophy Degree in Forestry.**

Dear Sir/Madam,

I would like to inform you that the following decisions have been taken for your enrolment as Research Scholar for the Degree of Doctor of Philosophy in Forestry in this Institute:-

1. You have been registered for Doctor of Philosophy w.e.f. **01.03.2014 to 28.02.2018** as Ph.D Research Scholar.

2. Your Enrolment number is: - 13PHD274
   **(For all further correspondence please quote your enrolment number.)**

3. Name of Research Centre: - **Wildlife Institute of India, Dehradun**

4. The Topic of research approved by the FRI University: **"Evaluating landscape connectivity and bottle-necks for tigers (*Panthera tigris tigris*) in Tadoba–Andhari landscape complex, Maharashtra India."**

5. Name of Discipline: - **Forest Geo-informatics**
   (As per clause 3.3 of the Ph.D. Ordinance)

6. (i) Name of Supervisor :- - **Dr. Gautam Talukdar**
   (ii) Name of Co-Supervisor:- - **Dr. Bilal Habib**

7.(a) You are advised to **deposit the next installment of Laboratory fee Rs. 5,000/- payable at FRIDU/Research Centre concerned through bank draft in the month of March, 2015**

(b) **Library fee of Rs. 2,000/- per year payable at FRIU/Research Centre concerned in the month of March for each year of registration till submission of thesis.**

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(d) **The above mentioned fee should be deposited during the due month i.e. March every year failing which a late fee of Rs.500/- (Bank Draft) will also have to be deposited in this office.**

(e) **You are also required to deposit the thesis fee Rs. 15.000/- and viva-voce exam fee Rs. 2,000/- at the time of submitting the thesis and viva voce exam respectively to the University.**

(f) **In case of extension of term of registration, the extension fee will also be charged. ( I$^{st}$ time Extension fee Rs. 25,000/- and for II$^{nd}$ time Extension fee Rs. 40,000/-).**

8. The research scholar is required to submit the six monthly progress report till the work is presented in the pre-thesis submission seminar and is approved by the committee for submission of thesis.
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i. Two consecutive six monthly progress reports are not submitted at all or are not satisfactory.

ii. The attendance of Research Scholar is less than 75% in any term.

iii. The scholar violates the clause 4.3 of the Ph.D ordiance regarding compulsion of 2 years Study leave for pursuing Ph.D in Case of in service candidates (except the employees of ICFRE and Research Center of FRI (Deemed) University).

10. No internal Ph.D. Scholar shall accept during the period of research any paid assignment apart from Research Fellowships. Research Assistantship etc. unless in the opinion of the RAC such an assignment will not interfere with his/her research work.

11. A Ph.D. Scholar shall not be permitted to take any other degree course. but may be permitted by the RAC to take part-time Diploma or Certificate course(s) not affecting the scholars research work adversely.

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13. **The Research Scholar may not later than three months from the date of issue of registration letter, modify the scheme of the research work or nature or scope of the subject, on the recommendation of the Supervisor and RAC, with the approval of Director.**

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15. **The research scholar should normally submit the thesis within 4 calendar years from the date of registration. Further extension of the term on yearly basis is possible only on specific recommendation of R.A.C., if approved by the R.D.C. However no extension is possible beyond 6 years of registration. The recommendation of Research Advisory Committee for extension of term of registration of the scholar should reach this office before expiry of term of registration.**

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**Encl:** **1. Fee receipt No.734 dated 14.08.2014 for Rs. 26,500/-**
**2. Format of progress report**

**Copy to:**

1. Dr. Gautam Talukdar, (Supervisor of the Scholar) Scientist-D, Wildlife Management and Conservation Education, Wildlife Institute of India, P.B. No.18, Chandrabani, Dehradun – 248 001, for information and necessary action.
2. Dr. Bilal Habib, (Co-Supervisor of the Scholar) Scientist-D, Department of Animal Ecology and Conservation Biology, Wildlife Institute of India, P.B. No.18, Chandrabani, Dehradun – 248 001, for information and necessary action.
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**(Dr. A.K. Tripathi)**
Registrar
FRI (Deemed) University

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Teachers have a huge role to play in a student's life during one's formative years and this defines what that person grows up to be, as a human being, a researcher or a scientist. I thank my teachers Mrs. Radhika Bagadthey and Ms. Tripti Singh for being huge inspirations during my school days. I owe a great deal to my geography teacher in school, Mrs. Sonali Sanyal for the immense interest in the subject of Geography that I developed at a young age. Later during my college and university days, I am indebted to Dr. Ashish Sarkar, my HoD in Presidency College, and Dr. Deepali Gadkari in Pune University respectively, for instilling and nurturing in me a growing interest in the subject of Geography. Deepali Mam, the recommendation letter that you wrote for me after I passed out from M.Sc., has been the best words that anyone has said about me as a student.

As a researcher during my Ph.D. I was lucky enough to be blessed with the perfect combination of supervisors that one can ever get: Dr. Gautam Talukdar and Dr. Bilal Habib. They have the perfect mix of qualities that a student needs from his/ her's supervisors to inspire, nurture and support them. Gautam Sir has always been very practical, straight forward and down to earth. His objective questioning to anything I proposed for my study helped me a lot to shape myself as a researcher. He was always quick to pull me down to earth when I was not being very practical. He instilled in me the quality to even question the smallest thing even if it may seem trivial. On the other hand, Bilal Sir has been the flamboyant and ambitious supervisor, always brimming with new ideas and I owe him a great deal for getting me all the funds that I needed for my study. Not just academically, both of them have been the source of a lot of life lessons that I have learnt during all these years. They have been the true friends, philosophers and guides one can ask for. Thank you Sirs, this work would not have been possible without your help, support and inspiration. I gratefully acknowledge Dr. Parag Nigam, who was a Co-Principle Investigator in my project, for all the help and support he provided. He has played a pivotal role in facilitating the collection of human-tiger conflict data for my study.

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Friends and colleagues form the support system of a student. I was blessed with a wonderful circle of friends and colleagues during my Ph.D. research. I am grateful to my lab mates Akanksha, Ankita, Pallavi, Hussain, Madhura, Nilanjan, Shaheer, Shivam, Shrushthi, Sougata and Zehidul, for standing beside me through good times and bad. Thank you all for all the love and support you guys provided.

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# EXECUTIVE SUMMARY


The theory of meta-population dynamics as proposed by Richard Levins in 1969 becomes more evident every day with wild animal populations being compartmentalized into far flung isolated habitats. Everyday animal populations are being driven into several isolated populations, and they face the risk of extinction as a consequence of demographic stochasticity which rises from the probable chance of inbreeding depression in smaller populations. It is important that these meta-populations are connected with an active source-sink dynamics in place for long term sustenance. The largest terrestrial carnivores of the world are wide-ranging species and most (77%) have experienced substantial population declines and range contractions (currently occupying on average only 47% of their historical ranges) throughout the world for the last two centuries. Such population declines and range contractions have been triggered by habitat loss, prey depletion, fragmentation and hunting by humans. Large carnivores need vast stretches of inviolate space for breeding and reproduction. Whatever remains of such inviolate habitats are also under constant stress with the percolating effect of anthropogenic pressure from the edge inwards. Aggressive development of linear infrastructure like roads, railways, canals etc. threaten the integrity of habitat corridors that could have ensured a viable meta-population.

The tiger features in the list of the most threatened large carnivores on this planet, with rapidly decreasing numbers across its range and a range reduction of 93%. Growth of human population and habitat loss does not hold a good picture for tigers in the future across its range. Several protected areas in Asia are relatively small and isolated. Where maintaining a connected tiger landscape is a global requirement, it is particularly important in a populous country like India with a rapidly growing human population undergoing rapid economic growth and development. India has 60% of the world's tigers with just 21% forest cover of which only 5% are inside PAs which are of inadequate size. The Central Indian Landscape (CIL) supports about 40% of India's tiger population and is a global priority landscape for tiger conservation, although it faces the same inherent problems of fragmentation and habitat destruction. Human presence and resource extraction in these forests are very high and there is a gradual conversion of forest land for agricultural purposes. Although the CIL has major source populations and an active source-sink and meta-population dynamics, maintenance of habitat connectivity is an imperative for the long term survival of the tiger in this important

tiger conservation landscape. The Tadoba Andhari Landscape Complex (henceforth EVL; 18° 11' 20.69" N to 21° 43' 15.79" N and 78° 03' 37.09" E to 80° 54' 09.42" E) commands a pivotal position in this landscape. It has a tiger population of about 150 and plays a key role in exchange of individuals and thereby facilitates gene flow in CIL. EVL has 6 protected areas (PAs) but they are scattered in a human-dominated landscape. Most of the studies in Central India on tiger corridors have been done using genetic data, expert opinion, or VHF radio collars and lacks adequate sampling from areas outside PAs. Such approaches fail to provide a robust and spatially explicit status of habitat connectivity outside PAs. The current study addresses these gaps and employs empirical models using a large sample of data points from areas outside PAs and a carefully selected set of eco-geographical variables.

Tiger presence data (n=310) from outside PAs and 6 eco-geographical variables were used to develop a MaxEnt model of habitat permeability for tigers in EVL. Model evaluation and the selection was done using Akaike information criterion (AICc), where the model with the lowest AICc value was selected as the final model. The habitat permeability surface was then used in Circuit Theory framework to delineate corridors for tigers using Circuitscape software. A combination of least cost pathway and Circuit Theory was used along with centrality analysis to identify pinch points or bottlenecks along the modelled corridors. Generated corridor and pinch point surfaces were categorized using Jenks Natural Breaks Optimization and area statistics were calculated. Land use/ land cover (LULC) statistics were also calculated in each of these categories. Tiger movement data from two sub-adult males (514 and 363 days), one adult male (75 days) and two adult females (78, and 66 days) totaling 14,299 GPS fixes was used to validate the modelled corridors. 7,555.28 $km^2$ of tiger corridors were identified in EVL. LULC statistics show that our modelled corridors constitute mainly Deciduous Forests followed by areas of agriculture (mainly monsoon and double/ triple crops) and to some extent by wasteland areas (read: scrubland in monsoon). Validation exercise shows that the modelled corridors are 76% accurate. The study also modelled several pinch points across the length and breadth of EVL.

It was hypothesized that when areas of high human use and high tiger use overlap the chances of human-tiger conflict is high. To test the hypothesis human-tiger conflict locations were collected from the landscape surrounding Tadoba Andhari Tiger Reserve in EVL, where an encounter has either led to human injury or death and a Chi-squared test was comducted. Spatial and seasonal pattern of human-tiger conflict was also investigated using Chi-squared tests to see if they varied across different LULC classes and seasons. The null model identified 2000, 3600 and 3375 $km^2$ area as areas with a very high, high and medium chances of conflict respectively. 36.41% of the total human population of EVL was found vulnerable to human-tiger conflict. Besides, the chi-squared test results indicate that with an increase in conflict potential in each category (null hypothesis/ null model), we have also seen a significant rise in actual conflict incidents in each category, $\chi^2$ (6) = 36.9780, $p < 0.001$. Chi-squared test results show that there was no significant different across seasons, $\chi^2$ (2) = 1.8016, p = 0.2031. Chi-squared test results of conflict occurrences in different LULC categories suggest that it did differ significantly across various categories, $\chi^2$ (7) = 38.949, $p < 0.001$, where it was significantly higher in deciduous forest areas (n=65), followed by cultivated areas (n=43) as against other LULC classes like Wasteland (n=4), Plantation/ orchard (n=3), Scrubland (n=2) and Waterbodies (n=1). Human-tiger conflict significantly varied across different seasons in monsoon croplands and wasteland areas only.

Tiger movement data was analyzed and pockets were identified in the landscape outside PAs where they were spending a considerable amount of time while dispersing or exploring. The eco-geographical characteristics of these pockets were extracted and based on this information we extrapolated it to other areas of the landscape using a MaxEnt model. By extrapolation, the study aimed at identifying patches potentially similar to the ones indicated by the tracking data, which may provide refuge to the dispersing or exploring tigers. Radio-collar data from two sub-adult males (514 and 363 days), one adult male (75 days) and three adult females (78, 66 and 422 days) totaling 14,448 GPS fixes was used to calculate Linear Time Density (LTD) Home Range in 500 X 500 m grids across the landscape. ArcGIS (ArcMET) 10.2.2v3 was used for this analysis. The LTD values were then divided into ten bins using Jenks Natural Break Optimization, the grids which fell in the four highest bins were selected centroid points of these selected grids were generated. Centroid of these grids and 17 non-autocorrelated eco-geographical variables were used in the MaxEnt model. The model identified 1587.88 $km^2$ area of refuge patches across the landscape. Securing these parcels of land is of paramount importance to aid tiger habitat connectivity in the landscape, as it provides stepping stones in a fragmented human-dominated landscape.

The current study has identified 7555.28 $km^2$ of area outside PAs that are crucial for the dispersal and movement of tigers in the Eastern Vidarbha Landscape (EVL) in CIL of which only 2481.23 $km^2$ (32.84%) fall inside notified forest lands. This area includes reserve forest, unprotected forests, and privately owned lands covered by forested or agricultural land use. These areas come under the "Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act" (Ministry of Law Justice, 2007) enabling local communities to derive their livelihood from these lands, including the forest. When important areas that needs to be conserved are outside the jurisdiction of the forest administration, resources directly available for conservation is limited. In the 3rd Asia Ministerial Conference on Tiger Conservation 2016 held in New Delhi, both the Honorable Prime Minister of India and the Honorable Minister of Environment, Forests and Climate Change addressed the government's initiative to save tiger corridors. They reflected a general positive public will toward tiger conservation, with further assurance being provided by available Government funds and policies. To effectively tap into all these resources and public will, we must follow an unconventional approach to prioritize alternative funding streams, where we channel available resources by prioritizing from among various schemes of government ministries/departments and also the corporate sector for tiger corridor conservation. This study proposes a novel approach to harness resources available from these sources. The merit of this proposed approach is its ability to draw resources from sectors, where tiger conservation is not the primary goal. It talks about harnessing funds available under various schemes with the Ministry of Rural Development and with various tiger states to formulate policies that indirectly benefit conservation of tiger habitats and corridors. If pursued, the strategies suggested in this study can clearly and objectively apportion funds from peripheral sources for corridor conservation that have been hitherto invisible and/or seldom tapped into. The crux lies in intelligently formulating policies and schemes to mainstream conservation for agencies without conservation mandates.

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| | |
|---|---|
| AIC | Akaike Information Criterion |
| AWiFS | Advanced Wide Field Sensor |
| DMSP | Defense Meteorological Satellite Program |
| EVL | Eastern Vidarbha Landscape |
| FDCM | Forest Development Corporation of Maharashtra |
| GIS | Geographical Information System |
| GPS | Global Positioning System |
| $H_0$ | Null Hypothesis |
| LTD | Linear Time Density |
| LULC | Land Use and Land Cover |
| MAXENT | Maximum Entropy |
| MH | Maharashtra |
| MP | Madhya Pradesh |
| NBT | National Biodiversity Target |
| NDVI` | Normalized Difference Vegetation Index |
| NGO | Non-governmental Organization |
| NNTR | Navegaon Nagzira Tiger Reserve |
| NOAA | National Oceanic and Atmospheric Administration |
| NRSC | National Remote Sensing Centre |
| OLS | Operational Linescan System |
| PA | Protected Area |
| SDM | Species Distribution Model |
| TATR | Tadoba Andhari Tiger Reseve |
| TCL | Tiger Conservation Landscape |
| TCU | Tiger Conservation Unit |
| TR | Tiger Reserve |
| VHF | Very High Frequency |
| WLS | Wildlife Sanctuary |

# CHAPTER 1
# INTRODUCTION

# CHAPTER 1: INTRODUCTION

## 1.1. Meta-population dynamics

The theory of meta-population dynamics as proposed by Richard Levins in 1969 becomes more evident every day with wild animal populations being compartmentalized into far flung isolated habitats. The isolation is not only defined by the distance between these populations but also by the characteristics of the non-habitat matrix into which they are embedded (Fahrig and Merriam, 1994; Ricketts, 2001). Driven into several isolated populations, they face the risk of extinction as a consequence of demographic stochasticity which rises from the probable chance of inbreeding depression in smaller populations (Levins, 1969; Verboom et al., 1991). Although these isolated populations are at risk, the meta-population as a whole (protected area network) may still be stable if there is a flux of immigrants and emigrants (Hanski, 1994; Harrison, 1991). Such a flux is only possible with an active source-sink dynamics in place where individuals from one population (source; high quality habitat) re-colonize habitats (sink: low quality habitat) vacated by the extinction of another population (Hanski, 1991; Hanski, 1998). Therefore connectivity between isolated habitats is an important component of a meta-population.

## 1.2. Large Carnivores

The largest terrestrial carnivores of the world are wide-ranging species and most (77%) have experienced substantial population declines and range contractions (currently occupying on average only 47% of their historical ranges) throughout the world for the last two centuries (Ripple et al., 2014; Wolf and Ripple, 2016). Such population declines and range contractions have been triggered by habitat loss, fragmentation and hunting by humans (Karanth and Chellam, 2009). Large carnivores need vast stretches of inviolate space for breeding and reproduction. Whatever remains of such inviolate habitats are also under constant stress with the percolating effect of anthropogenic pressure from the edge inwards. For a meta-population of large carnivores to be viable, suitable habitat patches, which may be far away from one another separated by a matrix of unsuitable land use, should be connected by corridors. Aggressive development of linear infrastructure like roads, rails, canals etc. (Ceia-Hasse et al., 2017; Espinosa et al., 2018; Habib et al., 2016; Laurance and Arrea, 2017) threaten the integrity of corridors. Depletion of prey worldwide has also been identified as a major cause of decline of large carnivores, with 40-50% of their prey species classified as threatened in the IUCN Red List living in habitats of which only 6.9% are protected (Wolf and Ripple, 2016). Cardillo et al., (2004) suggest that although extinction risks in large carnivores are largely determined by how their biology is altered under changes in their environment, 80% of the extinction risk is explained by changes in their biological traits in presence of high-density human populations. Such pressures of habitat loss, prey decline and hunting/ poaching has been the reason of local extinctions of large carnivores like the Asiatic Cheetah in India and the Tiger in Panna and Sariska Tiger Reserve in the Central Indian landscape (Divyabhanusinh, 1999; Sankar et al., 2010).

### 1.3. The Tiger

The tiger features in the list of the most threatened large carnivores on this planet, with rapidly decreasing numbers across its range (Wikramanayake et al., 1998) and a range reduction of 93% **(Figure 1.1)**.

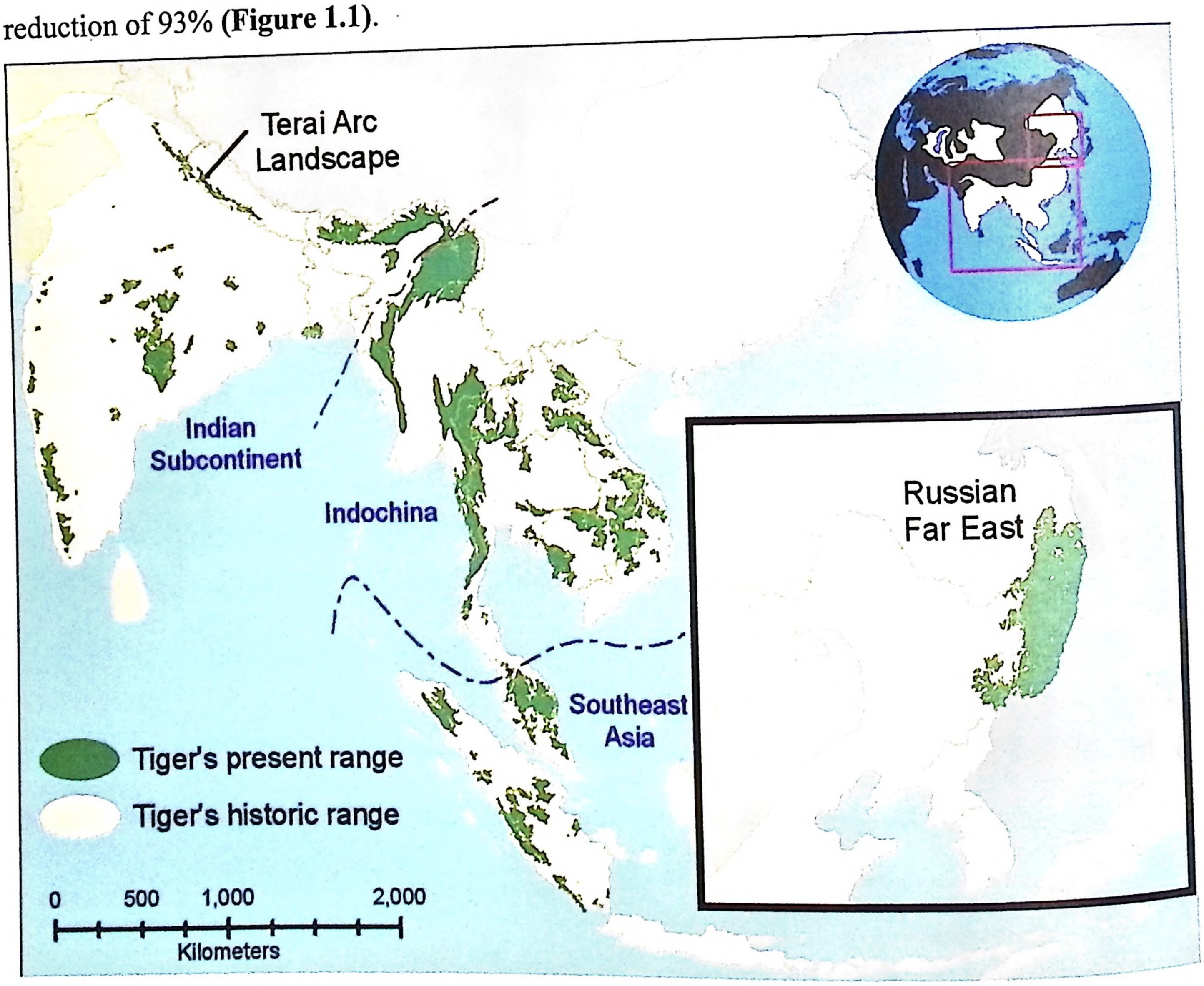


Figure 1.1: Range reduction of tiger (*Panthera tigris*). *Source: Dinerstein et al., 2007.*

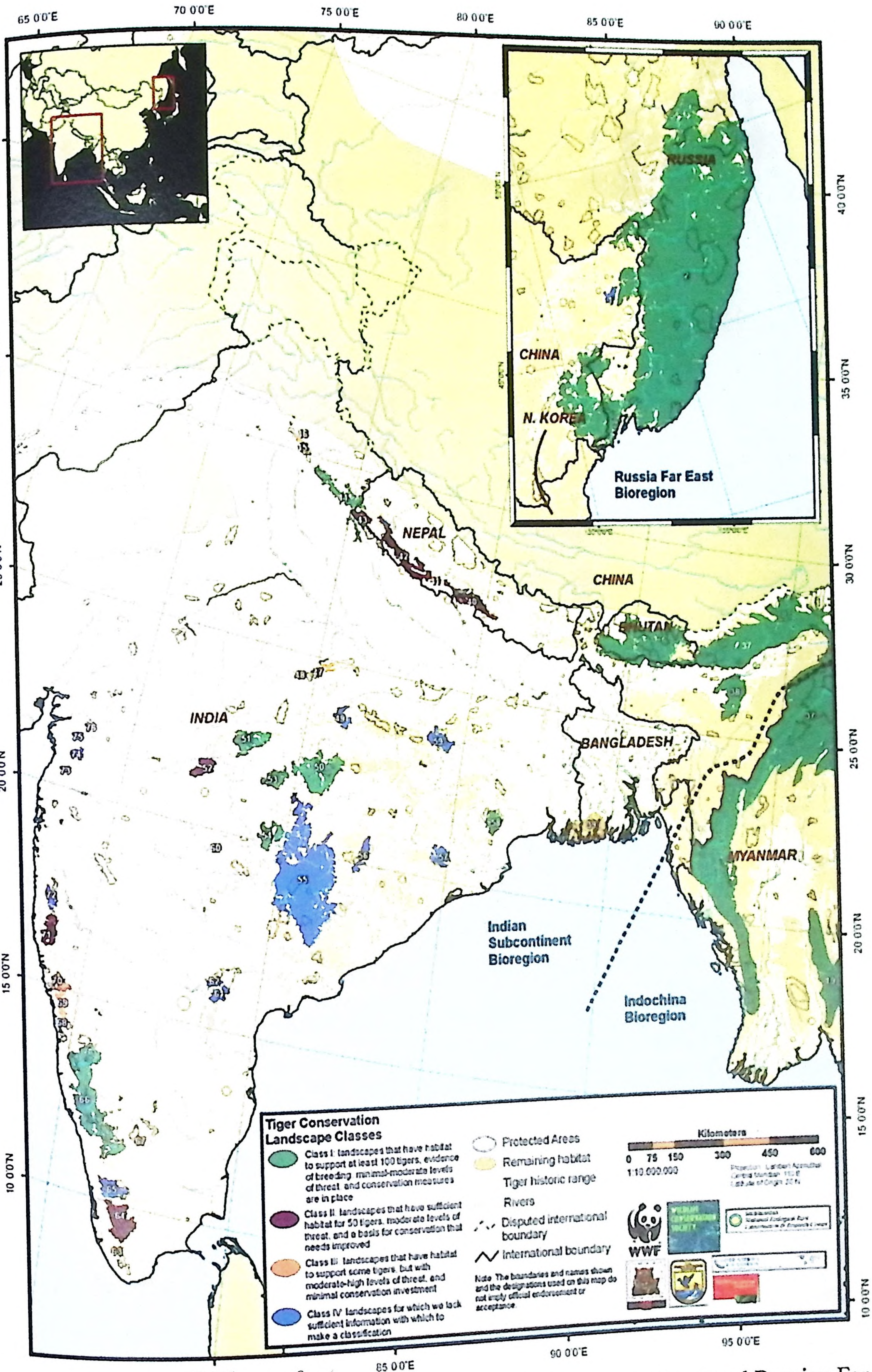


Figure 1.2: Tiger Conservation L Landscapes (TCLs) Indian Subcontinent and Russian Far East/China bioregions. Numbers refer to specific TCLs as listed in Sanderson et al., (2010).

An aggressive growth of human population and loss of its natural habitat across the continent of (Dinerstein & Wikramanayake, 1993) paints a grim picture for tiger in the future. The past 25 years have seen an increase in threats to tigers as a result of poaching, prey decline and destruction of valuable habitat (Nowell & Jackson, 1996). Several protected areas in Asia are relatively small and isolated (Dinerstein & Wikramanayake, 1993). Long-term survival of animals like large carnivores in such protected areas have a slim chance (Seidensticker, 1987; Rabinowitz, 1993) if these habitats are not linked to allow dispersal of tigers and their prey and are shielded by buffers to minimize impacts from other land uses around. Therefore, a landscape-level approach including corridors and buffer zones is essential to ensure long-term tiger conservation of tigers (Karanth, 1991; Karanth & Sunquist, 1995; Nowell & Jackson, 1996). In the Indian subcontinent bioregion, which also includes Nepal and Bangladesh, Wikramanayake et al., (1998) identified 59 Tiger Conservation Units (TCUs) which covers an area of 325,575 $km^2$ of which only 54,945 $km^2$ (16.87%) are protected. The Central Indian landscape contains 107,440 $km^2$ of TCUs of which 59,465 $km^2$ are Level I and Level II TCUs (Wikramanayake et al., 1998).

The concept of TCUs were further revised in 2010 (Sanderson et al., 2010) after a decade of studies leading to a better understanding of the role of prey communities in sustaining tiger populations (Karanth et al., 2004), how tiger densities vary across their range (Carbone et al., 2001), and with better techniques to estimate their abundance and monitor their population trends (Karanth et al., 2004). Unifying the disjoint findings of these studies Sanderson et al., (2010) proposed a new and improved framework of Tiger Conservation Landscapes (TCLs) **(Figure 1.2)** which was a result of the availability of a more accessible, highly accurate and spatially explicit dataset, and the availability of computational tools like as geographic information systems (GIS) and landscape modelling. Sanderson et al., (2010) classified the TCLs into 4 categories (Class I, II, III and IV). Class I indicates reserves which are source populations with a sizeable breeding population, sufficient area, good prey base and reduced threat levels. Classes down the list need to more efforts to restore habitat and prey and reduce threats to read at par with Class I and with dedicated efforts may even reach that level in a decade or two. Class IV are the ones where TCLs lack enough information to suitably put them into any class and proper surveys are required. Again in TLCs, as in TCUs, the Central Indian Tiger reserves feature heavily as source populations. It includes 5 reserves: Tadoba Andhari, Pench, Kanha and Satpura Tiger Reserve in TCL Class I and Melghat Tiger Reserve in Class II. A range-wide assessment of the TLCs by Wikramanayake et al., (2010) under 3 conservation scenarios (status quo, enhanced connectivity and habitat restoration, and stopping of tiger poaching to feed Chinese markets) show that with enhanced connectivity and habitat restoration with curbed poaching a 53% increase in favourable tiger habitats as covered under the TCLs can he achieved **(Figure 1.3)** in the Indian Sub-continent alone.

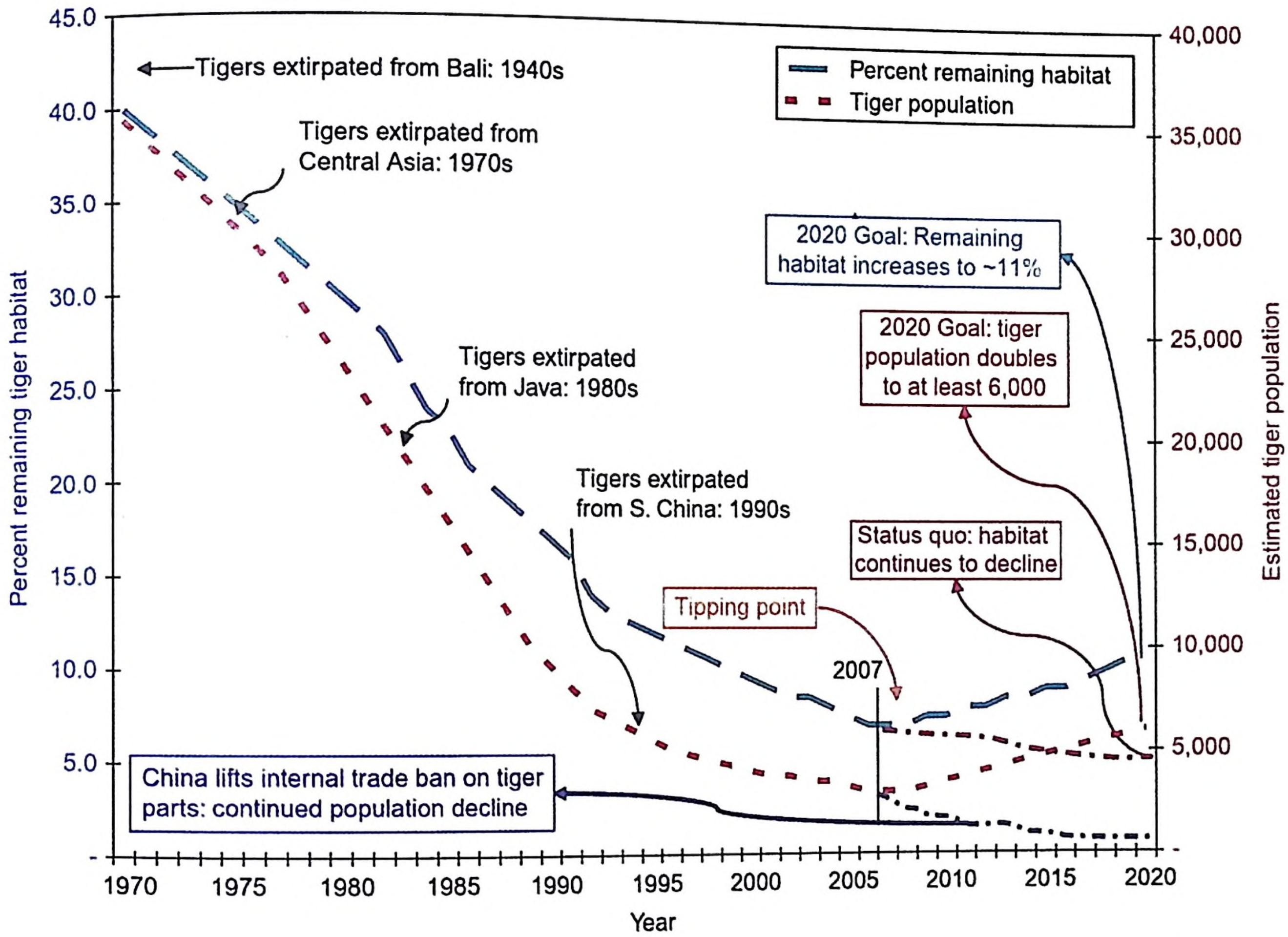


Figure 1.3: Graphical representation of loss of tiger habitat and population and potential trajectories based on future scenarios. *(Source: Wikramanayake et al., 2010).*

## 1.4. The Central Indian Tiger Landscape

Where maintaining a connected tiger landscape is a global requirement, it is particularly important in a populous country like India with a rapidly growing human population of 1.2 billion (Census of India, 2011) undergoing rapid economic growth and development (FAO, 2006). India has 21% forest cover out of which only 5% is under PAs, but also 60 % of the global population of wild tigers. This population is restricted to the Western Ghats, Central Indian Landscape (CIL), the Terai Arc landscape, Eastern Ghats, Northeast India, the Sundarbans and some patches in Western India (Jhala et al., 2015). CIL supports about ~40 % of the total tiger population in India (Jhala et al., 2015) and has been demarcated as a global priority landscape for tiger conservation (Sanderson et al., 2010), but it has the inherent problem of fragmentation and habitat destruction. Although the Central Indian meta-population of tigers is functionally connected, the corridors are highly fragmented in the structural sense, with the forest cover being lost to agriculture. The human presence in these forests is very high, where the forests are heavily used by local people for fuel wood, fodder and other livelihood needs. So although the CIL has major source populations and an active source-sink and meta-population dynamics, maintenance of habitat connectivity is an imperative for the long term survival of the tiger in this important TCL.

### 1.5. Study area

The Tadoba Andhari Landscape Complex (henceforth the Eastern Vidarbha Landscape or EVL) or the Nagpur Division is one of six administrative divisions of Maharashtra State in India. Nagpur is the easternmost division in the state, with an administrative headquarters in the city of Nagpur **(Figure 1.4)**. It lies between 18° 11' 20.69" N to 21° 43' 15.79" N and 78° 03' 37.09" E to 80° 54' 09.42" E. It encompasses an area of about 50,000 $km^2$ covering the six districts of Bhandara, Chandrapur, Gadchiroli, Gondia, Nagpur, Wardha. It houses a human population of 1,17,54,434 people (Source: Census of India, 2011), and at the same time has a forest cover of about 20,000 $km^2$ (India State of Forest Report, 2017). EVL lies within the biogeographic zone the Deccan Plateau (Rodgers and Panwar, 1988) and dominant vegetation type is dry deciduous forests (Champion and Seth, 1968). Elevation in EVL ranges from 64 to 930 m **(Figure 1.5)**. This patch of forest is very important as it harbours a population of about 150 tigers and forms the connecting link between the central and southern Indian tiger populations. It plays a pivotal role in exchange of individuals and thereby facilitates gene flow between these two populations increasing the viability of tiger populations in India. There are 6 protected areas where these tigers live, but these refuges are scattered like islands in a sea of human dominated landscape.

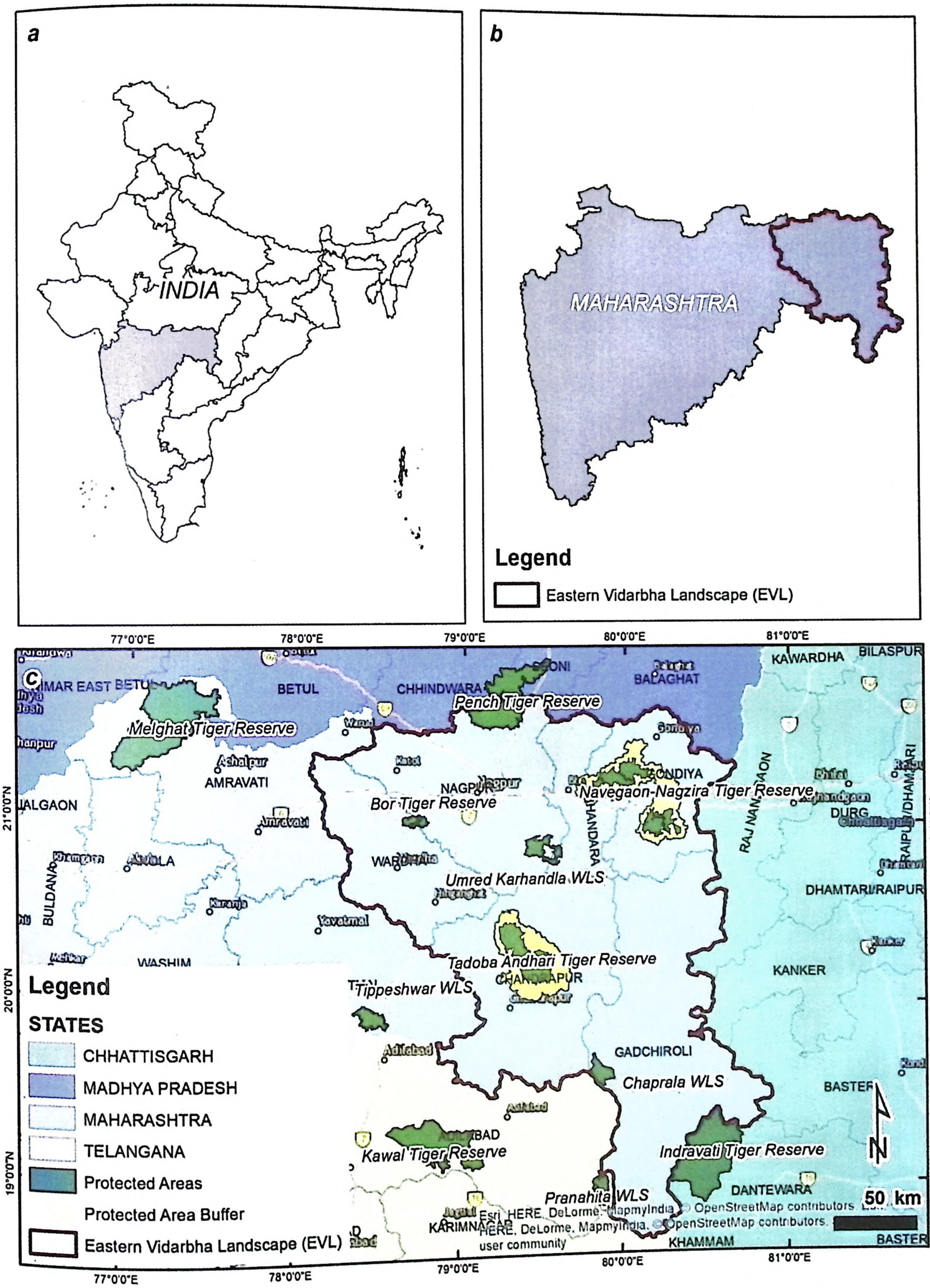


Figure 1.4: a) State of Maharashtra b) location of EVL in the state of Maharashtra and c) Political map of EVL on the easternmost part of Maharashtra surrounded by 3 states.
**Data sources:** *Political boundaries: Survey of India; Protected area boundaries: Wildlife Institute of India, GIS Cell; Elevation: National Remote Sensing Centre; Landuse/ Landcover: National Remote Sensing Centre*

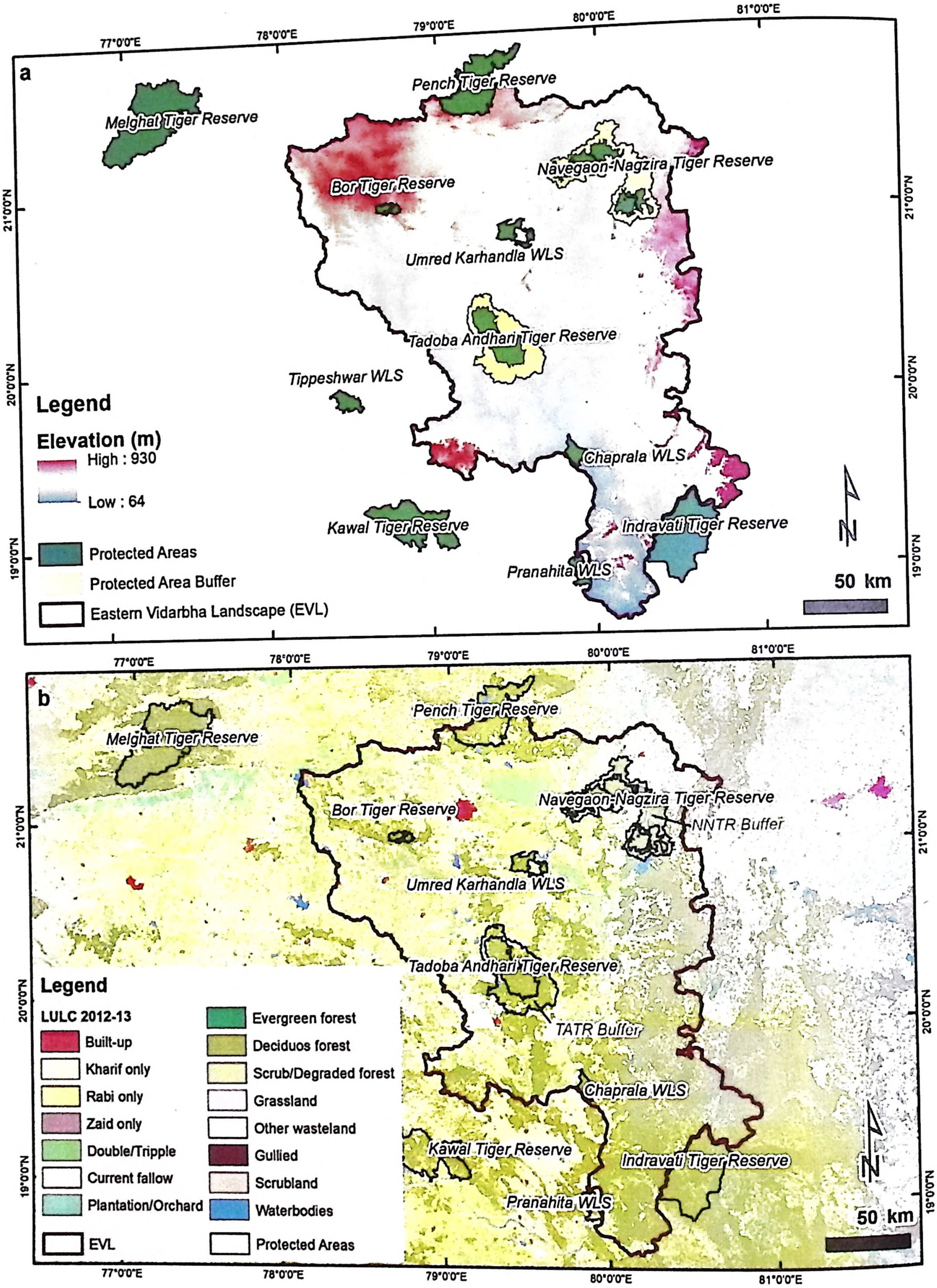


Figure 1.5: a) Elevation map of EVL b) Landuse/ Landcover map of EVL.

***Data sources:*** *Political boundaries: Survey of India; Protected area boundaries: Wildlife Institute of India, GIS Cell; Elevation: National Remote Sensing Centre; Landuse/ Landcover: National Remote Sensing Centre*

### 1.5.1. Land use/ land cover characteristics in Eastern Vidarbha Landscape

**Table 1.1** indicates the various land use categories found in EVL **(Figure 1.5 a)**. The major Land Use or Land Cover are forest areas followed by agricultural land. Although built-up areas constitutes 0.52% of the total geographical area, human population densities in some of these settlements is as high as 11,000 persons/ km$^2$. Most of the forest here is managed by the Maharashtra Forest Department but with different mandates inside and outside PAs. Inside PAs it is about protecting the wildlife and its habitat and to prevent poaching, while outside (territorial forests) it focuses on social forestry, production and regulate extraction of forest products. In certain pockets the Forest Development Corporation of Maharashtra (FDCM) manages, maintains and markets monoculture stands of valuable trees like teak and bamboo.

Table 1.1: Land use/ land cover statistics of Eastern Vidarbha Landscape. *(Source: Bhuvan, National Remote Sensing Centre).*

| **Sl. No.** | **LULC Category** | **Area (sq. km.)** | **% of total geographical area** |
|---|---|---|---|
| 1 | Built-up | 256.81 | 0.52 |
| 2 | Kharif only crop | 12,193.23 | 24.63 |
| 3 | Rabi only crop | 289.66 | 0.59 |
| 4 | Zaid only crop | 7.77 | 0.02 |
| 5 | Double/Tripple crop | 11,180.05 | 22.59 |
| 6 | Current fallow | 125.56 | 0.25 |
| 7 | Plantation/Orchard | 167.79 | 0.34 |
| 8 | Evergreen forest | 0.40 | 0.00 |
| 9 | Deciduos forest | 17,666.89 | 35.69 |
| 10 | Scrub/Degraded forest | 625.77 | 1.26 |
| 11 | Other wasteland | 2,116.75 | 4.28 |
| 12 | Scrubland | 3,750.67 | 7.58 |
| 13 | Waterbodies | 1,115.27 | 2.25 |
| **TOTAL** | | 49,496.61 | 100.00 |

*LULC = Land Use and Land Cover*

EVL also presents a high human-wildlife interface in the form of a 37,017.31 km long forest-agriculture edge **(Table 1.2)**, which forms a breeding ground of human-tiger conflict in the form of cattle and crop depredation, attacks on humans as well as mortality of wild animals from electrocution.

Table 1.2: Amount of forest-agriculture edge in EVL

| Forest classes | Amount of edge with agriculture (km) |
|---|---|
| Plantation | 809.55 |
| Evergreen | 1.30 |
| Deciduous | 3,123.44 |
| Scrub/ Degraded | 1,303.10 |
| Scrubland | 31,779.92 |
| **TOTAL** | **37,017.31** |

A large part of tiger use areas in EVL lie outside the PA network and under different land ownership tenures. It is in such areas that the poor farmers often set up illegal high-voltage electrical fences around their fields drawing power from electrical lines meant for home or agricultural use to safe guard their crop from wild ungulates. Subsequently, tigers using human dominated landscape like agriculture fields to move about, are at a great risk when they encounter such fences.

### 1.6. Scope of the current study

Most of the studies in Central India on tiger corridors have been done using genetic data (Joshi et al., 2013; Reddy et al., 2017; Sharma et al., 2013 a; Sharma et al., 2013 b; Thatte et al., 2018; Yumman et al., 2014). Dutta et al., (2016) used information from published studies to parameterize their model to delineate tiger corridors. Only one study has used movement data on collared tigers, where they used data from only one GPS collar and 3 VHF collars (Ramesh et al., 2016). Although results from genetic studies may indicate that source and sink habitats are functionally connected by means of exchange of individuals over time, they fail to elucidate the functionality of corridors between PAs in space. When corridors are highly threatened by habitat fragmentation and degradation, it is imperative to know their explicit spatial status with respect to the permeability they provide for exchange of individuals, thereby leading to the meta-population being functionally connected. Under such situations, a model based on expert opinion (Dutta et al., 2016), VHF locations obtained by triangulation (Ramesh et al., 2016), or data from a single collared dispersing individual (Ramesh et al., 2016), falls short of the necessary prerequisites to build a robust model.

The current study addresses these gaps and uses a set of tiger presence locations obtained from sign surveys and camera trapping exercises from areas outside protected areas to build a model to delineate corridors and even goes to the extent of explicitly demarcating them on the ground (down to the village level). This study also uses location from 8 GPS radio collars from 5 individuals to validate the modelled corridors to assess the accuracy of the model. Besides, the current study investigates the spatial and seasonal pattern of human-tiger conflict along the modelled corridors, a threat that act as a hurdle for tiger conservation in this landscape. It further delineates patches along the corridor to prioritize conservation action using location data from 8 GPS radio collars of 5 individuals. These identified patches act as refuges for tiger during movement in a human dominated landscape.

## 1.7. Objectives of the study

The principle aim of this study is to study habitat connectivity for tigers in the human-dominated landscape, outside protected areas, in EVL and also to investigate various threats to tiger movement in the landscape. The study focuses on modelling potential movement corridors for tigers in EVL using field collected presence data and then validate then using data from radio collared tigers. Weak links (pinch points/ bottlenecks) along corridors are also modelled which needs immediate attention from the management for conservation. Human tiger conflict forms a major barrier for the movement of tigers in the landscape as it decreases the tolerance of people towards the presence of tigers near them. We investigated the spatial and seasonal pattern of such conflict in thus study. Knowing the location of corridors and pinch points, or knowing about the hotspots of human-tiger conflict is counter-productive in such a large landscape unless one knows where to start addressing them. This study uses tiger movement data from areas outside PAs to model refuge areas/ patches, which maybe used by tigers as stepping stones while moving in this human-dominated landscape.

To address the above aims, this study was designed with the following objectives:

1. Mapping of habitat connectivity between various Protected Areas in Tadoba Andhari Landscape (EVL),
2. Modelling connectivity Bottlenecks and Pinch points in EVL,
3. Investigate human-tiger conflicts around Bottlenecks and Pinch points, and
4. Prioritization of Bottlenecks or Pinch Points for restoration and recovery in EVL

## 1.8. Chapter organization

Chapter one describes the background and the need for studying habitat connectivity for large carnivores like tigers in a human-dominated landscape. It also describes the global status of tigers and its status in the Central Indian context. This chapter also talks about the study area, scope and objectives of this study.

Chapter two merges the first and second objectives and describes the methods and results of modelling corridors and pinch points/ bottlenecks for tiger in EVL.

Chapter three deals with investigation of the spatial and seasonal pattern of human-tiger conflict along corridor areas in EVL.

Chapter four talks about the process of modelling refuge areas for dispersing/ exploring tigers in the landscape and how the results can be used to prioritize patches in the landscape to provide stepping stones to tigers to navigate a human-dominated landscape.

Chapter five concludes the study by providing options for tiger conservation in a human-dominated landscape under penny scare scenarios, where it talks about unconventional funding sources in the government and corporate sector that can be channelled to aid conservation of tiger corridors.

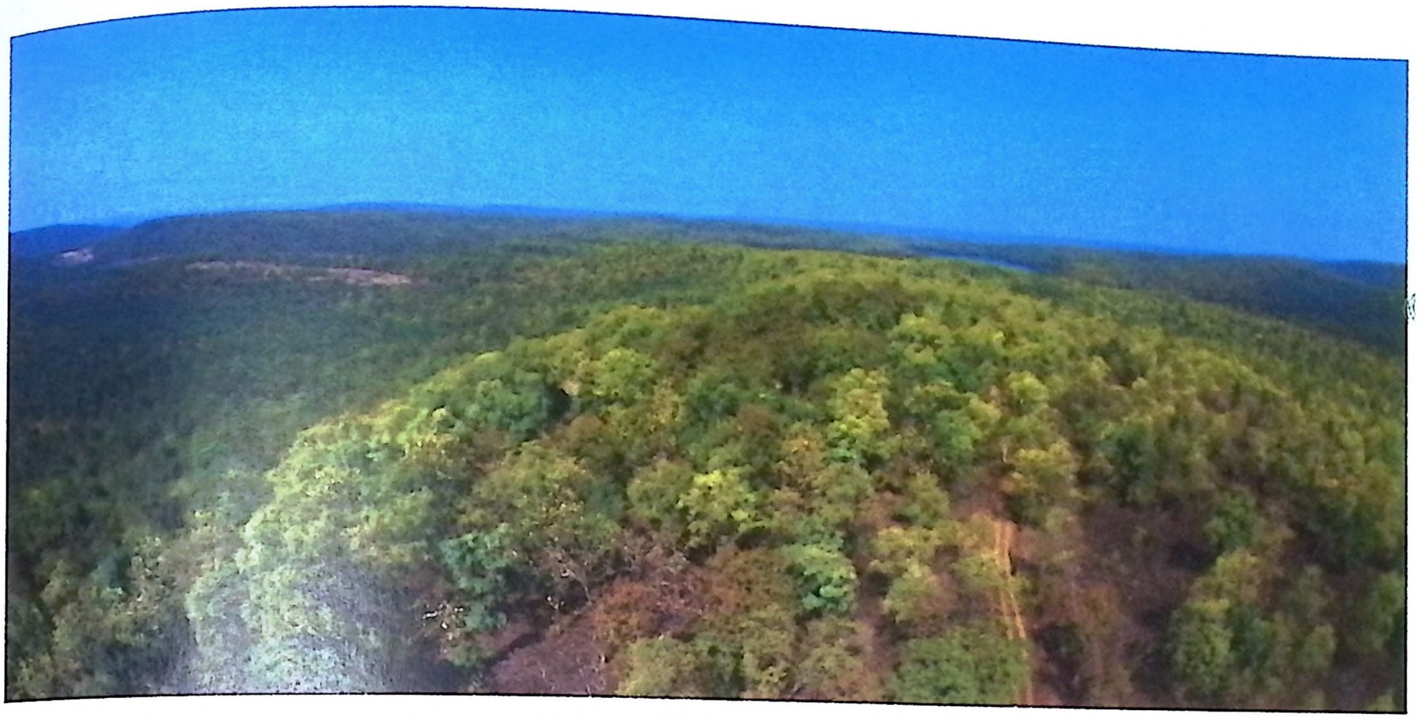

Plate1: Forest habitat inside Tadoba Andhari Tiger Reserve. *(Photo credit: Dhritiman Mukherjee)*

Plate 2: Forest-agriculture edge in Eastern Vidarbha Landscape. *(Photo credit: Pallavi Ghaskadbi)*

Plate 3: Degraded forests around forest edge.

Plate 4: Grazing cattle in forest fringe areas.

# CHAPTER 2
# CORRIDORS AND BOTTLENECKS

# CHAPTER 2: CORRIDORS AND BOTTLENECKS

## 2.1. Introduction

As a result of escalating anthropogenic pressures from an ever-growing human population in the country, the human-wildlife interface has increased, and wild habitats have become more and more fragmented. Protected areas (PAs) were established in India to provide wild animals with a refuge in the face of such habitat loss. Some of these PAs were later rechristened as tiger reserves (TR), under Project Tiger Scheme in 1973, with the intension of providing further protection to all the wild species present, under the umbrella of the Bengal Tiger (*Panthera tigris tigris*). This also marked the formation of the National Tiger Conservation Authority (NTCA) as a Centrally Sponsored Scheme of Government of India. The presence of viable populations of tigers is an indicator of the integrity, sustainability, and health of larger ecosystems. Tiger landscapes support tigers, co-predators, their prey, and a vast amount of biodiversity. They also contribute to human wellbeing, locally and globally, through the provision of many ecosystem services such as water harvesting, carbon sequestration, plant genetic materials, food security, medicinal plants, and opportunities for community-based tourism.

Most PAs and TRs appear as isolated patches of forest in a sea of human-dominated landscapes. In such a scenario, habitat connectivity is extremely essential to prevent species extinction by isolation of population and or restriction of gene flow. Loss of habitat connectivity near a tiger source area, owing to land use or land cover change due to various reasons, leads to straying of tigers near human-dominated areas in the landscape (NTCA, 2013). Besides, tigers dispersing from one landscape (source) to another (sink), traverse modified landscapes using agricultural fields and similar cover along river courses, feeding on livestock or Nilgai (*Boselaphus tragocamelus*). Dispersing tigers utilize habitats with varying degree of human disturbance and varying Landuse. After leaving the natal areas, the animals get noticed either by people or by the forest department in an area, which probably is not conducive for their movement (chance encounter of either sign or direct encounter with humans increase). Under such circumstances, studying how such dispersing/ exploring tigers use the landscape, becomes very important. It is also imperative to understand the degree/

extent of disturbance tolerated by dispersing tigers while moving through such mediated landscapes.

This chapter describes in detail the corridor modelling approach that was adopted in this study. It outlines the various datasets that were used (both remotely sensed and data collected from the field), modelling methodologies, maps of corridors and bottlenecks and the conclusions that were drawn from them.

### 2.2. Methods and materials

Tiger presence location and a set of eco-geographical variables were used to derive a model of habitat permeability for the movement of times for the landscape outside PAs. The habitat permeability surface was used in Circuit Theory framework to model tiger corridors (**Figure 2.1**), which was further validated with tiger tracking data. Thereafter, a combination of least cost path and Circuit Theory was used to model pinch points/ bottle necks along the modelled corridors (**Figure 2.2**).

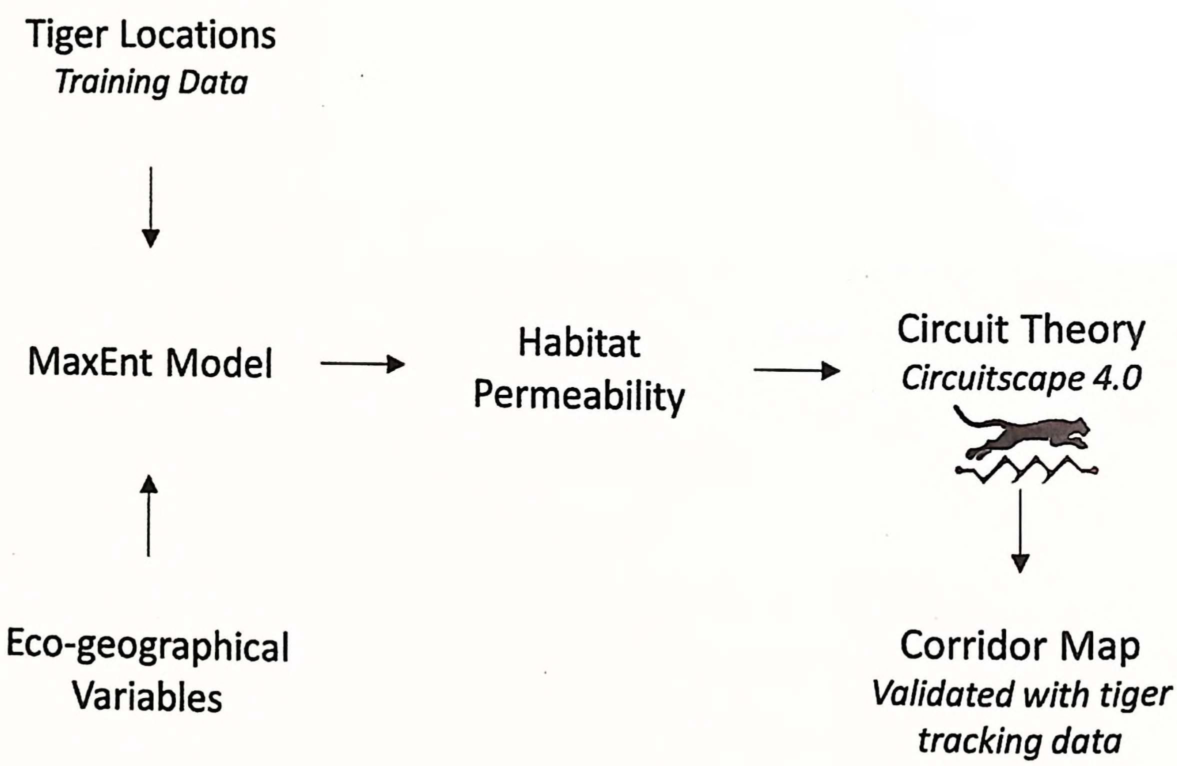


Figure 2.1: Flowchart of the methodology used for tiger corridor delineation.

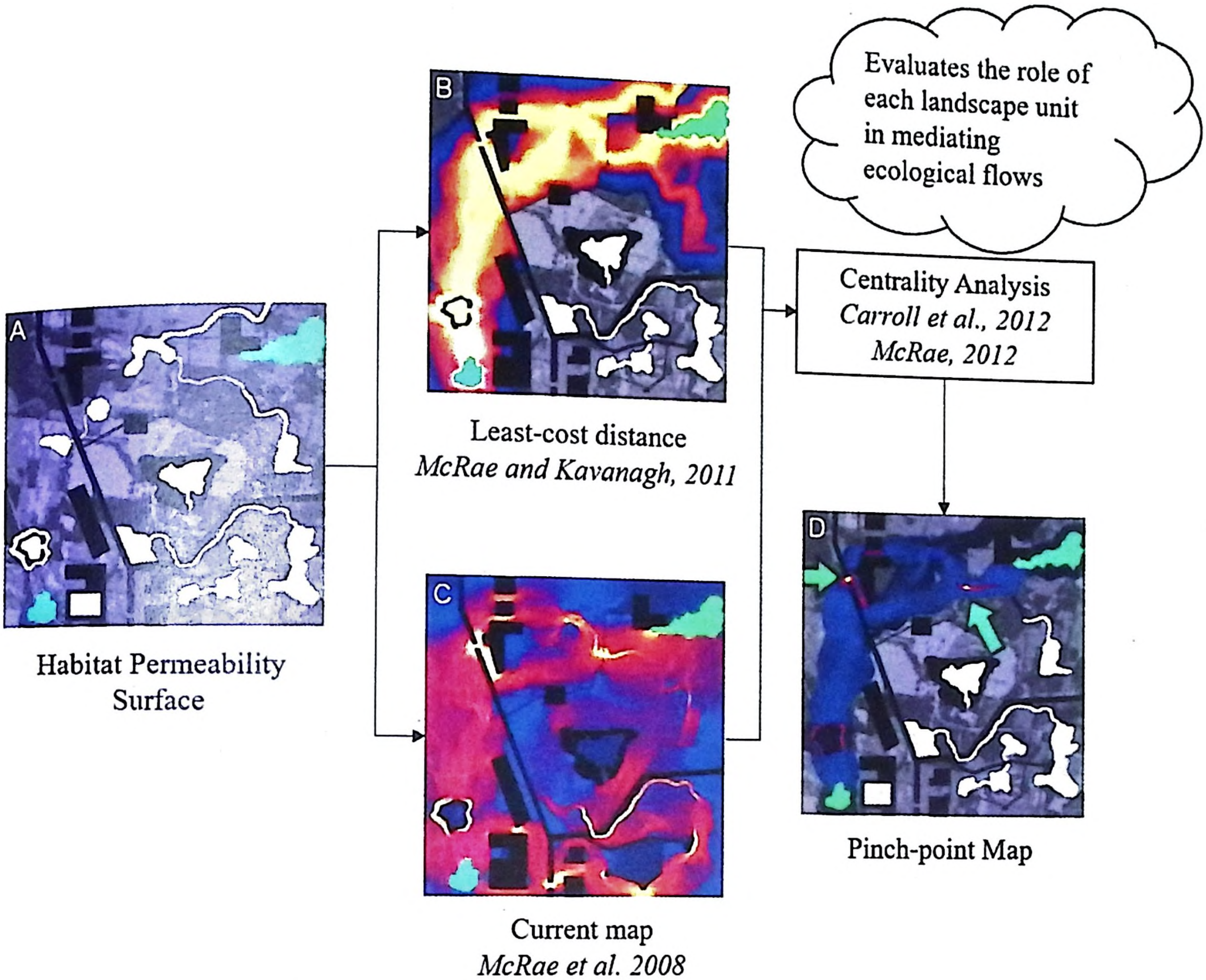


Figure 2.2: Flowchart of methodology used to delineate pinch points. *(Illustration Source: McRae, 2012).*

### 2.2.1. Tiger presence data

Tiger presence data was recorded during occupancy surveys and sign surveys in the corridor areas of Eastern Vidarbha Landscape. Presence locations were also obtained from locations of camera traps deployed by the forest department and from direct opportunistic sightings and indirect signs. Geographical coordinates of the locations in the form of latitude and longitude were compiled in Microsoft Excel 2013 and further appropriately filtered (as described in section 2.2.3.) to be used as a training dataset for modelling habitat permeability.

### 2.2.2. Remotely sensed variables

Land use and land cover data at a scale of 1:250,000 was obtained from Bhuvan, the online data dissemination portal of National Remote Sensing Centre (NRSC). This data is a product of the Ninth Cycle (2012-13) of National land use and land cover (LULC) mapping using multi-temporal AWiFS data (LULC-AWiFS). The LULC data came in 56 metre spatial resolution and 15 classes, namely – Built-up, Kharif only, Rabi only, Zaid only, Double/Tripple, Current fallow, Plantation/Orchard, Evergreen forest, Deciduous forest, Scrub/Degraded forest, Littoral swamp, Other wasteland, Gullied, Scrubland, and Waterbodies. Both forest cover and forest type data of 2014 was obtained from the Forest Survey of India which is based on IRS 1D LISS III satellite with four multispectral band data at 23.5 m resolution. Night light data, which was treated as a surrogate for the intensity of human use, was obtained from U.S. Air Force Defense Meteorological Satellite Program (DMSP) and National Oceanic and Atmospheric Administration's (NOAA) Operational Linescan System (OLS) (http://www.ngdc.noaa.gov/dmsp/sensors/ols.html). Road and drainage information were obtained from Digital Chart of the World (http://statisk.umb.no/ikf/gis/dcw/). PA shape files were obtained from the GIS cell of the Wildlife Institute of India. Euclidean distances to roads, drainage, PAs and forested areas (outside PAs) were computed in ArcGIS 10.2 (www.esri.com) software using Euclidean Distance tool in Spatial Analyst at 100 metre spatial resolution. All the remotely sensed data was then spatially resampled to a spatial resolution of 1 km, to match the resolution of the coarsest layer i.e. the night light layer.

### 2.2.3. MaxEnt Modelling of habitat permeability

Since the training data type (occurrence points) was presence only, MaxEnt was selected for modelling the habitat permeability for tigers in EVL. MaxEnt was selected as it is considered as one of the best performing models (Gils and Kayijamahe, 2010; Lazo et al., 2016; Mi et al., 2017; Qiao et al., 2015; Tarkesh and Jetschke, 2012) and the results, when compared on ground, provided the best representation of on-ground realities in the study area. Sampling bias of occurrence points is a major concern in species distribution models. Such bias was addressed employing the use of spatial filtering, where points were randomly selected from different environmental heterogeneity classes, by using a bias grid of kernel density of sampling points and by using different regularization parameters to lower the overfitting of the models (Aryal et al., 2016; Marino et al., 2011). Autocorrelation was checked between the 7 eco-geographical variables, namely – forest cover, forest type, night light, distance from roads, distance from drainage, distance from PAs, and distance from forests outside PAs. 6 out of 7 variables were found to be not auto-correlated at a Pearson's R of 0.4 and 0.5. So all variables excluding "distance from forests outside PAs" were retained for modelling. Presence data of tiger and associated environmental layers were used to build a MaxEnt model using MaxEnt version 3.3.1. to delineate areas that may be preferred by tiger across the landscape for movement. MaxEnt was run with all occurrence points (n=312), with spatially filtered points (n=180) and using a bias surface on all points (n=312) points (Anderson and Gonzalez 2011; Radosavljevic and Anderson 2014). In each of these 3 cases, seven regularization parameters (0.5, 1, 1.5, 2, 3, 4 and 5) were used. To avoid overfitting, linear, quadratic, and hinge features were selected (Merow et al., 2013; Phillips and Dudik, 2008). Model evaluation and the selection was done using Akaike information criterion (AICc), where the model with the lowest AICc value was selected as the permeability surface which was then used as the input cost surface for Circuit Theory analysis to delineate corridors.

### 2.2.4. Modelling of corridors and bottlenecks/ pinch points

Circuit Theory considers the landscape as an electronic circuit board and each suitable habitat patch as a node (**Figure 2.3**). Here the flow of electric current is analogous to the movement of a tiger. In the model, a current of one ampere is passed between the nodes, following all possible pathways made up by combining different landscape circuit linkages between the source and sink nodes. This operation assigns a current value to each landscape raster cell equivalent to the amount of current flowing through it, which yields a current map depicting the distribution of current values across the landscape. Places with high current values depicts areas, which are favored by the tiger for movement between habitat patches as compared to the low values. The current values in the Circuitscape output were classified into five classes (very low, low, medium, high and very high) using Jenks Natural Breaks Optimization following Jenks, (1967). This implementation was done using the software Circuitscape 4.0 (McRae, 2006; McRae and Beier, 2007; McRae et al., 2008; Shah and McRae, 2008). A combination of least cost pathway and Circuit Theory was used along with centrality analysis to identify pinch points or bottlenecks along the modelled corridors. Pinchpoint Mapper was used which is a part of the Linkage Mapper Toolkit (McRae and Kavanagh, 2011) a toolbox for ArcGIS 10.2 to model the pinch points. This analysis unifies least-cost corridor, and circuit theory approaches, by restricting current flow along least-cost corridors (best corridors), and identifies pinch-points. Identified pinch points are critical points along the corridors where the current flow is most concentrated, and a loss of even a small part of favourable habitat here can compromise the whole corridor. The output from pinch-point mapper was also classified into five groups (negligible (not displayed), low, medium, high and critical) using Jenks Natural Breaks Optimization following Jenks, (1967).

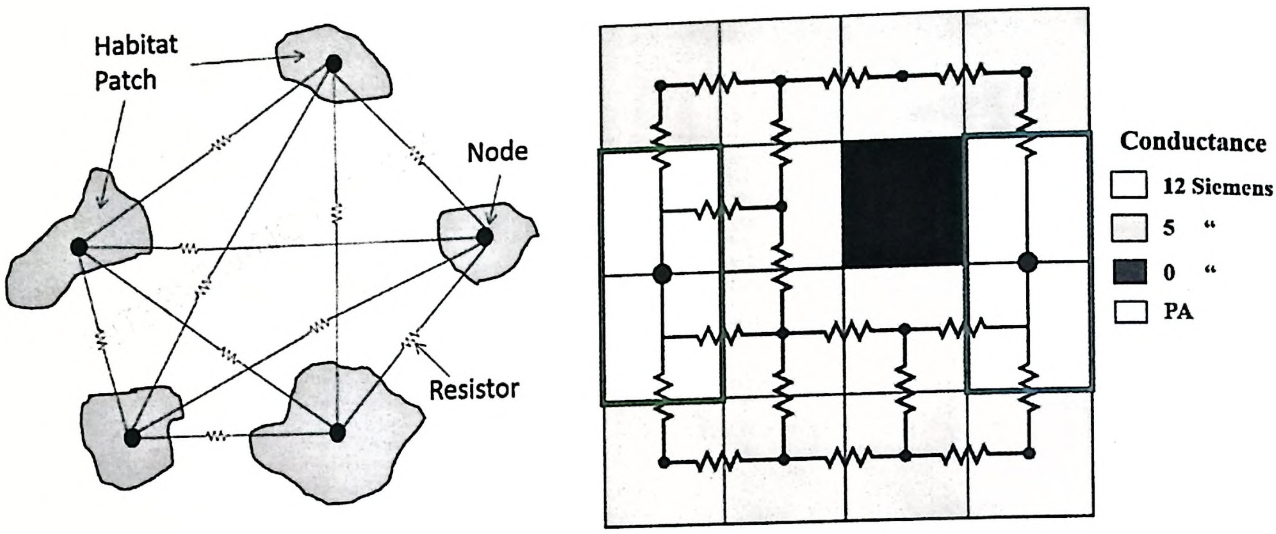

Figure 2.3: A landscape as depicted in Circuit Theory.

### 2.2.5. Validation of modelled corridors

Penny scarce conservation scenarios demand ground validation of modelled outputs before suggestions are communicated to managers and policy makers for effective management and conservation. Tiger movement data was used to validate modelled corridors which would aid in prescribing solutions that may be undertaken to safeguard these corridors. From September 2015 onwards till date we tracked two sub-adult males (514 and 363 days), one adult male (75 days) and two adult females (78 and 66 days) and obtained 14,299 GPS fixes from radio-collars which were used for validation of the modelled corridors. We used an overlay operation in GIS and calculated the percentage of points falling in the modelled corridors.

## 2.3. Results and discussion

### 2.3.1. Output of MaxEnt modelling

Based on the Jackknife estimates, distance from PAs influences habitat permeability for tiger in EVL contributes 50.7% to the model **(Figure 2.4)**. Likewise, forest type and human footprint (night light) have the second (36.9%) and third (4.2%) highest contributions to the model. Habitat permeability was also influenced by a much lesser degree by the distance from drainage (3.6%), forest cover (2.6%) and distance from roads (0.6%). The response curves in **Figure 2.5** shows how each eco-geographical variable affects the MaxEnt prediction. The curves show how the logistic prediction changes as each eco-geographical variable is varied, keeping all other eco-geographical variables at their average sample value.

The probability that a tiger may use a particular pixel in the landscape for movement shows a decline with increasing distance from drainage and PAs and with increasing value of human footprint, with the curves showing a steep decline for the distance from PAs and human footprint. The probability of movement shows a gradual increase with an increase in distance from roads. As far as the categorical variables are concerned: the probability is influenced most by dense (DF) and then open forest (OPF) in the forest cover data and majorly by Southern Dry Mixed Deciduous Forest (5A/C3), followed by Dry Bamboo Brake (5/E9) and Very Dry Teak Forest (5A/C1) in the forest type data. The output probability surface from MaxEnt which indicates the probability that a tiger may pass through was treated as the habitat permeability surface to be fed into Circuitscape. The probability values in the permeability layer (**Figure 2.6**) ranges from 0.000003 (low) to 0.83811 (high) and are displayed for the whole of EVL with areas inside PAs and Tiger Reserve Buffers masked.



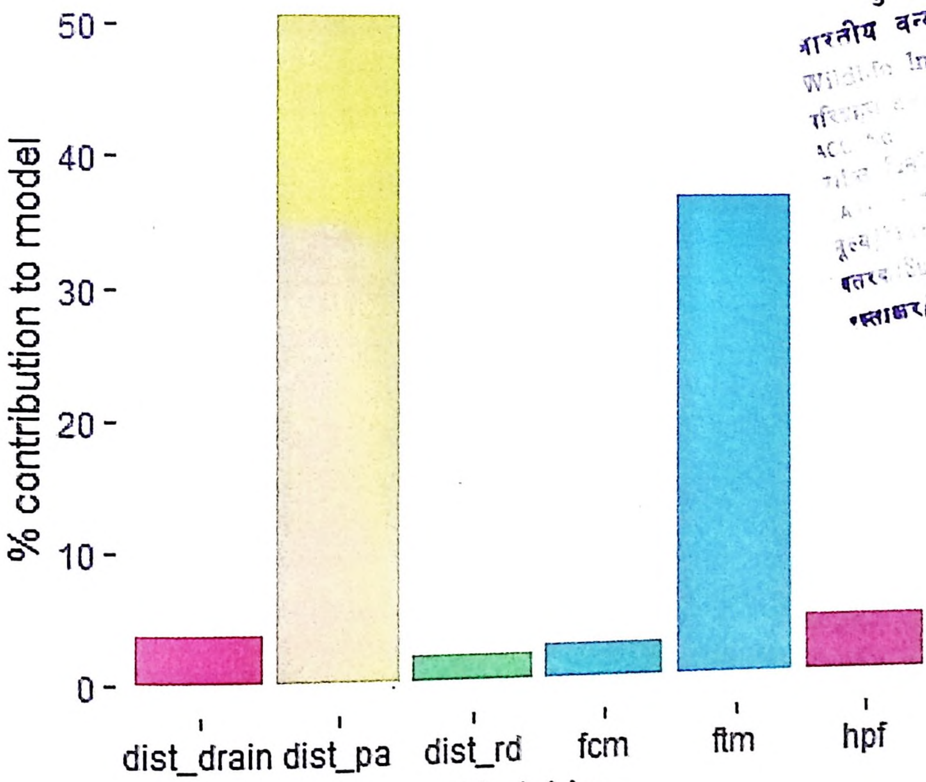


Figure 2.4: Relative contribution of response variables to the final model. *(dist_drain = distance to drainage, dist_pa= distance to PAs, dist_rd = distance to roads, fcm = forest cover, ftm = forest type and hpf = human footprint (night light).*

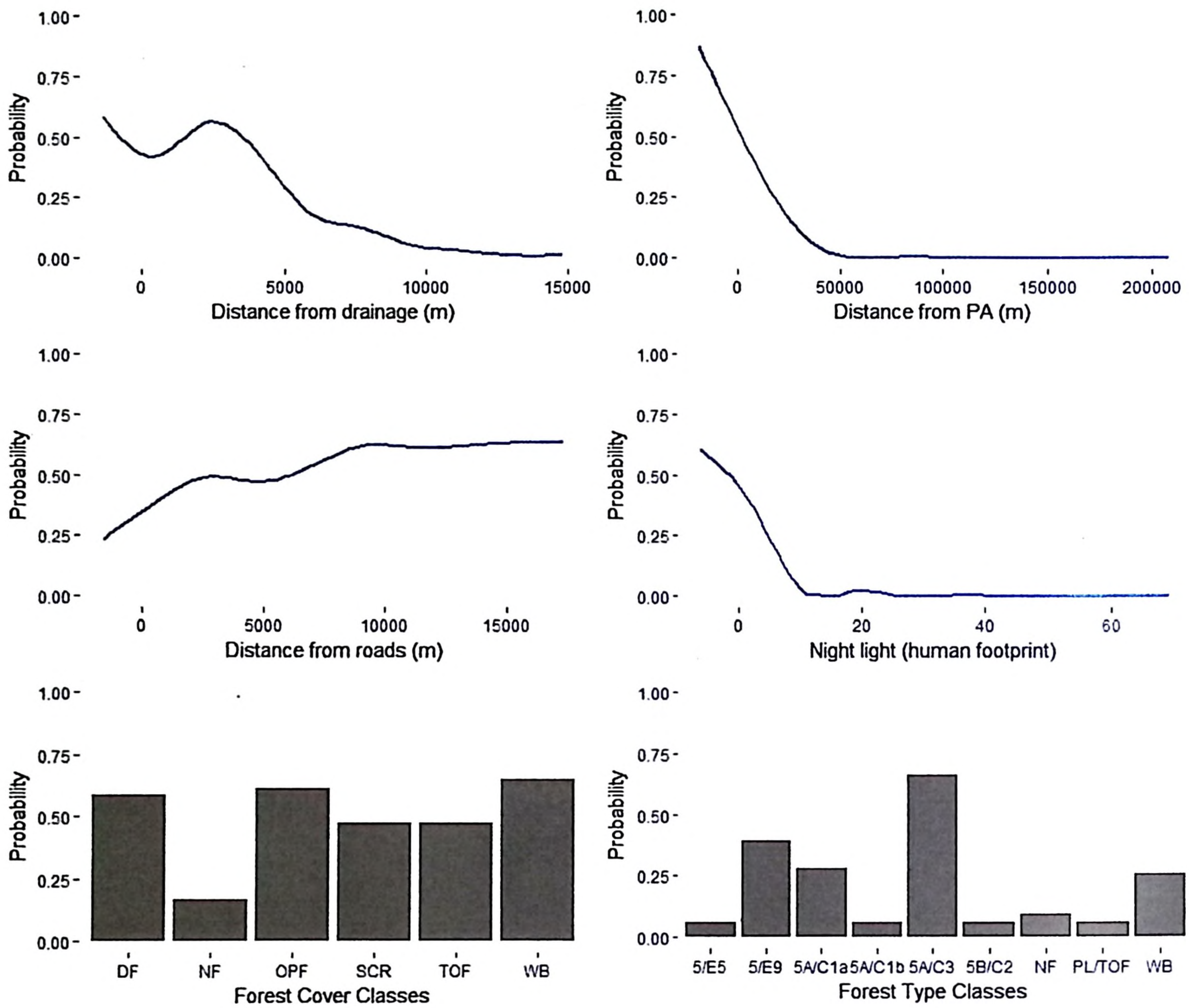


Figure 2.5: Response curves of different eco-geographical variables used in the MaxEnt model. *(DF = dense forest, NF = non-forest, OPF = open forest, SCR = scrub, TOF = trees outside forest, WB = water body; 5/E5 = Butea Forest, 5/E9 = Dry Bamboo Brake, 5A/C1a = Very Dry Teak Forest, 5A/C1b = Dry Teak Forest, 5A/C3 = Southern Dry Mixed Deciduous Forest, 5B/C2 = Northern Dry Mixed Deciduous Forest, NF = non forest, PL/TOF = plantation/ trees outside forest, WB = water body)*

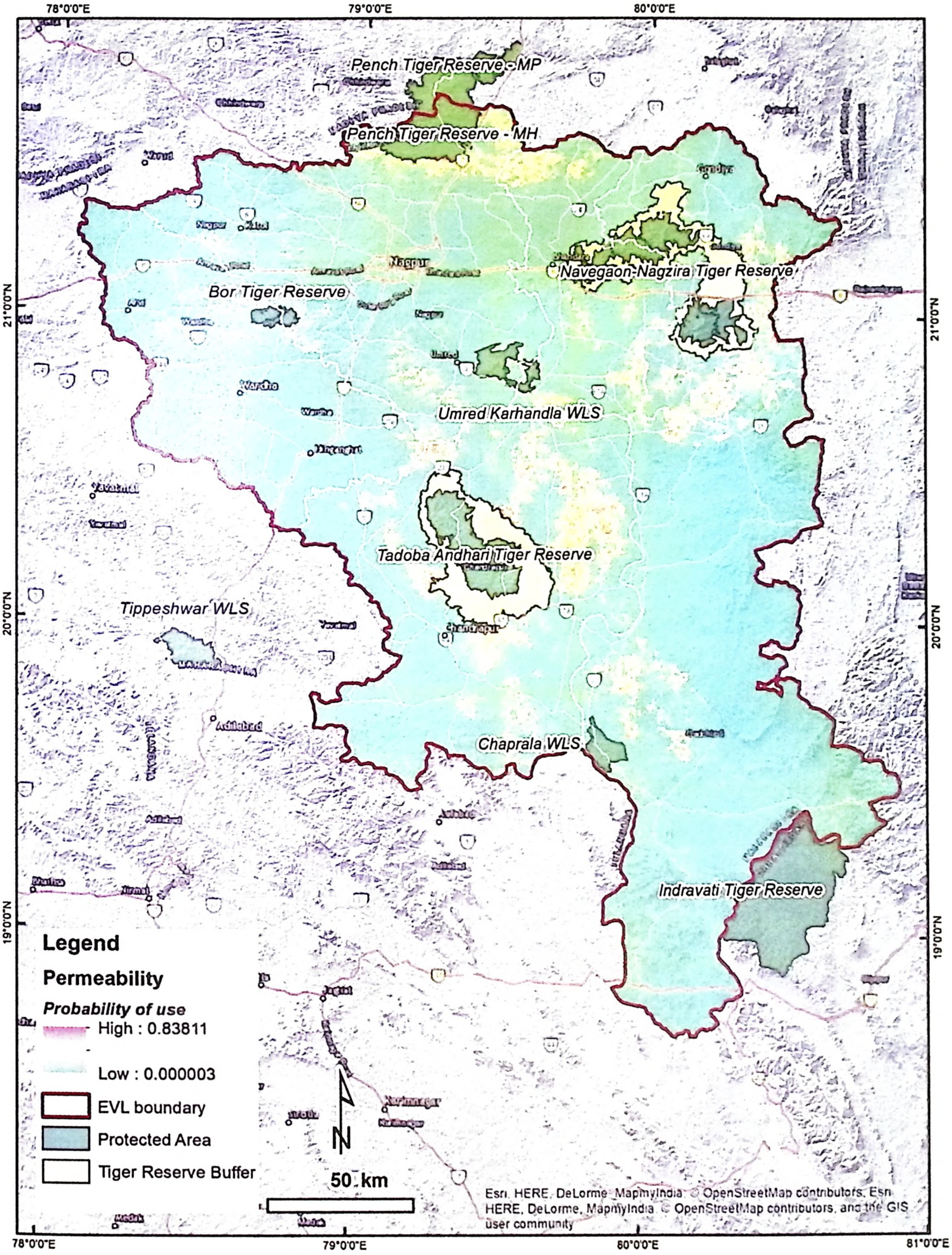


Figure 2.6: Map showing permeability for tiger movement in EVL, as derived from MaxEnt modeling. Values for PAs and Tiger reserve buffers have been masked.

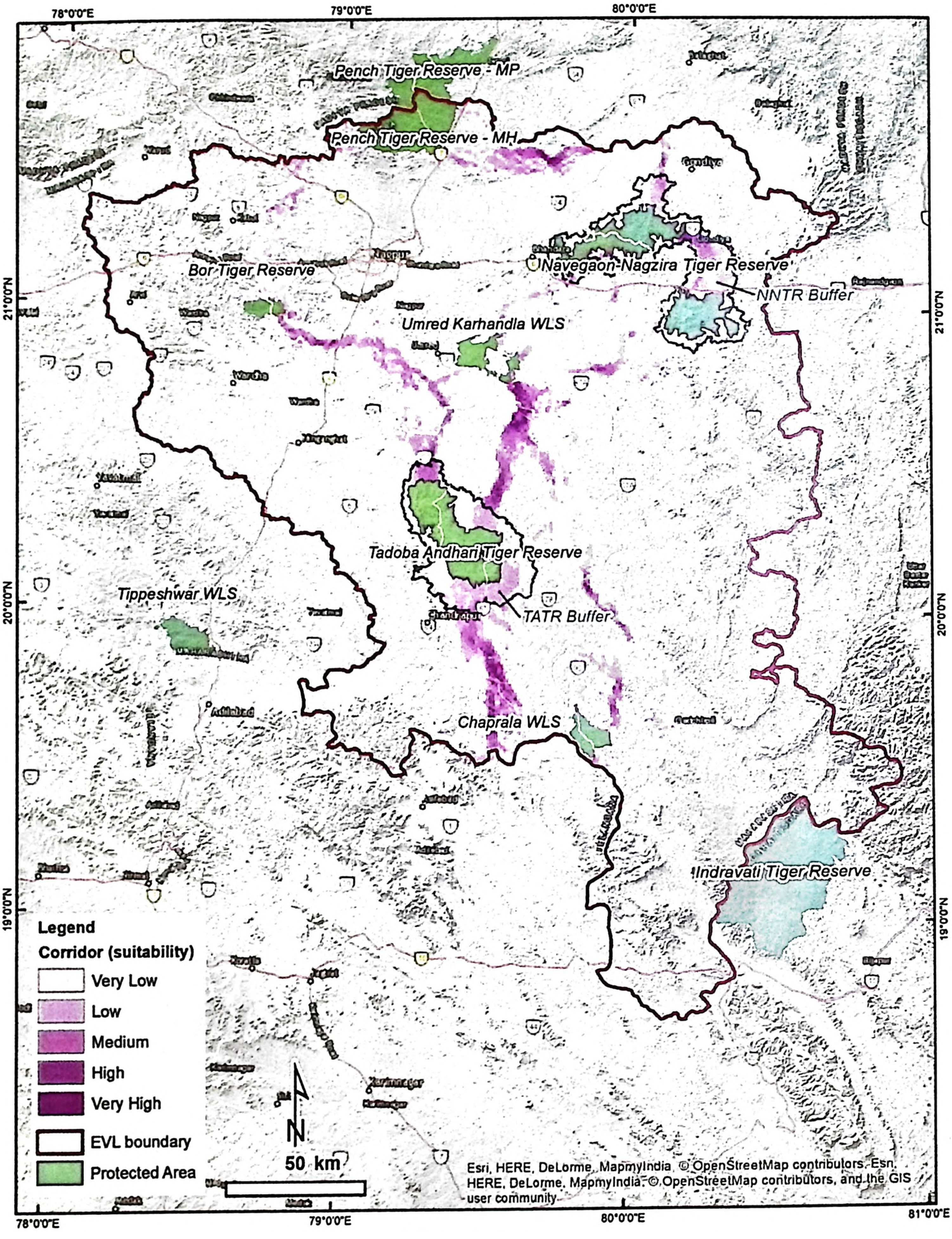


Figure 2.7: Map of tiger corridors in EVL.

### 2.3.2. Tiger corridors of EVL and validation using tiger tracking data

After running Circuitscape in pairwise mode, where it passes current between every possible pair of PAs following every possible pathway in the landscape, the generated output is displayed in **Figure 2.7**. Through this analysis 7,555.28 $km^2$ of tiger corridors were identified in EVL, which was further categorized into 5 classes from very low (4,983.25 $km^2$), low (1,569.06 $km^2$), medium (716.46 $km^2$), high (228.45 $km^2$) to very high (58.04 $km^2$) indicating the importance of that pathway or corridor. Umred Karhandla WLS forms a central node in this network connecting Tadoba with Bor and Navegaon-Nagzira and further north with Pench Tiger reserves both in Maharashtra and Madhya Pradesh. The modelled surface also shows a southbound corridor, some part of which is shared by the state of Telangana, connecting Chaprala WLS to Tadoba.

**Figure 2.8** shows the percentage of different LULC categories present in the five classes of corridors that were segregated. It was obtained after calculating zonal statistics on the LULC data obtained from NRSC at 1:250,000 scale. The statistics show that the maximum area in all the classes is covered by Deciduous Forests, which indicates that the best parts of the corridors are through forested tracts where there is good cover for tigers all throughout the year. It is followed by areas of agriculture (mainly monsoon and double/ triple crops) and to some extent by wasteland areas (read: scrubland in monsoon). This is contrary to popular belief that tigers use only forested areas for movement. The proportion of agricultural land increases as we move from more to less suitable areas in the corridors. The modelling approach adopted in this study was able to capture more corridors than Qureshi et al., (2014), due to the use of tiger presence data from outside PAs as against using a coarse scale occupancy model using data on tiger presence from inside PAs. It is also due to the finer scale of eco-geographical variables used in this study.

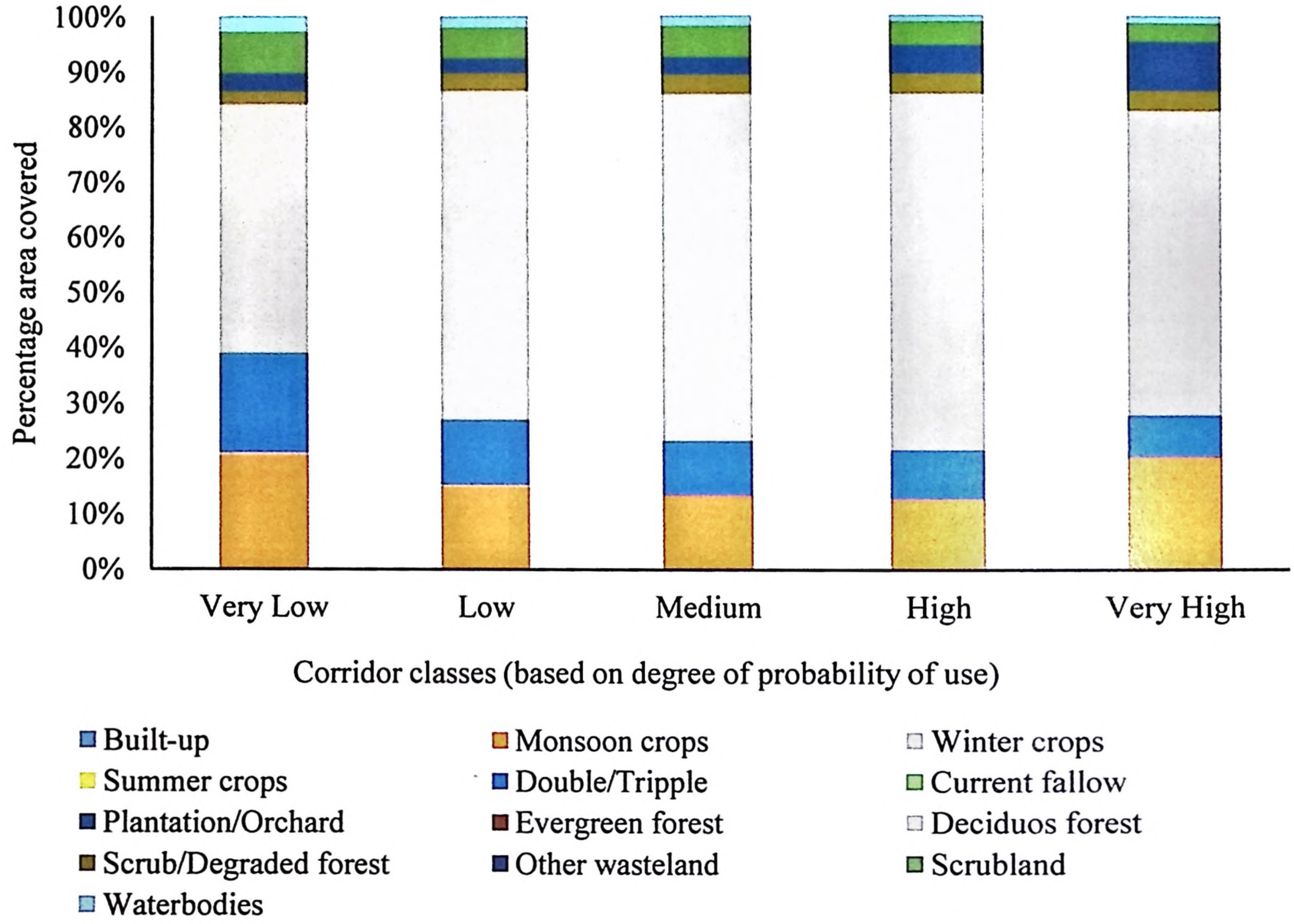


Figure 2.8: Proportion of landuse available in the modelled corridors

To validate the accuracy of the corridors modelled in this study 14,299 GPS locations were used from 5 radio-collared tigers. An overlay operation between the locations and the modelled corridors show an agreement level of about 76% **(Figure 2.9)**. These locations validated corridors between Tadoba, Umred WLS and Chaprala WLS, and that radiating out towards the North-West from Bor Tiger reserve towards Melghat Tiger Reserve. Data from collaring more tigers in different parts of the landscape which will provide more data to validate rest of the corridors. To further investigate the agreement between actual movement data and the modelled corridors, the proportion of GPS locations falling in each LULC category was compared against the proportion of that category available inside the modelled corridors. A chi-square test was performed, and a strong relationship was found between the observed land use pattern during tiger movement and the actual amount of that land use available in the corridors, $\chi^2$ (12) = 100, $p < 0.001$ **(Figure 2.10)**.

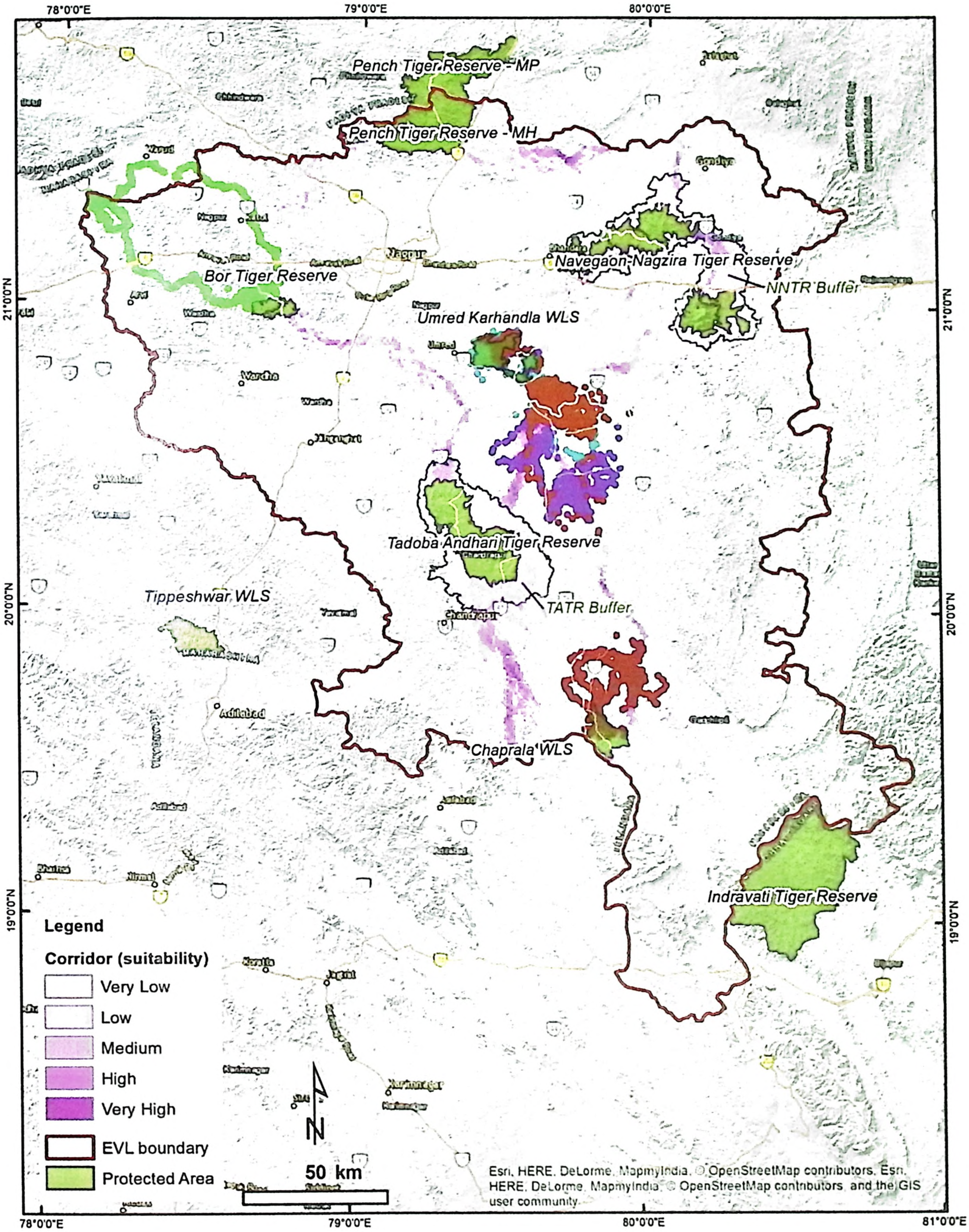


Figure 2.9: Validation of modelled corridors using tiger collar locations. Different colours of dots denote different individuals.

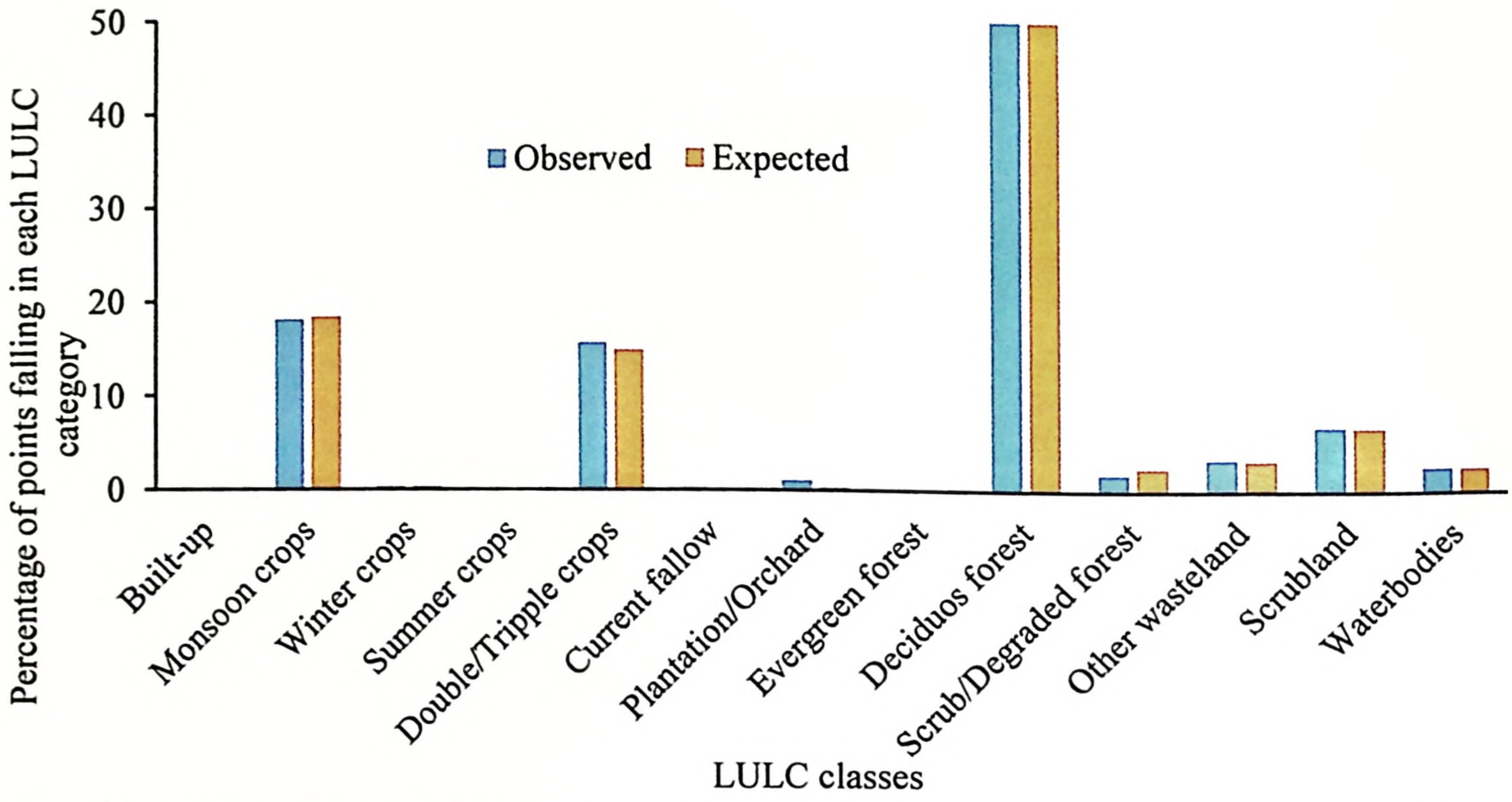


Figure 2.10: Proportion of various land use classes as used by tigers for movement in corridors.

### 2.3.3. Pinch-point/ bottleneck modelling

**Figure 2.11** shows a map of pinch points that were obtained from the use of Pinch Point Mapper software. It is a hybrid approach which combines circuit theory and least cost path approach. This method was able to model several pinch points across the length and breadth of EVL. They are categorized into four classes depending on how vulnerable they are. These pinch points are places where the corridor is in its most critical state, i.e., there may be fragmentation and excess human pressure because of the presence of a nearby villages or towns. In other words, at these places, the corridors are too narrow to tolerate the percolating effect of human disturbance, and they are devoid of any inviolate linear passages which the tiger may actually use for movement. These areas are also very prone to human-tiger conflict due to the presence of a very high degree of human-tiger interface. Post modelling the locations of known developmental projects mainly irrigation canals and dams (Figure 2.8) were superimposed on top of the modelled pinch points. The network of highways and roads were also superimposed to see if the model was able to capture various impediments to the movement of a tiger in the landscape. EVL is dissected by 36,990 km of roads (as of 2012-13) with consists of National Highways, State Highways, District Roads and Village Roads (Directorate of Economics and Statistics, Government of Maharashtra, 2014). The degree of impediment that a road provides to the movement of tiger depends on the width of the highway (2 lane/ four lanes) or the volume or heterogeneity of traffic passing through it (Habib et al., 2015).

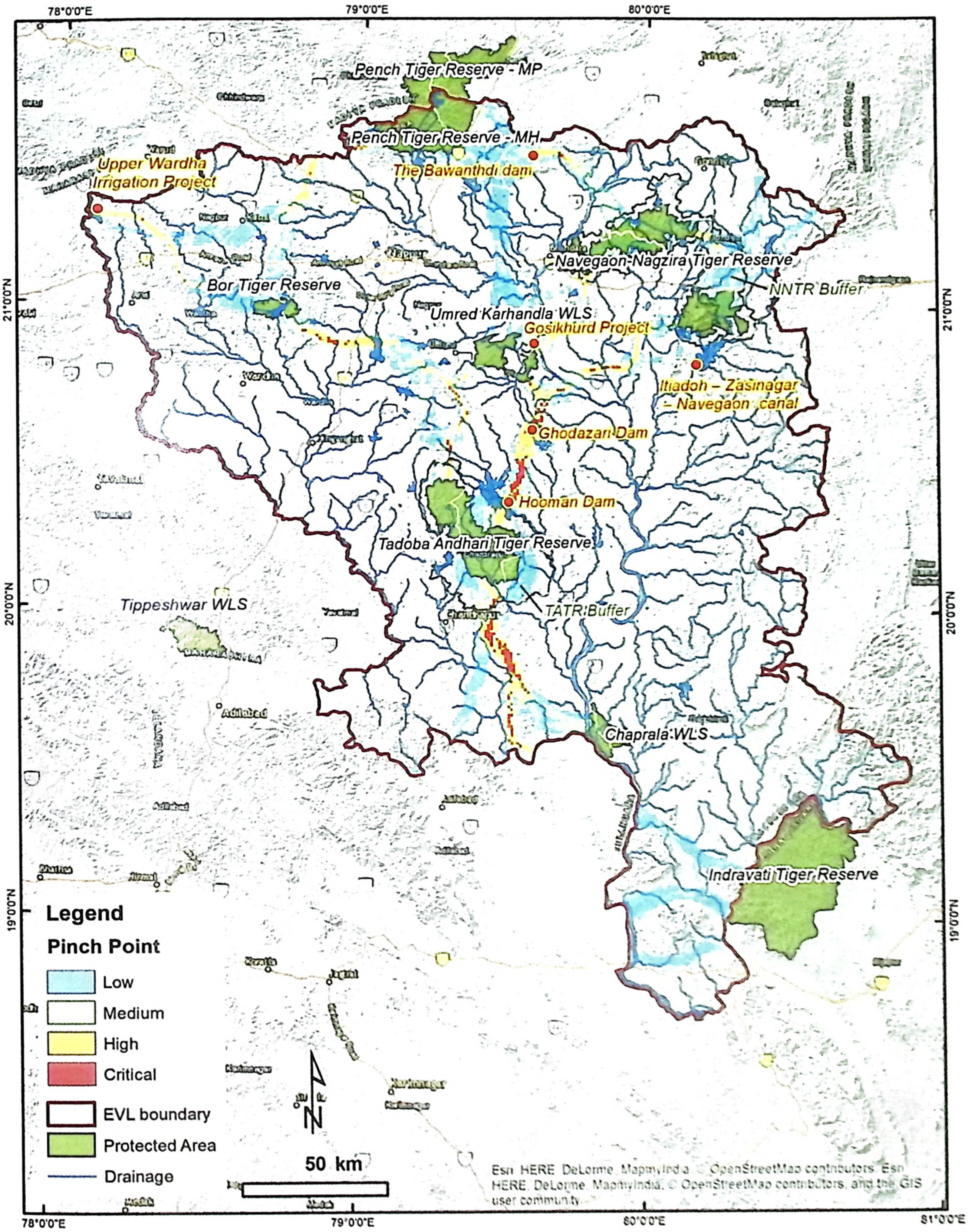


Figure 2.11: Pinch-point map of EVL showing locations of irrigation projects in red text.

**Figure 2.12** presents a simplified map of pinch points highlighting two categories: High and Critical from **Figure 2.11.** The Pinch points were overlaid on top of village-wise human population density, road layers, and locations of irrigation projects. It presents a complete set of disturbance factors that may affect the pinch points. The Pinch points have been numbered from A through K, to facilitate interpretation. As evident from the map, almost all pinch points are surrounded by areas of dense human habitation. This may imply high anthropogenic pressures on these fragmented patches of forest in the tiger corridor. Such pressures may manifest themselves in the form of resource extraction and encroachment leading to habitat degradation. The pinch point model in this study has appropriately captured the impediments to tiger movement as offered by irrigation projects (at A, D, H, and J), highways (at C, D, E, G and H) and mining (K). There are two major national highways that are cutting across important wildlife corridors in the landscape namely NH 6 (at A, F, and E) and NH 7 (west of D and at C).

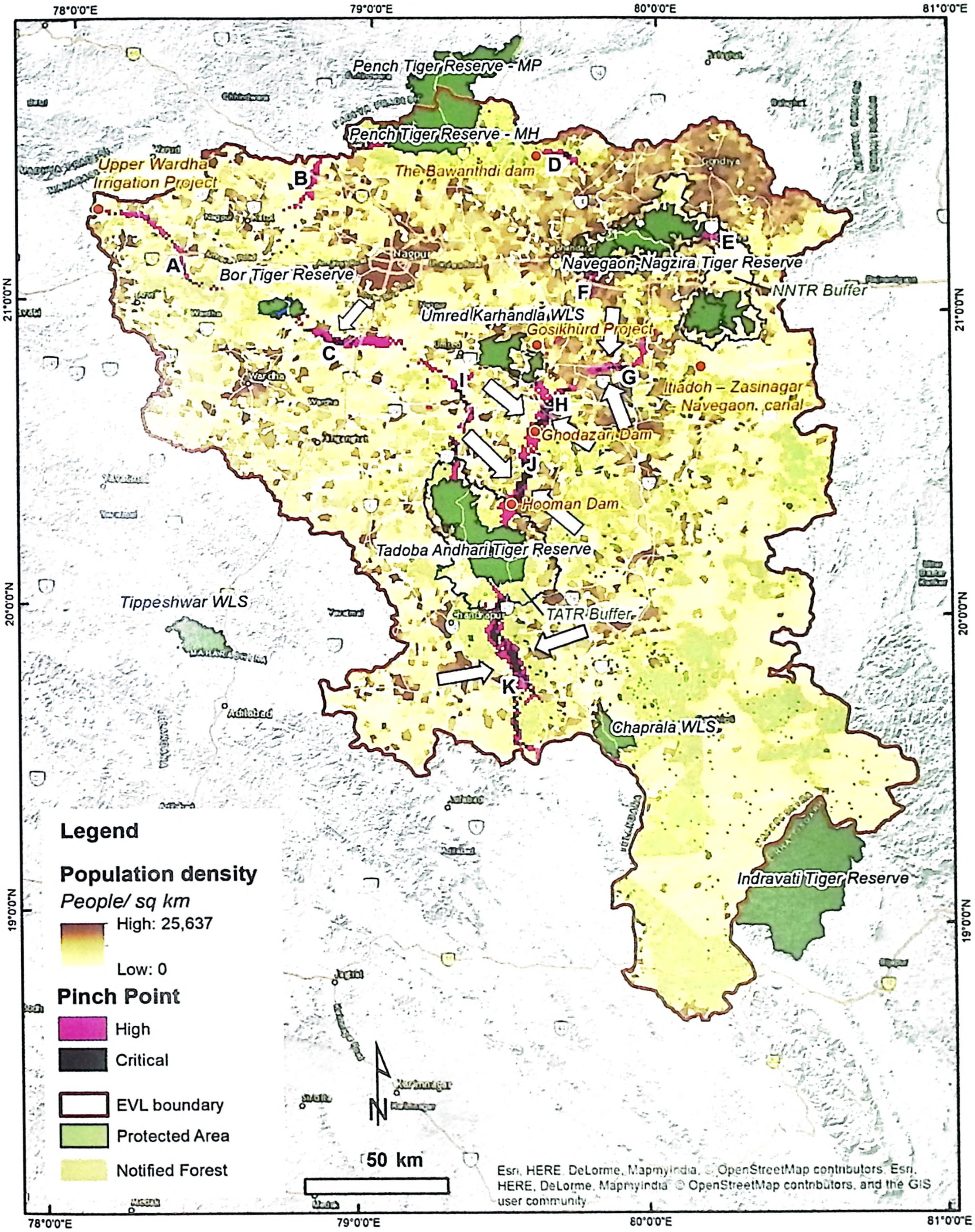


Figure 2.12: Critical pinch-points on a background of village-wise human population density.

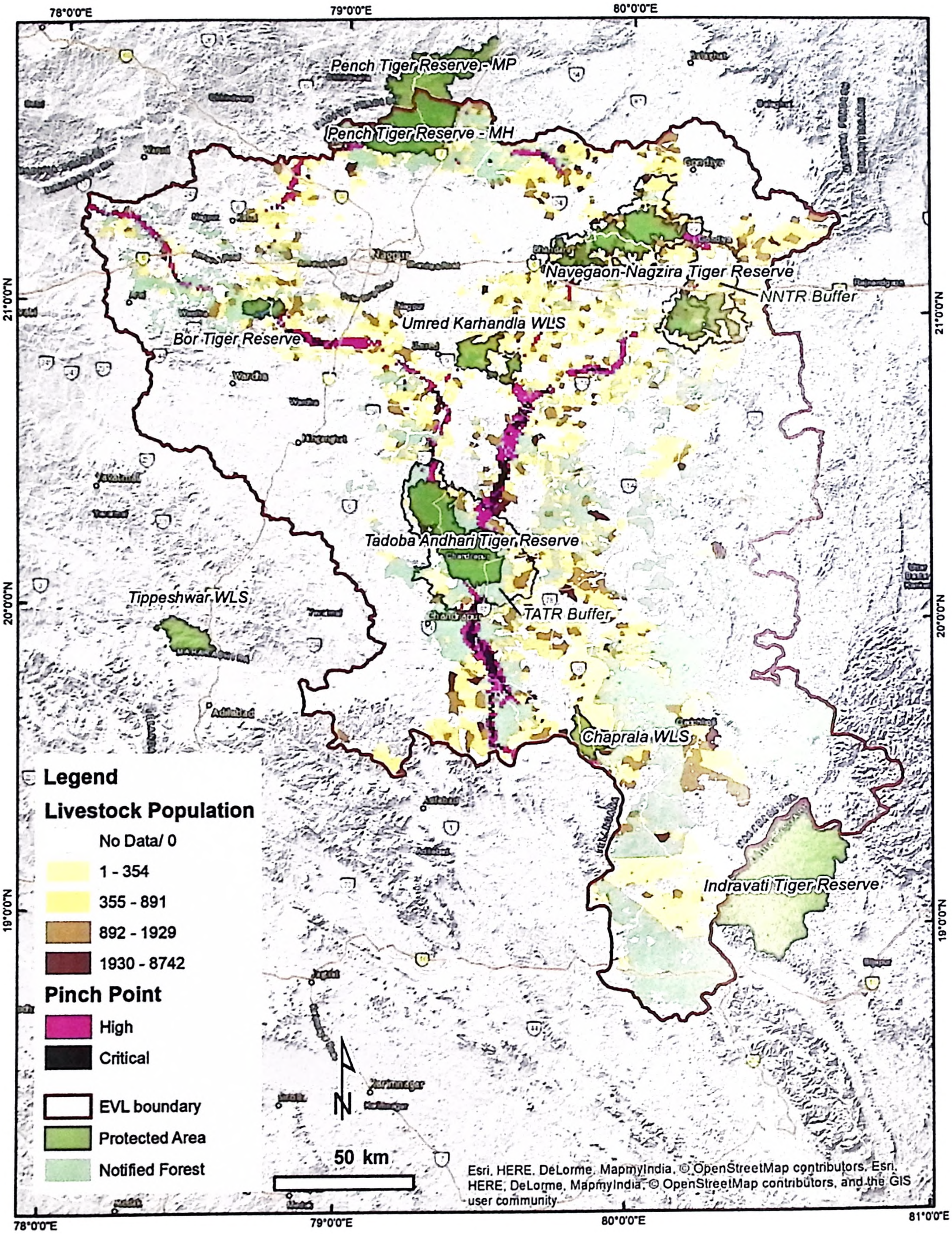


Figure 2.13: Critical pinch-points on a background of village-wise livestock population.

The corridor forests at these pinch point also suffer from high amounts of grazing pressure. **Figure 2.13** maps the livestock population of adjoining villages along the modelled corridors. As stated above, the map also indicates that all pinch points are surrounded by villages with large livestock populations. Habitat degradation from over-grazing is not the only concern in such cases; these areas are also fraught with human-tiger conflict. The topic of human-tiger conflict has been dealt in detail in the next chapter.

**2.4. Conclusion**

The finding in this chapter indicates that tigers in EVL are using a much wider swatch of the landscape outside PAs for movement than earlier known. It extends well beyond forested structural corridors or the least cost corridors modelled by earlier studies (Qureshi et al., 2014). Not only that, data from collared dispersing tigers have shown extensive use of agricultural lands for movement. In such cases they have used whatever small fragment of forest patch/ or a parcel of cultivated land with standing crops was available, to seek refuge during the day time. Tiger in this landscape were seen pushing their boundaries of human tolerance, ready to accept the risks of exploring a human-dominated landscape. Such findings from this chapter not only add to our knowledge of tiger movement ecology but has tremendous management implications on the ground. It changes the quantum of management efforts for creating awareness related to human-tiger conflict management and mitigation, connectivity conservation, etc. The predictive modelling of pinch points highlight the numerous barriers to tiger movement in the landscape, from canals to sudden land use change to roads. It provides directions as to where to focus management interventions on the ground to make the corridors more permeable and aid successful tiger dispersals.

The purview of tiger conservation, which till date was thought to be restricted to lands under the jurisdiction of the forest management, now seems to extend beyond such boundaries and into a realm where a successful conservation effort should necessarily include a much diverse array of stakeholders. The local people, the district administration, local NGOs and various developmental agencies should now work in tandem with the forest management. The findings of this chapter may provide clues to managers so as to target proactive and pre-emptive management interventions for conflict prevention/ mitigation and connectivity conservation.

**HIGHLIGHTS FOR MANAGERS**

Habitat permeability for tigers is favoured by Southern Dry Mixed Deciduous Forest, followed by Dry Bamboo Brake and Very Dry Teak Forest. Such forests in the landscape needs protection.

Study identified 7,555.28 $km^2$ of tiger corridors, which was further categorized into 5 classes according to the tigers using them into very low (4,983.25 $km^2$), low (1,569.06 $km^2$), medium (716.46 $km^2$), high (228.45 $km^2$) to very high (58.04 $km^2$). Attempt should be made to bring these identified areas unde corridor management plans.

EVL is dissected by roads totalling a length of 36,990 km. Pre-emptive mitigation needs to be drawn at places where such roads cross important tiger corridors **(Figure 2.11)**.

Tiger tracking locations falling outside modelled corridors indicating the need for better sampling to capture these deviations with more data points. More animals needs to be tracked not just for science but also for its effective conservation.

More advanced modelling techniques employing the use of more intensive data and Artificial Intelligence may provide improvements in model outputs.

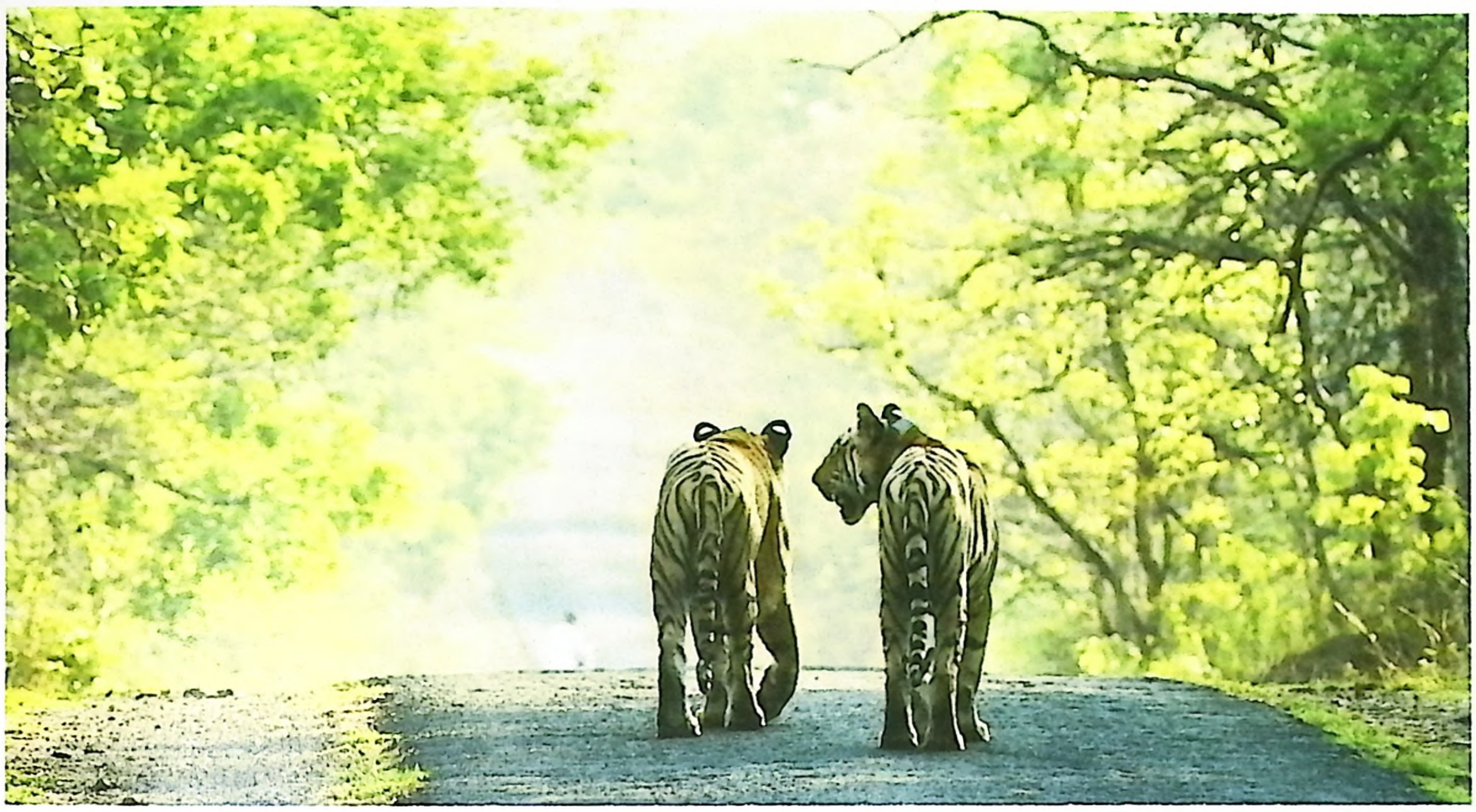

Plate 5: Two sub-adult male tigers collared during the study. *(Photo credit: Sudhir Gaikwad)*

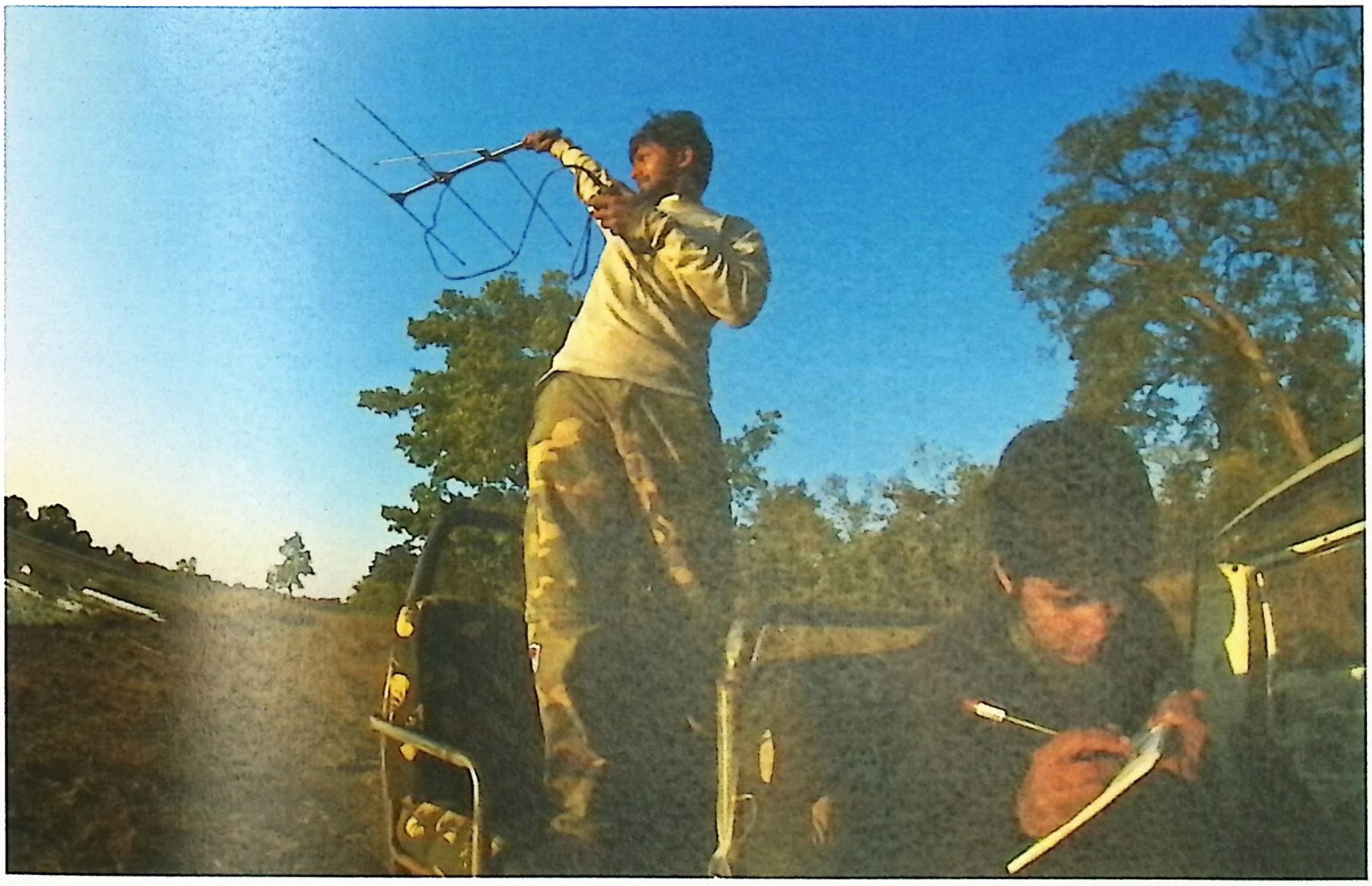

Plate 6: The ground tracking team in action. *(Photo credit: Dhritiman Mukherjee)*

# CHAPTER 3
# HUMAN-TIGER CONFLICT

# CHAPTER 3: HUMAN-TIGER CONFLICT

## 3.1. Introduction

Human dominated landscapes form a sea of matrix around islands of protected areas which harbours the majority of the biodiversity in our country. When wildlife becomes abundant in such small pockets of favourable habitats, they spill over into human dominated areas causing conflict. This is especially true for large carnivores like tigers in EVL, and stands as a major barrier against its conservation since it goes against the interest of the local stake holders who should be responsible for its conservation. Such events are triggered by large home range sizes of tigers and the inadequate size of the PAs in the landscape (Chundawat et al., 2016), which forces this large carnivore to push their boundaries outside PAs and use areas with human interference for movement. EVL is also criss-crossed by tiger corridors (Mondal et al., 2016), which are heavily fragmented at places by mining activities, infrastructural developments, and irrigation projects. Such human interference disrupts the linear contiguity of corridors forcing dispersing tigers to traverse pathways in the human dominated landscape to seek out the next patch of corridor forest. Often these alternate pathways are densely populated with humans and these tigers face grave risks of being involved in human-tiger conflict and getting killed in retaliation (Karanth & Gopal, 2005; Kolowski & Holekamp, 2006; Loveridge et al., 2010).

Man-animal conflict is responsible for global declines of most large carnivores populations (Woodroffe & Frank, 2005; Michalski et al., 2006) including the tiger. Historical records suggest that among the large cats, tigers may experience the most conflict with people (McDougal, 1987), with the number of people dying from tiger attacks ranging from ,<1 per year in the Russian Far East (Miquelle et al., 2005) to dozens per year in the Indian and Bangladesh Sundarbans (Barlow, 2009). As incidents of human-tiger conflict have risen in EVL over the years (Dhanwatey et al., 2013) an understanding of the dynamics of tiger attacks on humans is critical for effective conflict prevention and formulation of effective management strategies for the long term survival of the tigers in this landscape. Therefore, in this chapter, we have analyzed the seasonal and spatial characteristics of human-tiger conflict in the landscape.

### 3.2. Methods and materials

We collected human-tiger conflict locations from the landscape surrounding Tadoba Andhari Tiger Reserve in EVL, where an encounter has either led to human injury or death. A null hypothesis (**Figure 3.1**: when areas of high human use and high tiger use overlap the chances of human-tiger conflict is high) was tested and the spatial pattern of human-tiger conflict was investigated using Chi-squared tests.

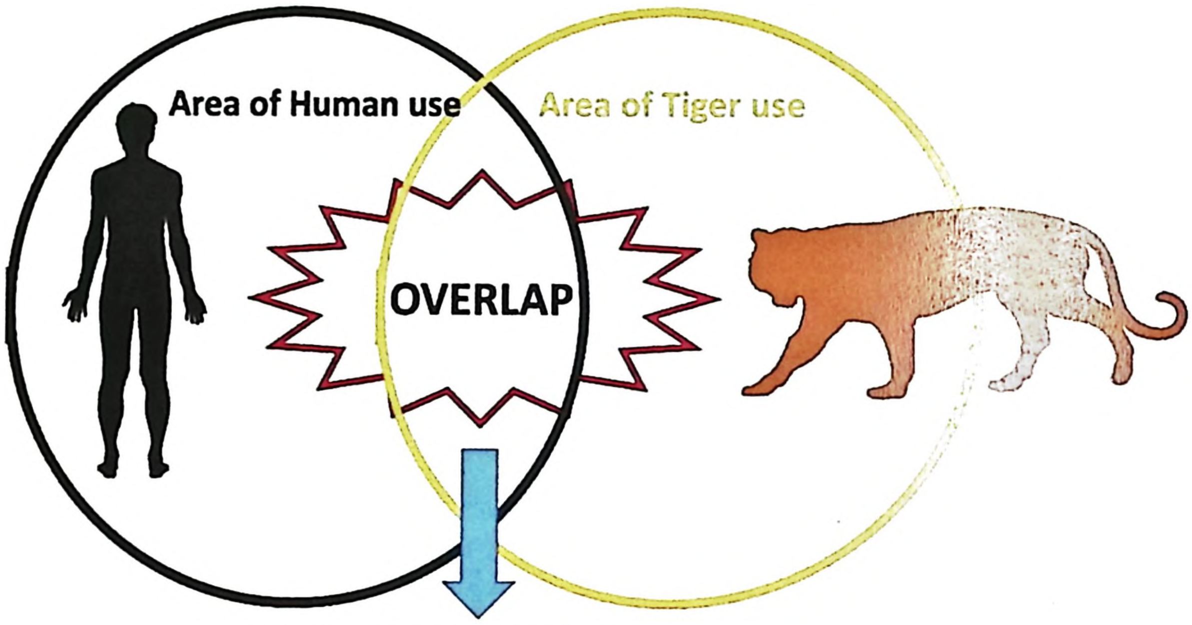


Figure 3.1: Null hypothesis ($H_0$) of human-tiger conflict.

#### 3.2.1. Mapping of human tiger conflict potential for EVL

To map the potential of human-tiger conflict in EVL a null hypothesis ($H_0$) was formed and tested with conflict locations as collected in section 3.2.2. The $H_0$ assumed that when areas of high human use and high tiger use overlap the chances of human-tiger conflict is high. The modelled corridor surface was used as a surrogate to indicate the use of the landscape by tigers. Village-wise population density surface was used as a surrogate for human use of the landscape. Information of tiger use and human use from the above layers were summarized at 5 X 5 km grids across the landscape. Then these grids were categorized into four bins using Jenks Natural Break Optimization, ranking each bin from 0 to 3 in increasing order of the intensity of use **(Figure 3.2)**. Then these two rankings (one based on tiger use and the other on human use) were multiplied **(Figure 3.3)** to obtain the null model of human-tiger conflict potential. To test $H_0$, a chi-square test was conducted, where in each conflict potential category we compared the proportion of grids expected to have human-tiger conflict against the grids from which actual incidents were reported.

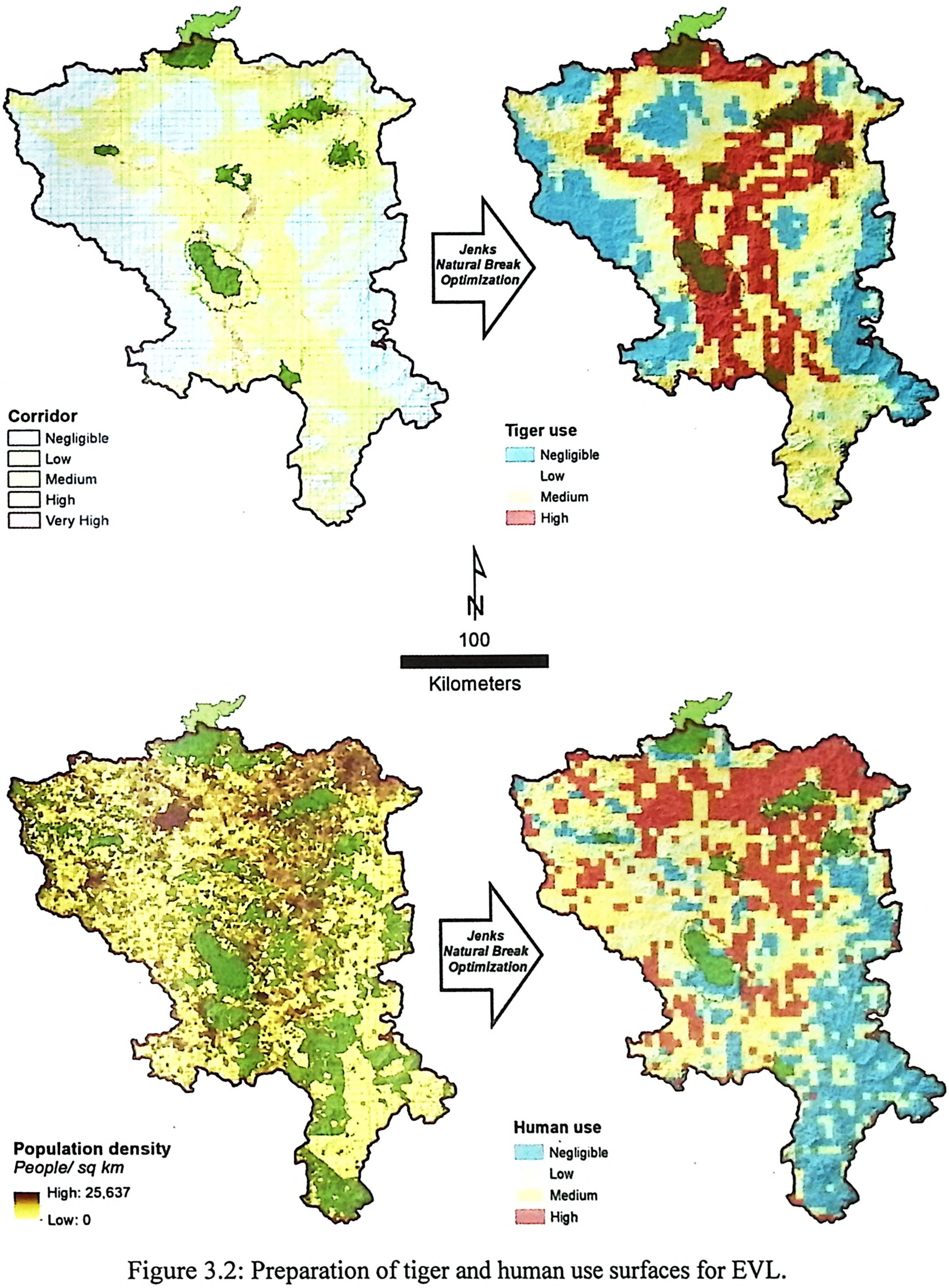


Figure 3.2: Preparation of tiger and human use surfaces for EVL.

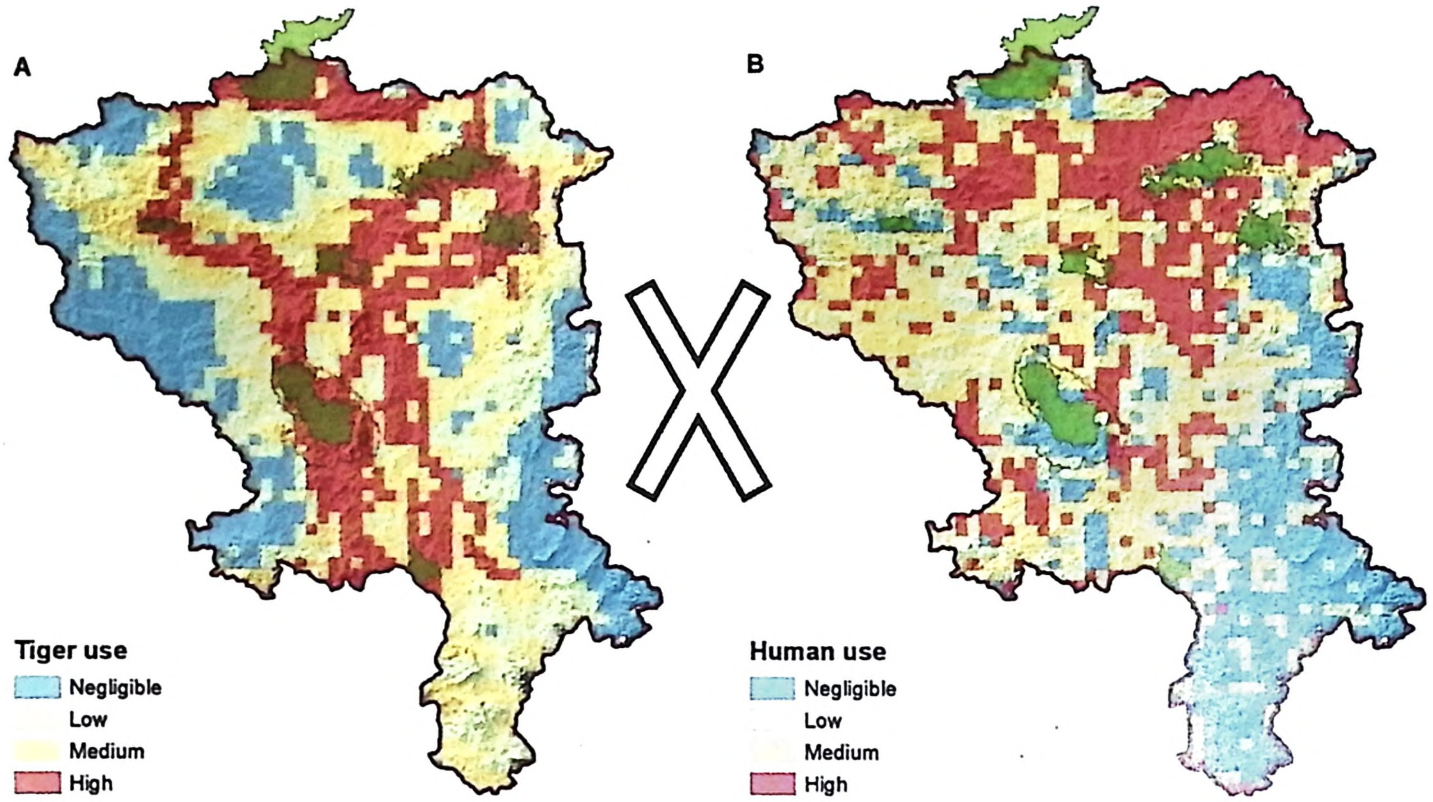


Figure 3.3: Multiplication of A) Tiger use and B) Human use surfaces.

### 3.2.2. Human-tiger conflict locations

121 locations of attacks on humans by tigers were collected from 2005 to 2017 from the compensation records of the Maharashtra Forest Department **(Figure 3.4)**. GPS coordinates of these locations were compiled with Microsoft Excel along with the date of the incident. Due to the large size of the landscape in question and the decentralized maintenance of compensation database, the number of conflict cases complied during the study is not exhaustive.

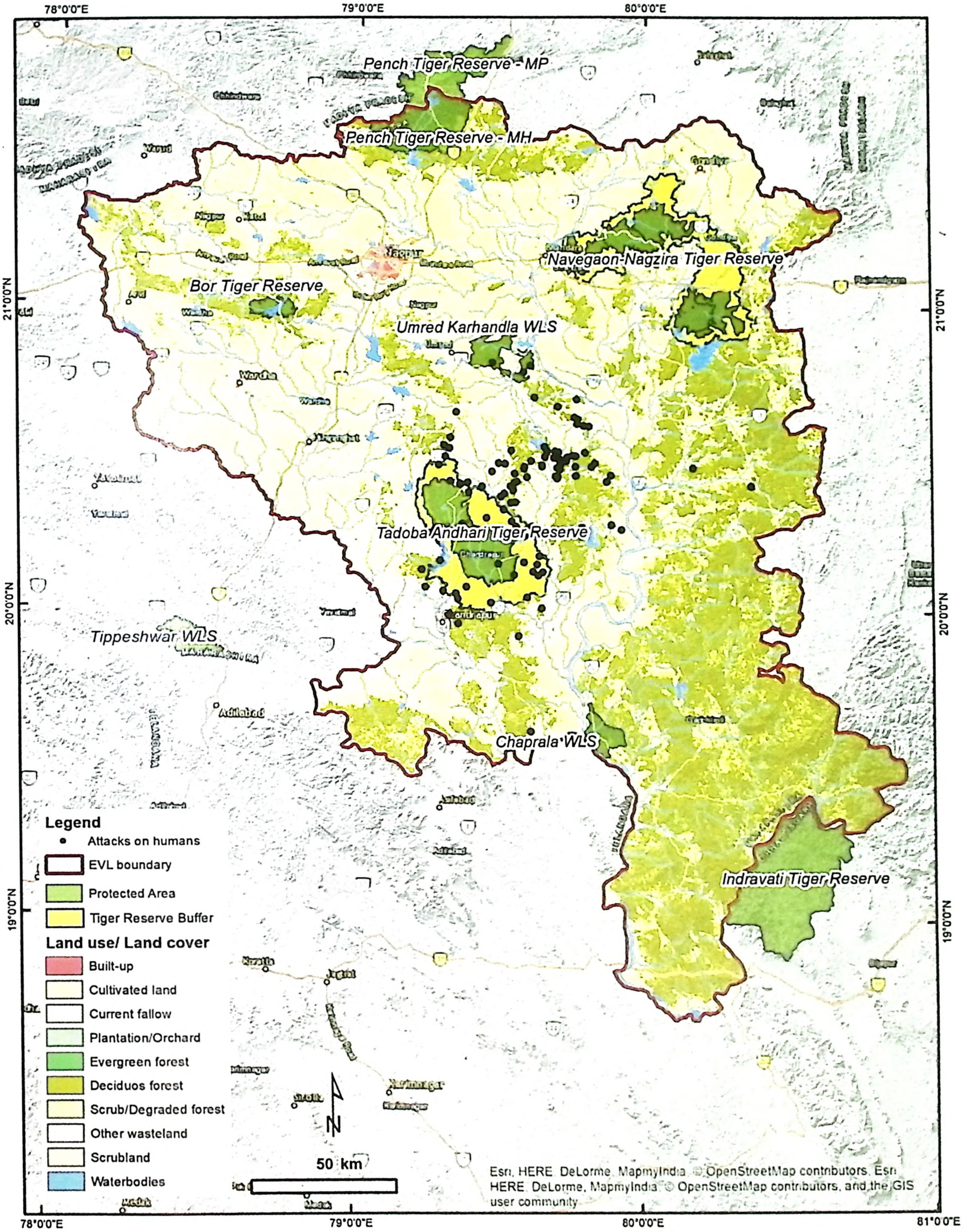


Figure 3.4: Location of human-tiger conflict incidents in EVL.

### 3.2.3. Characterization of human-tiger conflict

To delve deeper into "when and where" of conflict incidences, the seasonal and spatial attributes of the human-tiger conflict locations were looked into. The month information from the date of the incident was extracted and categorized into seasons 3 seasons: summer (March to June), monsoon (July to October) and winter (November, December, January, and February). A Chi-squared test was conducted to see whether the incidents significantly differed across seasons. The human-tiger conflict incidents were also dissected across different LULC classes, to see if there were any significant differences between landuse categories. Additionally, the seasonal differences across different land uses were looked into. In both cases, Chi-squared statistics was used to test whether they were significantly different across seasons and across different land uses, against random chance.

## 3.3. Results and discussion

### 3.3.1. Mapping of the null model of human tiger conflict potential for EVL

Multiplication of the intensity of use ranks (0, 1, 2 and 3), both for tigers and humans, generated a set of new ranks (0, 1, 2, 3, 4, 6 and 9), indicating the amount of overlap or the degree of potential conflict **(Figure 3.5)**. Ranks 0 and 1 was clubbed into "No Conflict" category and the subsequent ranks (2, 3, 4, 6 and 9) were parsed into Very Low, Low, Medium, High and Very High conflict potential categories, respectively. 25,825 $km^2$ area is under a "safe zone" of No Conflict, followed by 6,700 $km^2$ in Very Low and 7,650 $km^2$ in Low conflict potential categories. Areas with a medium conflict potential cover 3375 $km^2$, followed by 6300 $km^2$ being covered by high and 2000 $km^2$ by very high conflict potential categories. This has very important management implications on the ground as human-tiger conflict poses a burden on tiger conservation in the landscape. The burden is not only in the form of the high amount of economic compensation that needs to be paid to the human victims, but it is also in the form of the antagonistic perception of the people towards the presence of tigers that arises out of such incidents. When the village layer (with total human pollution data attached to them) was overlaid on top of the conflict potential map (Medium, High, and Very High categories), it was found that 36.41% of the total population of EVL are vulnerable to human-tiger conflict. Besides, the chi-squared test results indicated that with an increase in conflict potential in each category, a significant rise in actual conflict incidents in each category was also seen, $\chi^2$ (6) = 36.9780, $p < 0.001$ **(Figure 3.6)**, validating $H_0$.

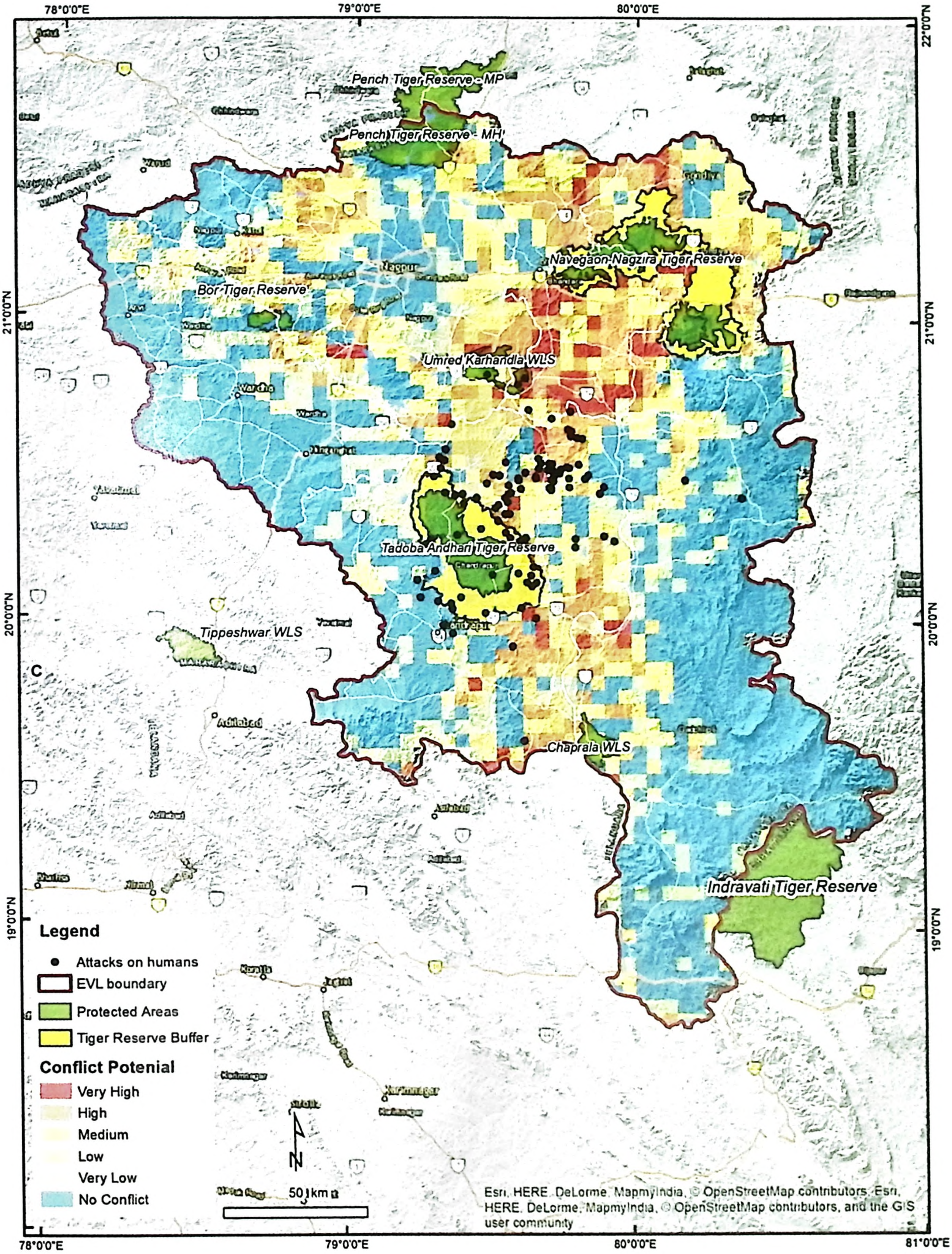


Figure 3.5: Human-tiger conflict potential map of EVL.

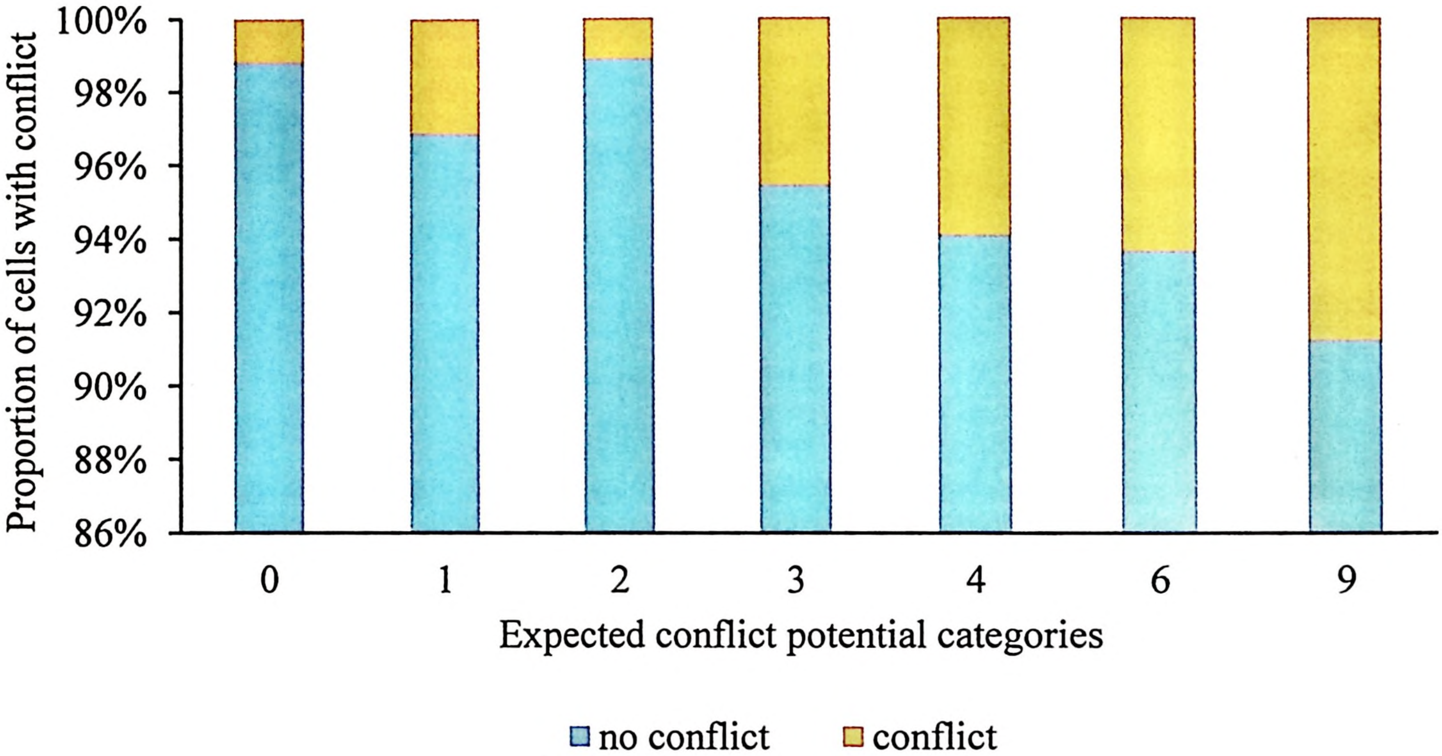


Figure 3.6: Human-tiger conflict incidents in each category of modelled conflict potential.

### 3.3.2. Characterization of human-tiger conflict

To investigate whether the number of human-tiger conflict incidents varied significantly across different seasons a Chi-squared test was conducted. The number of cases in summer was 34, in monsoon it was 46, and in winter it was 41. Chi-squared test results show that there was no significant different across seasons, $\chi^2$ (2) = 1.8016, p = 0.2031. Chi-squared test results of conflict occurrences in different LULC categories suggest that it did however differ significantly across various categories, $\chi^2$ (7) = 38.949, p < 0.001 **(Figure 3.7)**. The number of recorded human-tiger conflict cases were significantly higher in deciduous forest areas (n=65), followed by cultivated areas (n=43) as against other LULC classes like Wasteland (n=4), Plantation/ orchard (n=3), Scrubland (n=2) and Waterbodies (n=1). The highest frequency of attacks were seen in deciduous forest areas. This may be due to chance encounters between humans and tigers when people venture into forest areas to extract timber, fire wood or other non-timber forest products. Conflict incidents are also high in cultivated lands (monsoon and double/ triple crops). This may be attributed to the good cover provided by a standing crop which may be used my dispersing tigers or by tigers who may be exploring areas outside forests. Agricultural workers tending to their crops can then have chance encounters with these tiger individuals as visibility is obstructed by the height of the crops. A small number of attacks were also seen happening in Wasteland followed by Scrub/

Degraded Forest and Scrubland. These areas are mainly found adjacent to forest areas and have a high tiger as well as human footprint. These results highlight our findings in section 3.3.1 that a high number of conflict cases occur in agricultural fields, i.e., areas with high human use.

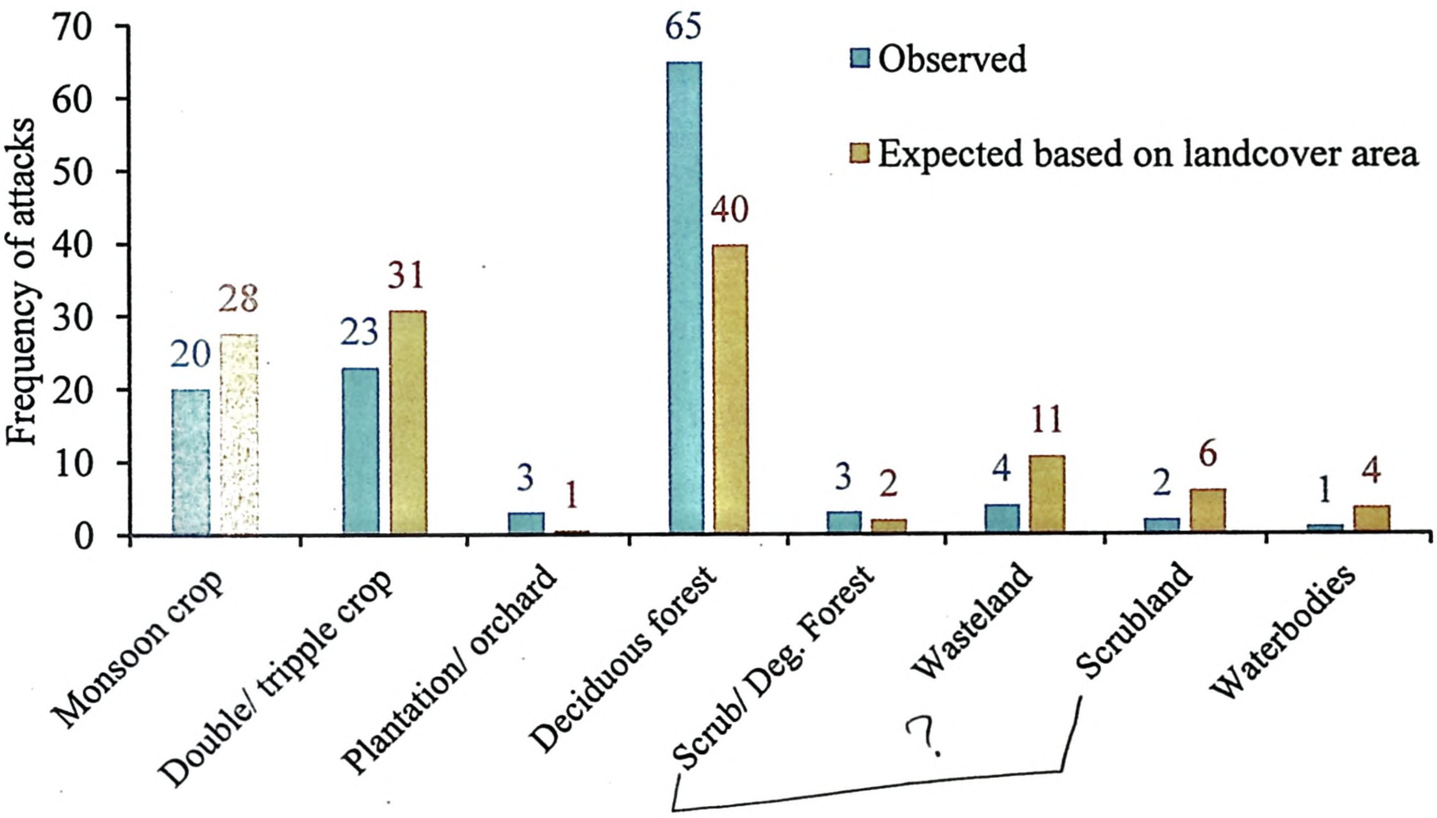


Figure 3.7: Number of human-tiger conflict incidents in each LULC category.

Table 3.1: Season-wise human-tiger conflict incidents in each LULC category.

| LULC Category | Monsoon | Summer | Winter | Grand Total |
|---|---|---|---|---|
| Monsoon crop | 13 | 2 | 5 | **20** |
| Double/ triple crop | 5 | 8 | 10 | **23** |
| Plantation/ orchard | 0 | 3 | 0 | **3** |
| Deciduous forest | 24 | 20 | 21 | **65** |
| Scrub/ Degraded Forest | 1 | 0 | 2 | **3** |
| Wasteland | 2 | 1 | 1 | **4** |
| Scrubland | 0 | 0 | 2 | **2** |
| Waterbodies | 1 | 0 | 0 | **1** |
| **Grand Total** | **46** | **34** | **41** | **121** |

As shown in **Table 3.1** human-tiger conflict incidents were divided into different seasons across different LULC categories. Then 4 LULC categories with the highest number of conflict cases were selected, namely deciduous forest, double/ triple crop, monsoon crop and wasteland and a Chi-squared test was conducted to check for seasonal variations **(Figure 3.8)**. Attack incidents have been constant in deciduous forest areas, $\chi^2$ (2) = 0.1053, p =

0.474, as these forests see a uniform degree of resource extraction by local communities across different seasons accounting for an equal probability of chance encounters leading to attacks. Double/ triple cropping areas are ones where agriculture is practiced throughout the year. There are no significant seasonal differences in the number of attacks, $\chi^2$ (2) = 1.368, p = 0.252, as the cover they provide to dispersing/ exploring tigers is constant throughout the year. Areas covered by monsoon crops show a significantly high number of attacks, $\chi^2$ (2) = 12.333, p = 0.001, during monsoon season when they have standing crops like paddy (height: 1 – 1.8 m), cotton (height: ~ 1.3 m) or soybean (height: 0.2 – 2.0 m). These crops grow to a height of about 1 m and provide good cover. Since human find it difficult to detect the presence of a tiger under such cover, probability of conflict increase on chance close encounters. Wasteland class experiences more number of attacks during monsoon although it is not statistically significant, $\chi^2$ (2) = 0.500, p = 0.389, due to the low number of observations. During monsoon, there is a growth of shrubs and grasses, and wastelands are used as grazing pastures increasing the chances of attacks on humans guarding their livestock. As depicted in **Figure 3.9** there is a sharp rise in Normalized Difference Vegetation Index (NDVI) over wastelands after monsoon rains. Higher NDVI values indicate growth of vegetation, which in this case are manifested by the proliferation of shrubs and grasses. Such a fresh growth of greens provide ideal pastures for grazing cattle, attacking herders from local communities who bring their cattle to this highly vulnerable fringe habitats.

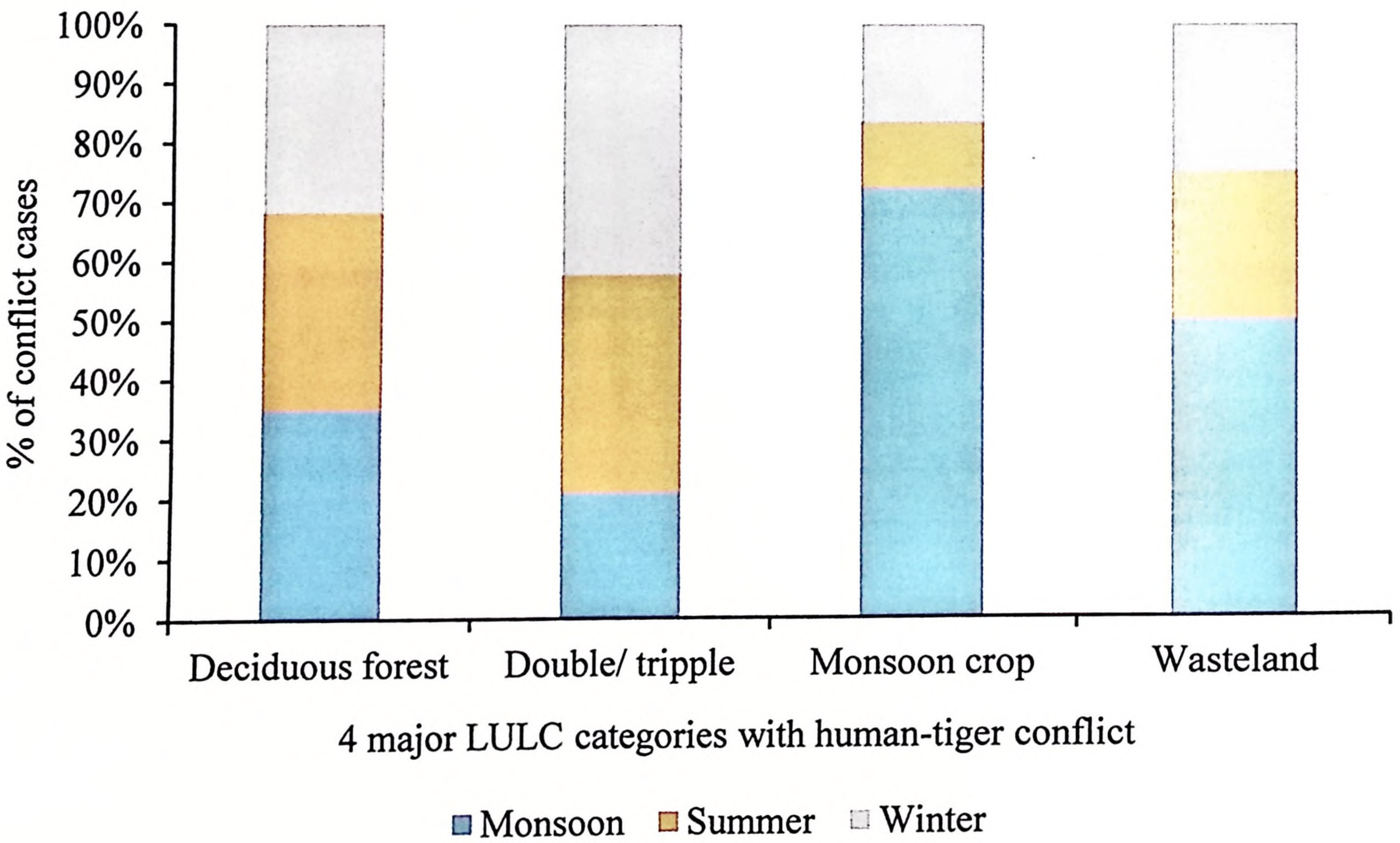


Figure 3.8: Seasonal variation human-tiger conflict incidents across different LULC category.

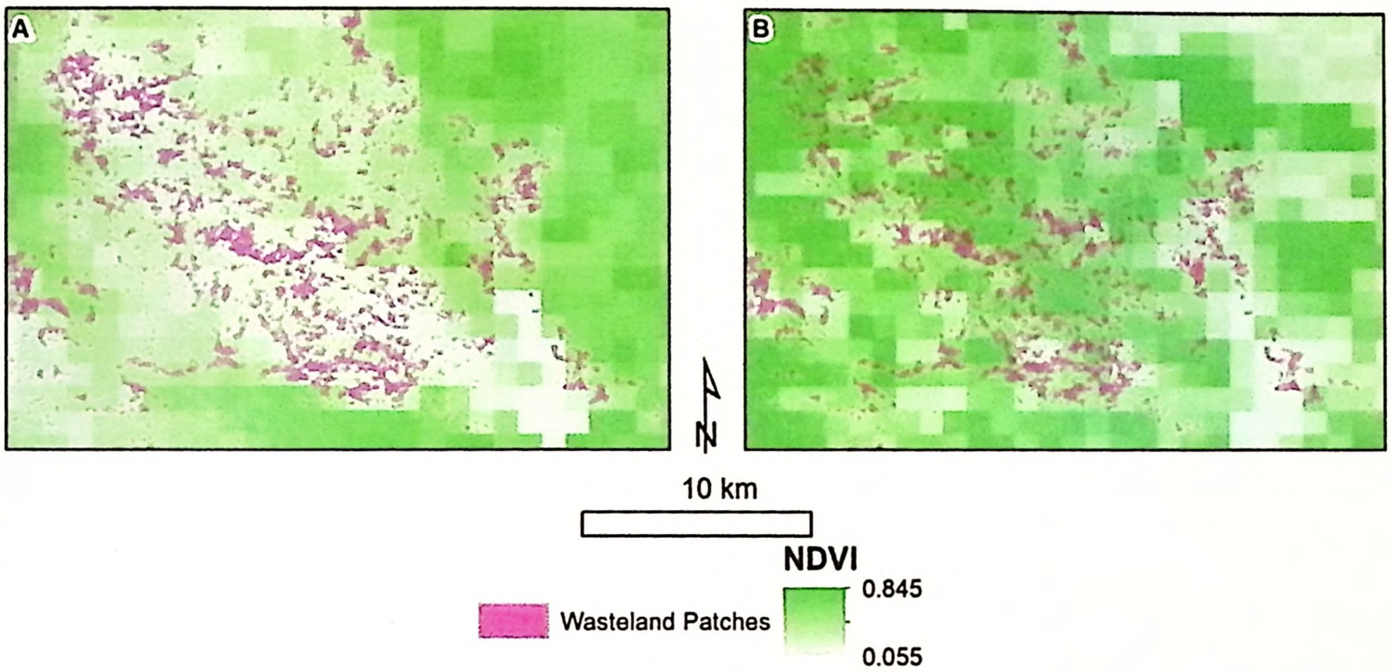


Figure 3.9: Change in NDVI values in wasteland areas: from A) in summer to B) in monsoon.

**3.4. Conclusion**

This study shows that conflict is occurring in areas adjacent to Protected Areas and degraded stepping stone corridors and bottlenecks along them, depending upon how intensely these areas are being used for agriculture or grazing. Overlay analysis shows that there is a high incidence of conflict in bottleneck areas and places where forested corridors are patchy. A high number of conflict cases were reported from villages with high human and livestock population, and where agriculture and grazing were practiced adjacent to dense forest areas. Conflict occurrences showed significant differences across different land uses. Highest number of attacks happened in the periphery of tiger reserves or PAs in both forests and agricultural fields. Inside prime tiger habitats often older established individuals push out young ones. When these young tigers starts dispersing, they come in contact with humans for the very first time and conflict occurs (Dhanwatey et al., 2013; Goodrich, 2010). These peripheral forests are suboptimal habitats with a shortage of wild prey (Nyhus and Tilson, 2010).

60% of the people of EVL primarily depend on natural resources for earning their bread and butter (Ministry of Home Affairs, Government of India, 2001). Illegal extraction of resources from the forest and livestock grazing adjacent or side the forest leave people particularly vulnerable to attack by tigers. Such activities should be curbed near forests areas, which is difficult since without an alternative people are forced to take such risks even with apriori knowledge about the presence of tigers. Increasing access to alternative fuel sources (e.g., biogas, solar) would lessen reliance on forest products, reduce harvest pressure on forests and lower the likelihood of attacks on people by large felids.

The human–carnivore conflict in EVL is influenced by an intricate interplay between the demography of the local people, their occupation, landscape characteristics as well as carnivore biology. We recommend focused restoration of corridors and bottlenecks, sensitization of local communities and regulated grazing near tiger corridors as the key to managing conflict in the area. Our map of high risk areas **(Figure 3.5)** will provide guidance to reserve managers and policy makers to identify in advance areas unsuitable for human use because of the potential for high conflict (Treves et al., 2004), with further value addition from Participatory Risk Mapping (Inskip et al., 2013).

**HIGHLIGHTS FOR MANAGERS**

This study modelled the potential of human tiger conflict in the EVL. 2000 $km^2$ and 6300 $km^2$ was identified as very high and high potential areas respectively.

36.41% of the total human population of EVL are vulnerable to human-tiger conflict (falling under Medium, High, and Very High categories).

Areas covered by monsoon crops show a significantly high number of attacks during monsoon season when they have standing crops like paddy (height: 1 – 1.8 m), cotton (height: ~ 1.3 m) or soybean (height: 0.2 – 2.0 m).


Plate 7: A collared tiger chasing domestic buffalo. *(Photo credit: Amrut Naik)*

# CHAPTER 4
# LANDSCAPE PRIORITIZATION FOR CONSERVATION

# CHAPTER 4: LANDSCAPE PRIORITIZATION FOR CONSERVATION

## 4.1. Introduction

Tiger dispersal assisted by unhindered movement within the landscape is significant for tiger conservation and long term survival in the landscape. Connectivity patterns are a result of the interactions between dispersing individuals and the environment (Vasudev and Fletcher Jr., 2015). The environment here is chiefly characterized by the heterogeneous land use patterns, where inviolate habitats inside PAs are surrounded by areas of multiple human uses. Movement in many species is influenced by the variation in landcover types surrounding remaining habitats (Ricketts, 2001; Stevens et al., 2006; Zeller et al., 2012). Heterogeneity of such landscape mosaics makes biodiversity conservation planning a daunting task (Fahrig, 2007). Intermediate patches resembling their habitats that exist in the matrix creates potential functional links for the biota (Shanthala Devi et al., 2013) in the form of stepping stones. The coherence of these stepping stone habitat network within the matrix depends on patch characteristics and spatial configuration.

Connectivity conservation initiatives should focus on first conserving areas that facilitate movement; and second on restoring connectivity across areas that impede movement (McRae et al., 2012). Habitat restoration is one way of reducing landscape fragmentation, which is seen as a threat to biodiversity. It consists of renovating disused or degraded habitat patches or in creating new habitat patches in suitable areas (Clauzel et al., 2014). Most connectivity analyses have focused on the former strategy by modeling and mapping areas important for movement under present landscape conditions. This study too mapped the areas important for movement in the landscape, but it has also highlighted suitable habitat patches, away from core habitat areas, that are embedded in a multiple use matrix, to secure multiple stepping stone patches to aid connectivity. Currently, most restoration measures draw on the local knowledge of experts for selecting the best locations (Clauzel et al., 2015). This study has used tiger movement data to build a model which quantifies the potential of patches in the landscape to be used by dispersing/ exploring tigers as refuge while moving in a highly disturbed heterogeneous landscape. Chapter 2 identified tiger corridors in EVL which covers an area of 7555.28 $km^2$ of which only 2481.23 $km^2$ (32.84%) fall in notified forest lands. The remaining 67.16% falls in private and public lands. Such a fact highlights the paramount importance of securing these parcels of land to aid tiger habitat connectivity in the landscape.

This chapter aims to prioritize parcels of lands or pockets in the landscape (both inside and outside modelled corridors) which may be used by tigers as a refuge during movement in a human dominated landscape.

### 4.2. Methods and materials

Tiger movement data was analyzed and pockets in the landscape outside PAs were identified where they were spending a considerable amount of time while dispersing or exploring. The eco-geographical characteristics of these pockets were extracted and based on this information it was extrapolated to other areas of the landscape **(Figure 4.1)**. By extrapolation, the study aimed at identifying patches potentially similar to the ones indicated by the tracking data, which may provide refuge to the dispersing or exploring tigers.

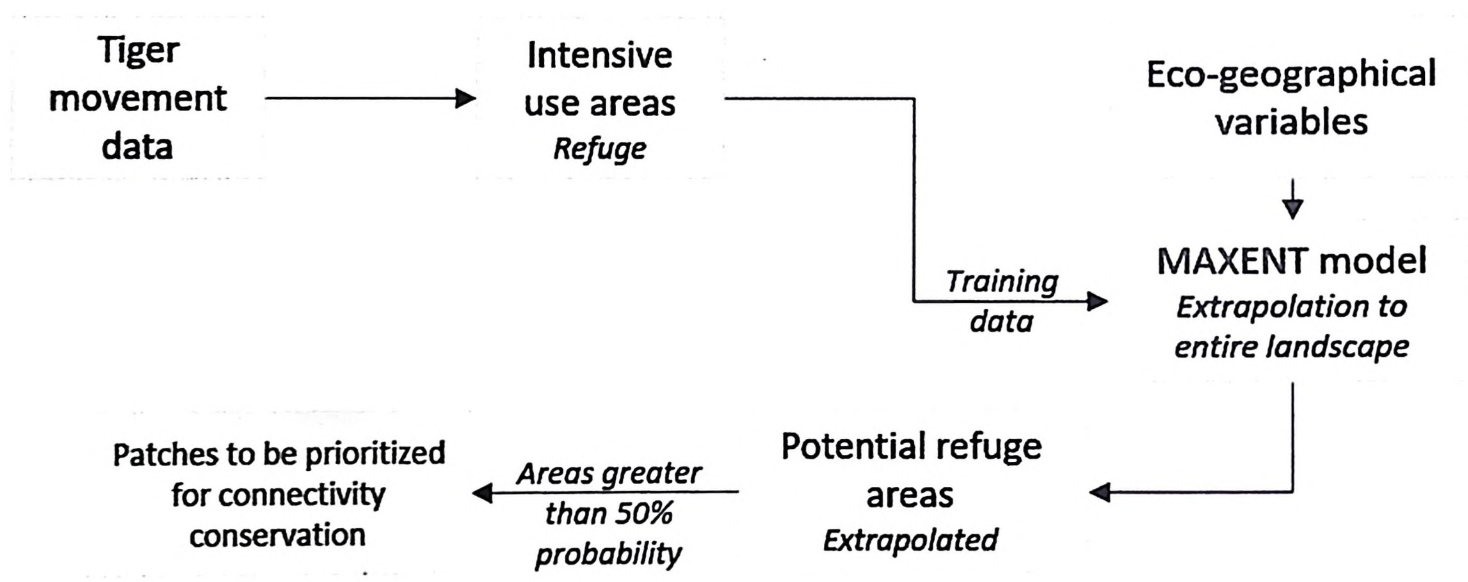


Figure 4.1: Flowchart of methodology used to identify patches which can potentially act as refuge for tigers outside PAs during movement.

#### 4.2.1. Tiger movement data

From September 2015 onwards till date two sub-adult males (514 and 363 days), one adult male (75 days) and two adult females (78 and 66 days) were tracked and a total of 14,299 GPS fixes from radio-collars **(Figure 4.2)** were obtained. Location information from these GPS fixes were further used to identify pockets in the landscape which dispersing or exploring tigers are using as a refuge.

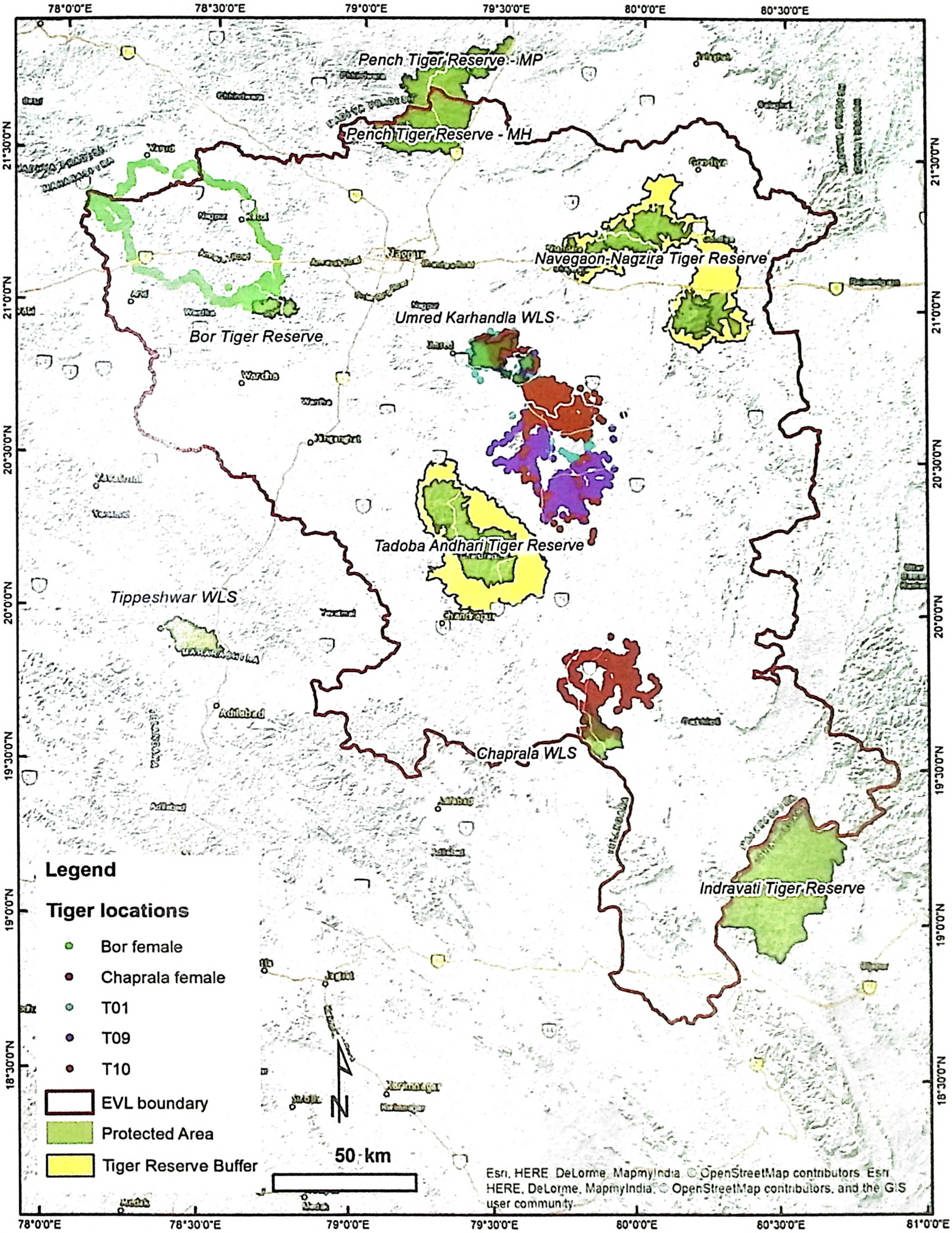


Figure 4.2: GPS locations obtained from radio collars of 5 tigers tracked during the study.

### 4.2.2. Use of the landscape by tigers during movement

Movement Ecology Tools for ArcGIS (ArcMET) 10.2.2v3 was used for this analysis (Wall et al., 2013). Using this tool on the GPS fixes of the tiger collars the Linear Time Density (LTD) Home Range was calculated. The LTD tool calculates the percentage of time spent per grid cell based on the approximated, straight-line movement by the animal from one recorded position to the next. Although it is well understood that animals rarely travel in straight lines, it is nonetheless a useful approximation in this situation. The landscape was divided into 500 X 500 m grids (which is more than the daily average movement of a tiger in this landscape i.e. 302.33 m) and the LTD values were calculated along the path of tiger movement. The LTD values were then sub-divided into ten bins using Jenks Natural Break Optimization, the grids which fell in the four highest bins were selected and centroid points of these selected grids were generated. Using SDMToolbox in ArcGIS 10.2, a heterogeneity layer of the eco-geographical variables was generated and the centroid points were spatially rarefied, in the process removing spatially autocorrelated ones. Spatially rarefied locations were then used as a training dataset to train a MAXENT model to predict the occurence of refuge pockets across the landscape.

### 4.2.3. Modelling of refuge pockets across the landscape

The diverse set of eco-geographical variables were considered: land use, elevation, terrain ruggedness, night light, and distance from the roads, drainage, PA and forests outside PA. Land use was converted from a categorical variable to a continuous one by considering the proportion of each landuse category in each grid. Proportion of 14 land use categories in grids in our study area translated to 14 eco-geographical layers, each indicating the proportion of that category in the grid. Autocorrelation was checked between the set of 21 eco-geographical variables and 17 were retained which were not auto-correlated at a Pearson's R of 0.4 and 0.5. 180 locations (training dataset) and 17 variables were used to bulid a MAXENT model using a random test percentage of 25%, with ten times cross-validation while varying the values of the regularization multiplier. Warren and Seifert (2011) examined the effects of regularization on model performance and suggested evaluating the effects of regularization on model performance and structure. Since change in regularization parameters substantially lowers overfitting of the model (Anderson and Gonzalez 2011; Radosavljevic and Anderson 2014), regularization multiplier values (0.5, 1 (default), 1.5, 2, 3, 4, and 5) were manipulated following the recommendations of Anderson and Gonzalez, (2011), Radosavljevic and Anderson, (2014), and Muscarella et al., (2014). Results of replicate runs were averaged from the models that were run in three different scenarios (using all points, using points spatially rarefied points, and using all points along with a bias surface) and with seven regularization multipliers. To avoid overfitting, linear, quadratic, and hinge features were selected (Phillips and Dudik, 2008; Merow et al., 2013). Model evaluation and the selection was done using Akaike information criterion (AICc), where the model with the lowest AICc value was selected as a prediction of areas across the landscape with varying degrees of probability that a dispersing/ exploring tiger may use it as a refuge.

## 4.3. Results and discussion

### 4.3.1. Use of the landscape by tigers during movement

**Figure 4.3** shows the temporal use of the landscape (500 X 500 m grids) by five collared tigers as a function of the percentage of total tracking time. The percentage time spent in each grid ranged from 0 to 0.08 % across five tiger datasets. 50% kernel density contours (as shown by magenta coloured ellipses) of the GPS locations indicate core areas of use for movement outside protected areas. These contours are highlighting areas where these tigers have spent 0.004 to 0.08% of the total time tracked. The proportion of time spent in each grid may seem very less, but it should be noted that this is a human dominated landscape where even small forest patches that they use for refuge are highly disturbed. Under such conditions, long ranging large mammals move faster to avoid human disturbance (Gara et al., 2016; Oriol-Cotterill et al., 2015). The depiction of landscape use with 50% kernel density contours could be provided initially only in areas where we had tiger movement data.

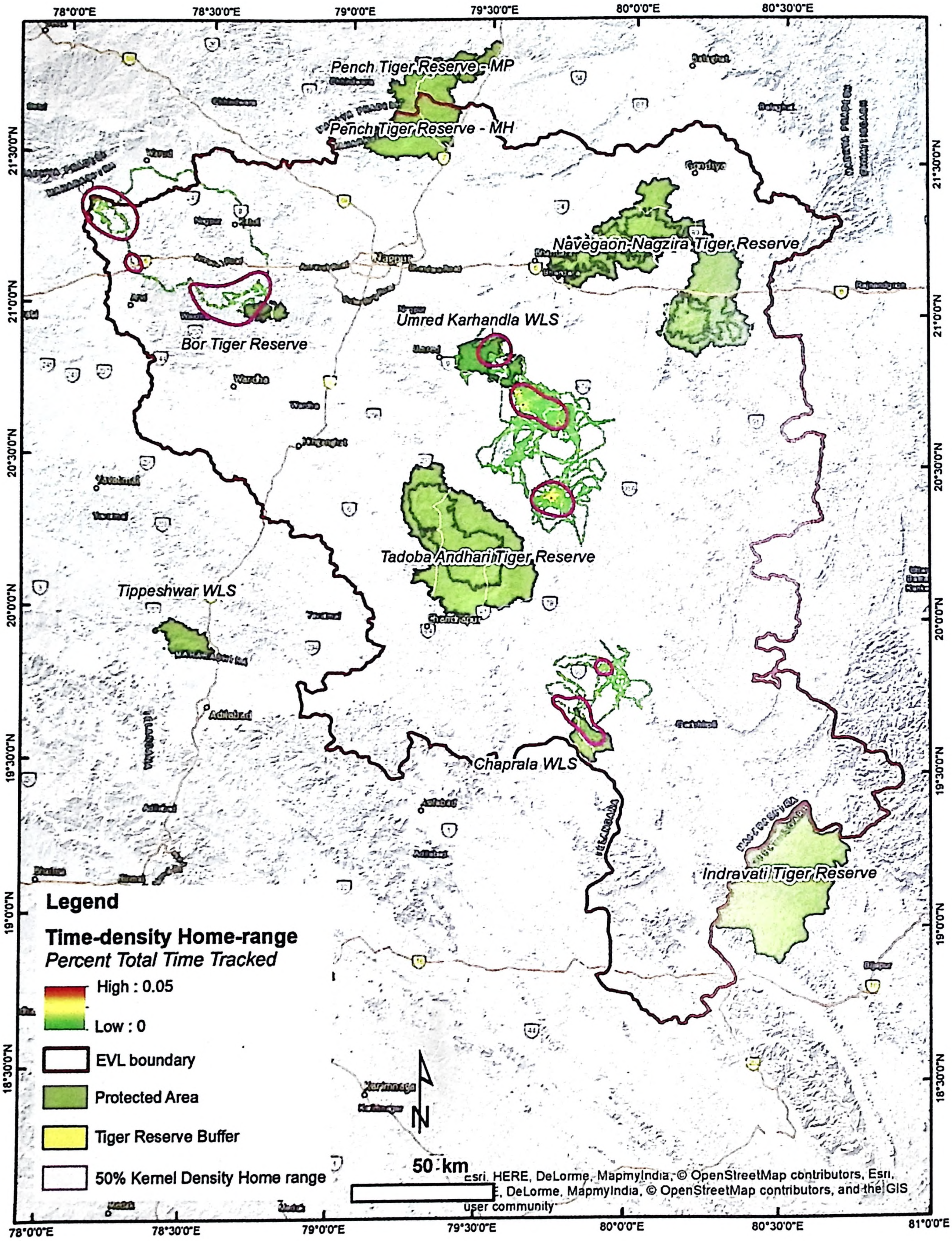


Figure 4.3: Linear time-density home ranges of 5 tigers in EVL. Magenta coloured ellipses show 50% kernel density contours of the GPS locations from radio-collars.

### 4.3.2: Refuge pockets across the landscape

Using the methodology as described in section 4.2.3, a MAXENT model was built to predict the occurrence of refuge pockets across the landscape, using 17 eco-geographical variables. After a jackknife test of variable importance, out of 17 variables only 7 were retained to build the final model. As shown in **Figure 4.4**, the final model was influenced most (36%) by the distance from forests outside PAs, followed by distance from PAs (26.3%), elevation (12.2%) and ruggedness (8.4%). The model was influenced by the distance from roads (6.5%), distance from drainage (5.4%) and NDVI (5.2%), to a lesser degree.

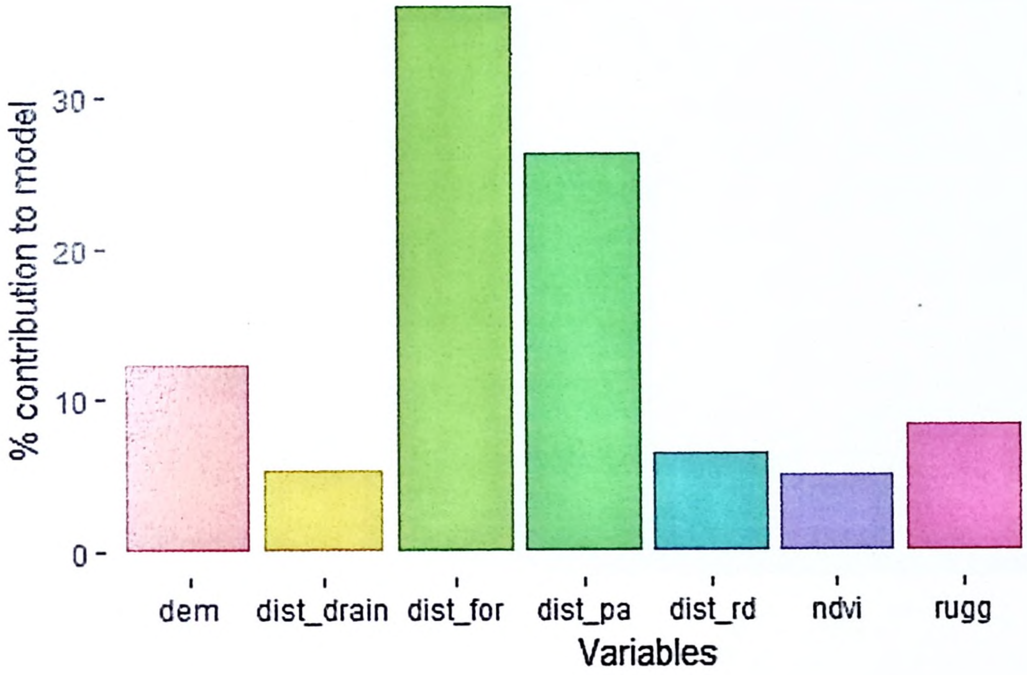


Figure 4.4: Relative contribution of response variables in the final model *(dem = elevation, dist_drain = distance from drainage, dist_for = distance from forests outside PAs, dist_pa = distance from PAs, dist_rd = distance from roads, ndvi = normalized difference vegetation index (proxy for vegetation cover), rugg = terrain ruggedness index)*

The response curves **(Figure 4.5)** show how each eco-geographical variable affects the MAXENT prediction. The curves show how the logistic prediction changes as each eco-geographical variable are varied, keeping all other eco-geographical variables at their average sample value. The probability that a tiger may use a particular area outside PA as a refuge while dispersing or exploring shows a decline with increasing distance from drainage, PAs, and forests outside PAs, with the curves showing a steep decline for the distance from forests outside PAs. Probability values show a gradual increase with increasing elevation and distance from roads. Probability values peak a certain amount of terrain ruggedness and then decreases gradually, while the opposite happens for NDVI, where there is a gradual rise in probability values with increasing NDVI until it reaches a peak and then falls suddenly.

Summing up, the response curves indicate that they refuge patches are away from roads and excessive interference, and occur near forest patches both near and away from PAs with some water sources nearby. The probability of occurrence of these patches is also high where there is good vegetation cover, and there is some rugged terrain (scrubland areas on hilly terrain).

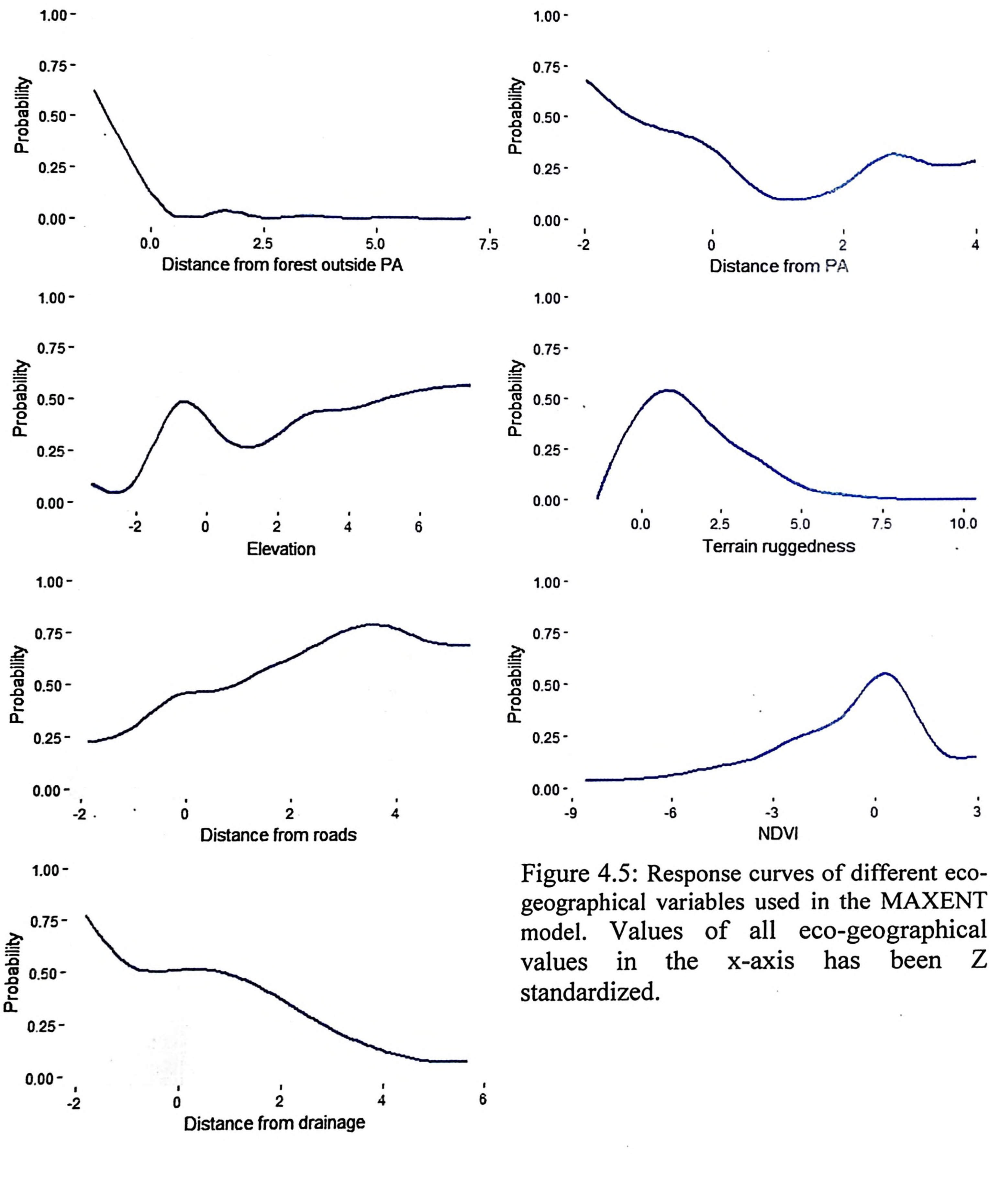


Figure 4.5: Response curves of different eco-geographical variables used in the MAXENT model. Values of all eco-geographical values in the x-axis has been Z standardized.

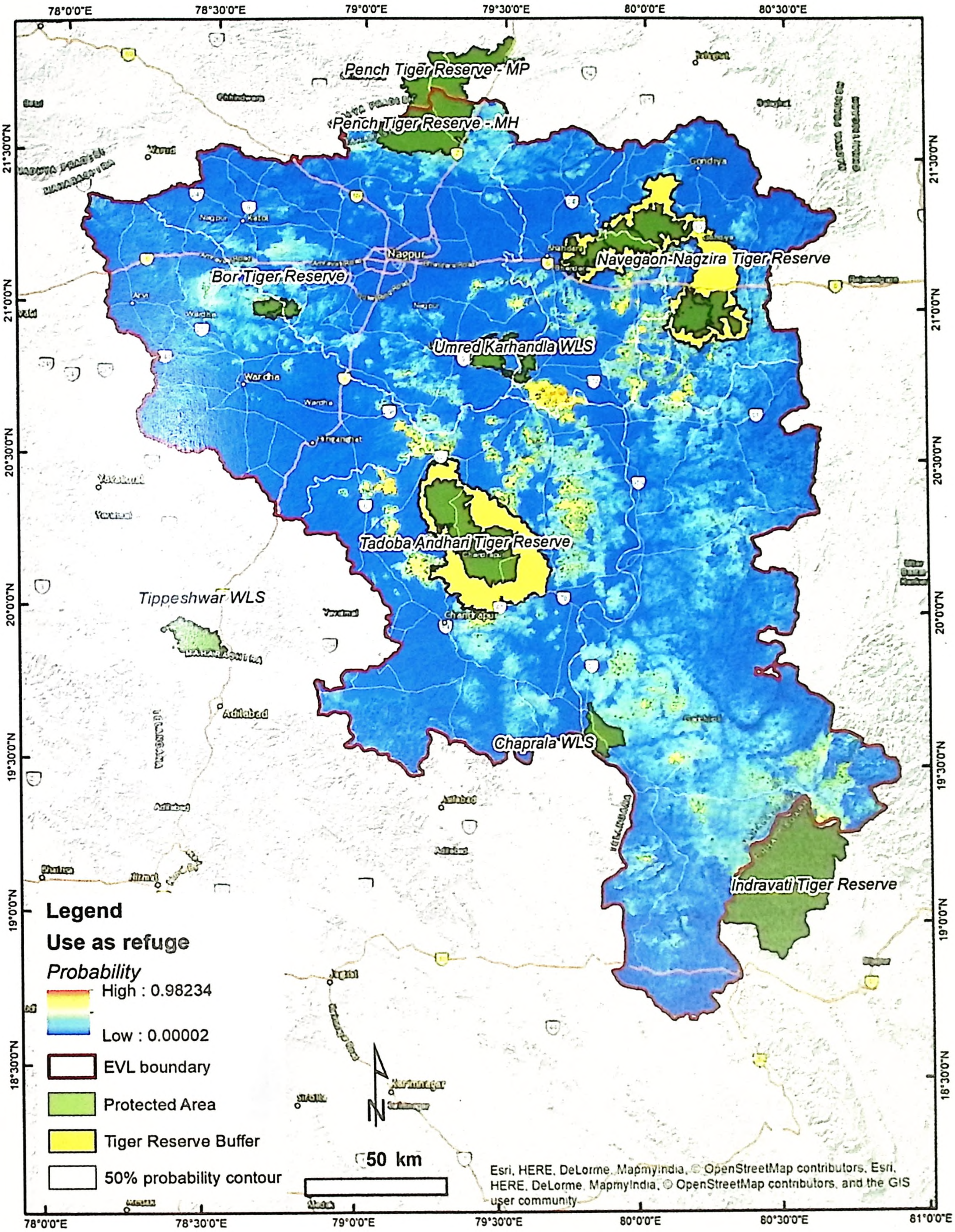


Figure 4.6: Map showing the potential of areas across the EVL as a refuge. Areas with a probability of more than 50% are bound by a contour line.

The probability values in the final model range from 0.00002 (low) to 0.98234 (high) and are displayed for the whole of EVL with areas inside PAs and Tiger Reserve Buffers masked **(Figure 4.6)**. The best patches in the modelled surface were identified by drawing 50% probability contours in the entire landscape thereby identifying a total area of 1677.26 $km^2$ of which patches greater than 0.5 $km^2$ (minimum patch size used by tigers as a refuge as recorded from tracking data) covers an area of 1587.88 $km^2$. Inside corridors modelled in this study, such patches (greater than 0.5 $km^2$ in area) cover an area of 1368.06 $km^2$. Protecting these patches would need active management by the forest department on the ground in the form of reducing anthropogenic pressures like grazing, resource extraction and human presence in general. Under such needs, it is important to highlight that only 647.38 $km^2$ (40.77%) in the total landscape and 582.70 $km^2$ (42.59%) inside modelled corridors, falls inside notified forest areas. So effectively about 60% of the potential refuge patches in the landscape, that needs to be secured for improving connectivity for tigers, falls in private or publicly owned lands and are outside the direct jurisdiction of the forest department. This not only indicates a higher quantum of work to secure these patches but also highlights the needs for a conservation approach that necessarily involves multiple stake holders in the landscape.

## 4.4. Conclusion

Improvement of habitat connectivity for wild animals in fragmented landscapes is increasingly being used as a strategy to mitigate the effects of habitat fragmentation, land-use dynamics and climate change (Doerr et al., 2011). However, movement data are yet to be systematically incorporated into assessments and prioritization of connectivity (Sawyer et al., 2011; Zeller et al., 2012). This study uses movement data to quantify habitat use outside PAs and prioritize connectivity. Results of this study imply that if the persistence of the tigers is to be ensured in the Central Indian landscape, undisturbed areas of relatively moderate to high vegetation cover needs to be conserved within a human dominated matrix. Refuges need to be created with minimum human presence even within high human use areas. If large carnivores are expected to avoid human dominated landscapes, it could limit their ability to utilize this "Landscapes of Coexistence," particularly where the density and distribution of people and livestock are such that complete avoidance is difficult (Oriol-Cotterill et al., 2015). Incorporating movement data into connectivity assessments can improve our understanding of dispersal and provide a mechanistic basis for conservation prioritization in heterogeneous landscapes (Vasudev and Fletcher Jr., 2015). Conservation of connectivity to facilitate gene flow, climate adaptation and other processes is challenging without reliable maps to guide managers (Beier et al., 2011). This study provides a landscape-wide spatially explicit mapping of potential refuge patches that can be used by managers to their advantage to better conserve connectivity in the landscape. Connectivity analyses have provided valuable implementation guidance in the past. Prioritization of habitats to effectively target connectivity improvement can increase the efficacy of such analyses and the range of conservation options they reveal (McRae et al., 2012). It can help managers a) decide if connectivity conservation is a worthy investment in a landscape; b) identify opportunities to restore vs. conserve different areas, and c) balance potential improvement against costs so that investments can be prioritized. Successful tiger conservation in EVL will hinge on land management practices that conserve the integrity of large habitat patches, but also protect the small, high-quality habitat patches that can sustain small tiger populations or act as stepping stones which facilitate dispersal. This is especially important in case of EVL since the average size of PAs here are less than 1000 km$^2$ and the concentrating conservation efforts in PAs alone cannot sustain a viable tiger population. If these small stepping stones are not conserved, centuries of efforts and resources pumped into conservation to safeguard the tiger will be all in vain.

**HIGHLIGHTS FOR MANAGERS**

This study identified tiger corridors in EVL which covers an area of 7555.28 km$^2$ of which only 2481.23 km$^2$ (32.84%) fall in notified forest lands. The remaining 67.16% falls in private and public lands.

Patches that a tiger may chose as refuge usually occur away from roads and excessive interference, and occur near forest patches both near and away from PAs with some water sources nearby. The probability of occurrence of these patches is also high where there is good vegetation cover, and there is some rugged terrain (scrubland areas on hilly terrain).

Minimum patch size used by tigers as a refuge as recorded from tracking data is 0.5 km$^2$.

Refuge patches modelled by the study across the landscape that are greater than 0.5 km$^2$ covers an area of 1587.88 km$^2$.

1368.06 km$^2$ of such areas are already included inside the modelled corridors.

Only 647.38 km$^2$ (40.77%) in the total landscape and 582.70 km$^2$ (42.59%) inside modelled corridors, falls inside notified forest areas.

Areas heavily highlighted as refuge by the model are Pauni Territorial, Godazari and Bramhapuri Forest Division. Pauni Territorial should be made a part of Umred Karhandla Wildlife Sanctuary to give it more protection and Bramhapuri needs to be converted to a Wildlife Division.

# CHAPTER 5
# CONCLUSION

# CHAPTER 5: CONCLUSION

## 5.1. Introduction

India harbours over half the global tiger (*Panthera tigris tigris*) population within just 7% of their historic range (Jhala et al., 2015). These tigers are distributed in geographically isolated populations (Qureshi et al., 2014), being separated by landscapes of intensive human occupation, such as expanding agriculture, urbanization and an aggressive infrastructural development fueled by a national aspiration to achieve 8% economic growth (Ministry of Finance, 2016). However, India does not have a comprehensive landuse policy (Department of Land Resources, 2013), which may lead to unchecked land conversion near forest fringes. Moreover, most of the reserves that contain these isolated tiger populations are not large enough to sustain the steadily growing tiger population (Chundawat et al., 2016). This leads to an intensification of conflict between the growing tiger population and a human population of 1.25 billion increasing at a rate of 1.7% annually (Chandramouli, 2011). Dispersing tigers from protected reserves are prone to confrontations with humans, resulting in human-tiger conflict (Dhanwatey et al., 2013). Isolation and inadequate reserve size (average size is 486 $km^2$, Karanth and Defries, 2011) amongst sites that harbors the fragmented tiger populations highlight the need of connecting these forest patches and the importance of corridors in doing so.

## 5.2. Connecting links for long term conservation

The last decade in conservation research has illustrated that habitat corridors are an important conservation intervention to offset negative impacts of habitat fragmentation and to maintain meta-population dynamics (Hilty et al., 2012). The Central Indian Landscape which roughly covers an area of 76,913 $km^2$ (Yumnam et al., 2014), sets a perfect example of the importance of connecting fragmented tiger populations by corridors (Dutta et al., 2016). Deforestation, road widening, mining, aggressive urbanization and unchecked human activity in corridors are major concerns about the viability of corridors in the Central Indian landscape (Borah et al., 2016; Sharma et al., 2013b; Yumnam et al., 2014). Most studies unanimously suggest that reducing anthropogenic pressure (Joshi et al., 2013) and restoring habitat (Yumnam et al., 2014) are solutions for the long term sustainability of corridors. In addition, others have suggested involving local communities through community centered conservation programmes and eco-tourism (Rathore et al., 2012; Ravan et al., 2005), which may ensure that local communities are still able to derive their livelihood from the corridor forests. Elevating the legal status of corridors lands (Ravan et al., 2005; Yumnam et al., 2014) and use of smart green infrastructure in critical corridor habitats (Yumnam et al., 2014; Habib et al., 2015) has also been advocated as an alternative solution to safeguard corridors in the landscape. In areas where corridors span across multiple states, co-operation between different state agencies has been suggested (Ravan et al., 2005). However most these studies have either used genetic data, or expert opinion with sampling done from mostly inside PAs to model habitat connectivity in the landscape and falls short of the necessary prerequisites to build a spatially explicit and robust model.

### 5.3. Option for conserving tiger corridors

Recommendations by various research groups to safeguard the tiger and its habitat in India often hits the same road block of where and what to conserve. The importance of protected areas (PA) for conserving natural resources has been highly recognized worldwide (Hockings, 2003; Rodrigues et al., 2004) and successful conservation strategies often consider connectivity with adjacent PAs (Jackson and Gaston, 2008; Ladle and Whittaker, 2011). The current study has identified 7555.28 $km^2$ of area outside PAs that are crucial for the dispersal and movement of tigers in the Eastern Vidarbha Landscape (EVL) in Central India (Mondal et al., 2016) and only 2481.23 $km^2$ (32.84%) fall in notified forest lands **(Figure 5.1)**. This area includes reserve forest, unprotected forests, and privately owned lands covered by forested or agricultural landuse. These areas come under the "Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act" (Ministry of Law and Justice, 2007) enabling local communities to derive their livelihood from these lands, including the forest. Using tiger movement data, the current study has modelled areas across the landscape that needs to be conserved as refuge patches for tigers moving in the human dominated landscape. Analysis shows that such patches greater the 0.5 $km^2$ covers only 1587.88 $km^2$ in EVL of which only 40.77% falls inside notified forest areas. The rest, about 60% lies in multiple use private or public lands.

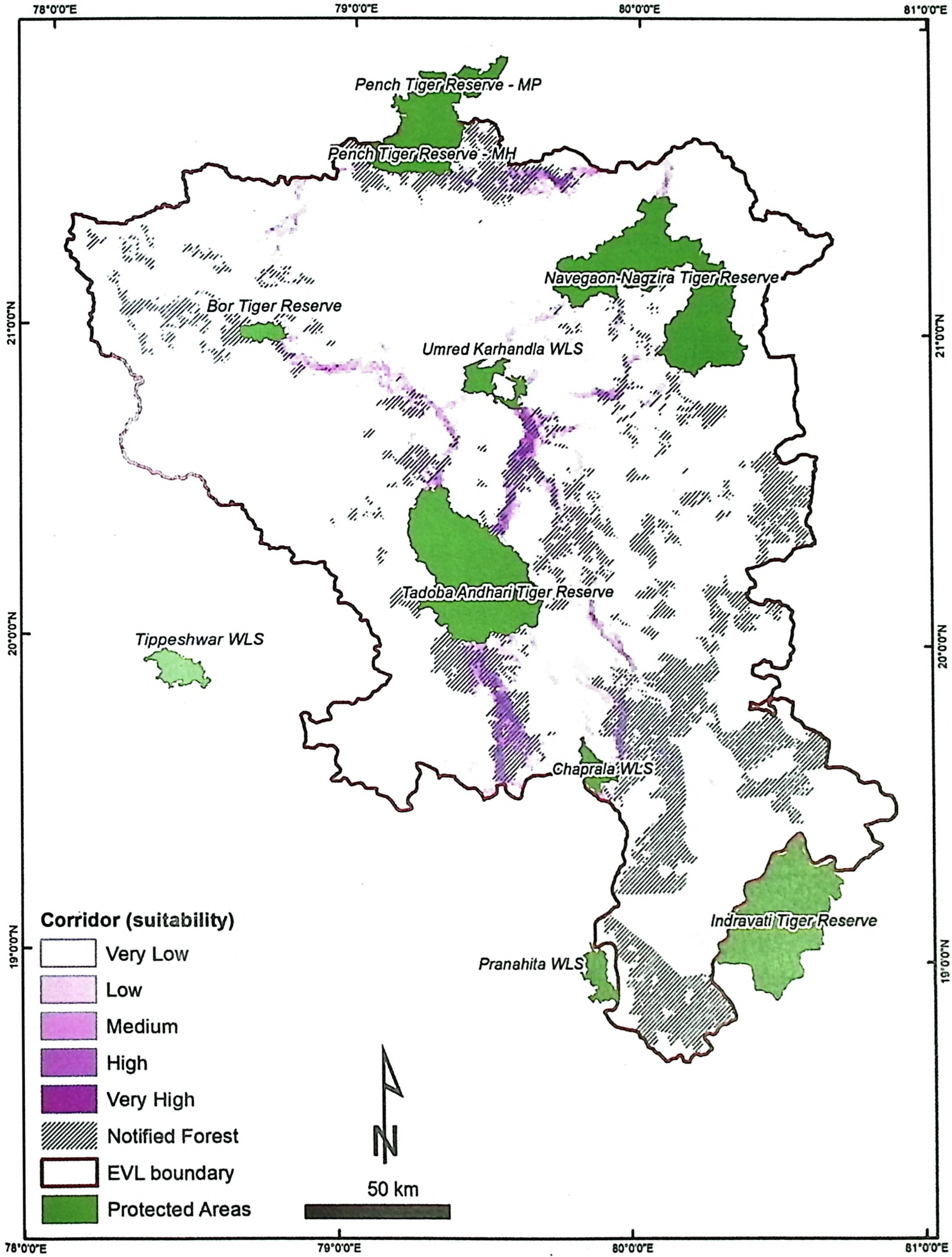


Figure 5.1: Map showing amount of under forest jurisdiction along corridors modelled in this study.

Due to its proximity to intensive human use areas, these multiple use forest areas suffer from anthropogenic pressures like resource extraction, grazing, mining, infrastructural developments and noise, light and air pollution. Despite the plethora of impediments, these corridors are still functional to allow the movement of animals across the landscape (Joshi et al., 2013; Sharma et al., 2013a). Many areas along these corridors are in a critical state due to fragmentation, degradation, and resource extraction. Habitat connectivity is uncertain at these spots and loss of contiguity here may render the entire length of the corridor non-functional. Overlap of human use and tiger presence leads to the prevalence of human-tiger conflict, including direct attacks on humans and livestock depredation (Miller et al., 2016). The current study calculated that about 2000 $km^2$ area in EVL potentially falls under very high human-tiger conflict zones and that 36.41% of the total population of EVL are vulnerable to human-tiger conflict. Such events contribute to negative attitudes of the local community toward tiger conservation in the area. On multiple occasions, deforestation occurring along corridor habitats occur outside of notified forest boundaries (Joshi et al., 2016) and the forest administration, as an advocate of conservation, hardly has a say.

The above points highlight the magnitude of mitigation measures that need to be employed for successful conservation of tiger corridors in the EVL, which includes protecting corridor forests, restoring degraded habitats, buying lands along corridors, and paying compensation to villagers suffering from human-tiger conflict. In the 3rd Asia Ministerial Conference on Tiger Conservation 2016 held in New Delhi, the Honorable Prime Minister of India stated that "conservation of tigers is not a choice, it is an imperative." He further added, "I believe Tiger Conservation and Conservation of Nature is not a drag on development, both can happen in a mutually complimentary manner, all we need is to reorient our strategy by factoring the concerns of the tiger in sectors, where tiger conservation is not the goal." At the same meeting, the Honorable Minister of Environment, Forests and Climate Change addressed the government's initiative to save tiger corridors: "We will incentivize project proponents to give land for compensatory afforestation in tiger corridors. By such measures, we can free tiger corridors from private incumbents, and it will become forest land. It will protect tiger corridors which will protect the growing tiger population." All this reflects a general positive public will toward tiger conservation, with further assurance being provided by available Government funds and above mentioned policies. To effectively tap into all these resources and public will, we must follow an unconventional approaches to prioritize alternative funding streams, where we channel available resources by prioritizing from among various schemes of government ministries/departments for tiger corridor conservation. Under provisions of clause 135 of the Companies Act, 2013[1] funds are available from the corporate sector as well in the form of 2% of their average net profit in the previous 3 years toward Social Corporate Responsibility (CSR). Such CSR funds can also be used for tiger conservation. The merit of this proposed approach is its ability to draw resources from sectors, where tiger conservation is not the primary goal. Such indirect funds can be leveraged by mainstreaming the conservation agenda in these sectors.

### 5.4. Elucidating this novel approach

The key strategy of this novel approach is to harness resources available from several areas, which typically lie in the purview of different ministries of the Central Government of India (GoI)[2]. This can only be achieved if environmental concerns are internalized in policymaking in a large number of sectors. The major portion of funds available for conservation in India is under various programs of the Ministry of Environment, Forest and Climate Change (MoEF & CC) which constituted only about 0.11% of the Union Budget of India for 2016-17.

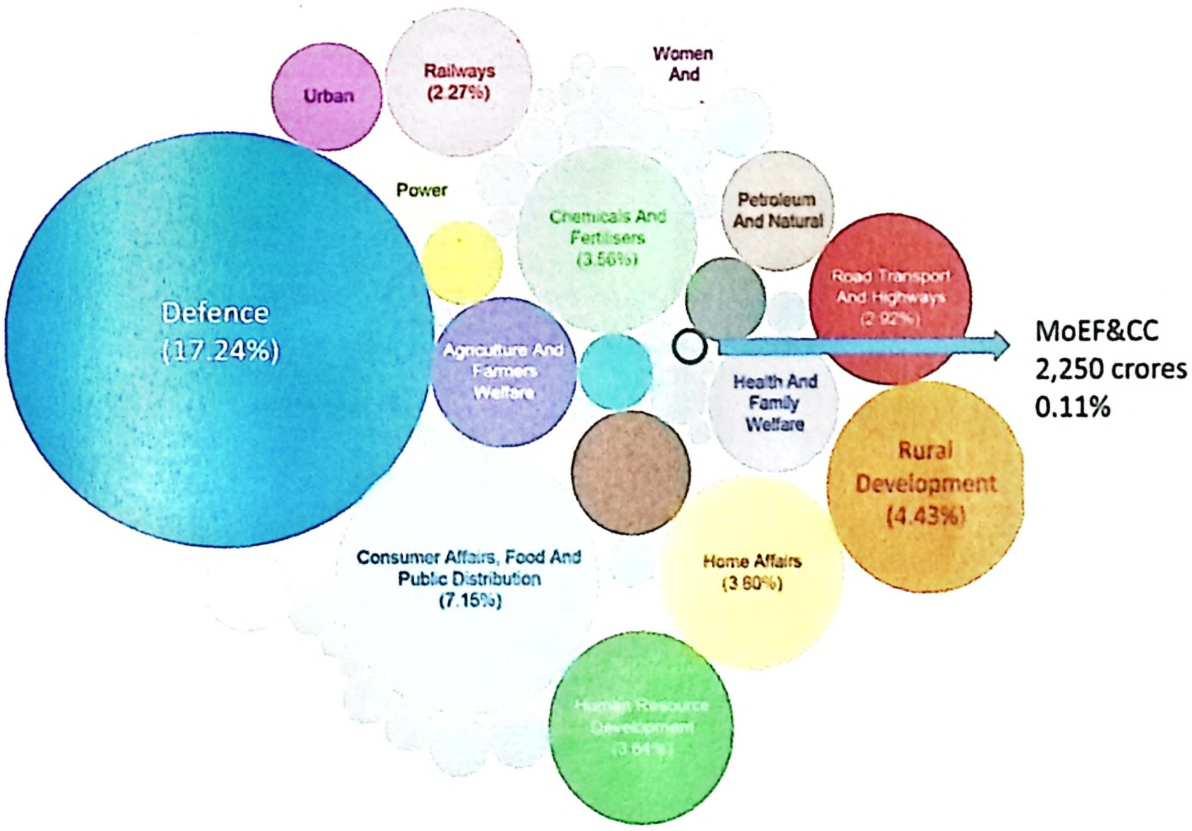


Figure 5.2: Allocation of Union Budget of India for financial year 2016-17.

1 www.mca.gov.in/Ministry/pdf/CompaniesAct2013.pdf

2 www.cbd.int/financial/doc/india-assessment-funding-support-en.pdf

These funds are available in the form of core (direct and immediate biodiversity impact), and non-core funding (pollution, hazardous substances management, etc. which facilitate biodiversity conservation of river streams, wetlands) from MoEF & CC (MoEF, 2012). Out of the MoEF & CC's aggregate budget of INR 1824.14 Crores for the year 2013–14, the core funding constitutes INR 1564.34 Crores while the non-core accounts for INR 259.8 Crores (MoEF, 2014). Apart from MoEF & CC, states in India also allocate a part of their budget for biodiversity conservation. It amounts to INR 5025.57 Crores as per their 2013–14 budget **(Table 5.1)**. The indirect peripheral funding amounting to INR 2354.74 Crores is available from 77 schemes from 23 Ministries/Departments of GoI **(Figure 5.3)**.

Table 5.1: Potential funding sources for biodiversity conservation from various sources in GoI.

| **Nature of funding** | **Amount (Crore Rupees)** |
|---|---|
| MoEF&CC | 1824.14 (Core: 1564.34, Non-core: 259.8) |
| States | 5025.57 |
| Peripheral | 2354.74 (23 Ministries/ Departments, 77 schemes) |
| **Total** | **9204.45 Crore Rupees** |

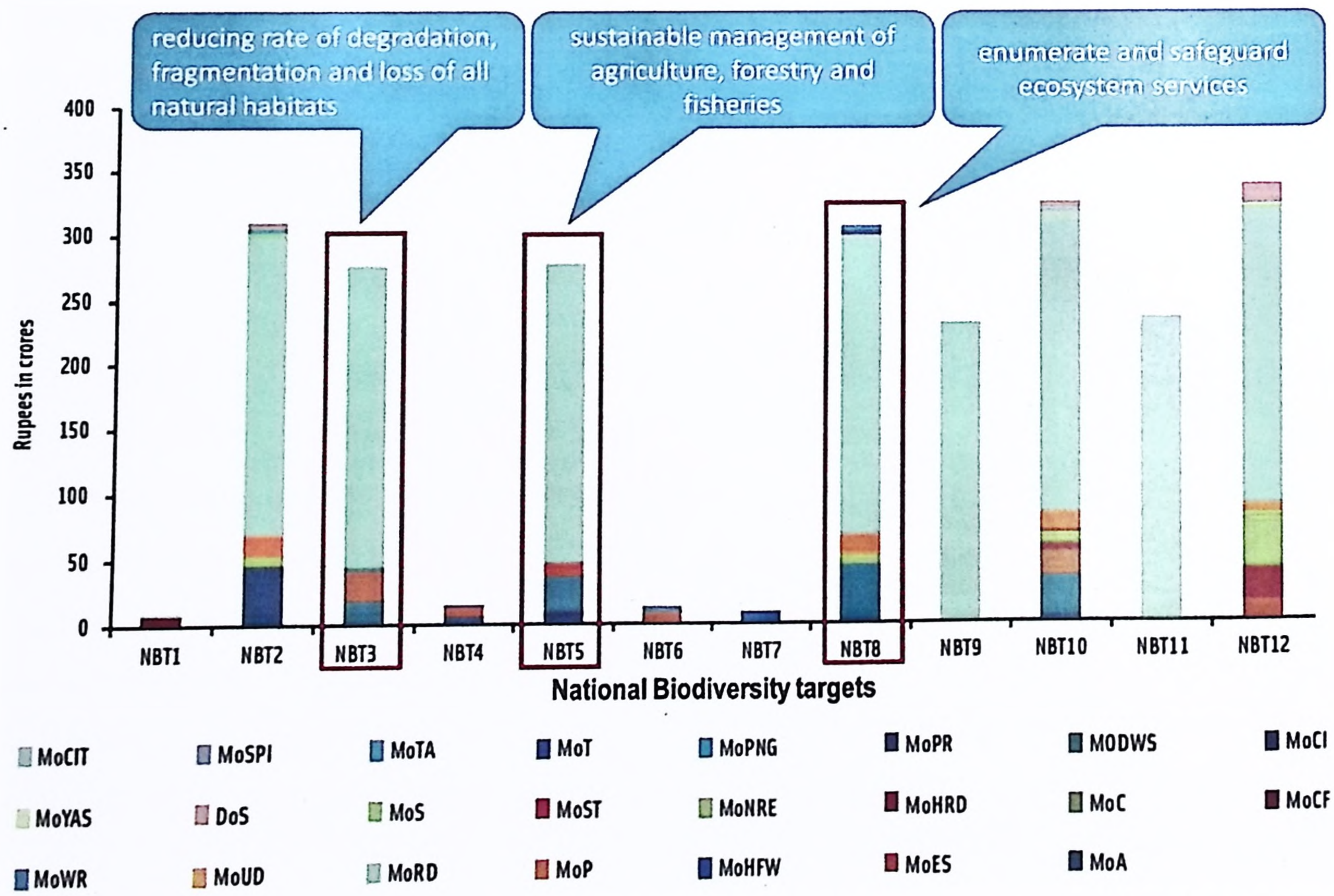


Figure 5.3: Budget allocations of 21 Ministries of GoI that contribute towards NBTs. *Source: National Biodiversity Action Plan (Addendum 2014 to NBAP 2008).*

They support activities that benefit biodiversity but for which biodiversity conservation is not the main focus. They have certain contributions towards India's National Biodiversity Targets (NBTs), especially NBT3, NBT5 and NBT8, which can be used towards corridor conservation. Core and some part of non-core funding from MoEF & CC are directly available to be used in protected areas or lands, yet it fails to consider areas outside the purview of this protection and financial assistance. Our approach is about opportunistically amalgamating resources from peripheral funding sources.

### 5.5. Implementing our novel approach

Corridor habitats in India often consist of degraded forest surrounded by human-dominated landscapes. Due to this close interface, the corridors are facing intense anthropogenic pressures, such as extraction of fuelwood and fodder, the presence of invasive species and excessive grazing. Here we try to suggest options how we can mobilize resources from other sectors to reduce these pressures on the corridors.

The National Rural Employment Guarantee Act (NREGA) 2005, under the Ministry of Rural Development, provides secure livelihood to rural populations in the form of 100 days of wage employment for unskilled manual labor[3]. It has been recognized as the most ambitious example of rural social security and public works programme in the World Development Report, 2014 by World Bank (2013). However, in the monsoon season, this scheme fails to provide any jobs to the local villagers due to flooding and muddy conditions. On the other hand, this workforce of thousands of manpower can be well employed in corridor forest areas in weed removal exercises and habitat restorations. This way the NREGA scheme picks up even in monsoon providing employment to thousands of villagers, and at the same time improve habitat quality in the corridor areas.

Dr. Shyama Prasad Mukherjee Van Vikas Yojana by the Government of Maharashtra aims to provide the rural population with cooking gas (Liquid Petroleum Gas) or biogas (made from cattle dung) as an alternate source of daily household energy needs in the state of Maharashtra. Such schemes, when targeted in villages near corridor areas, can reduce their dependency on forests and reduce extraction of firewood and fodder. Lesser ventures into the

[3] http://rural.nic.in/sites/downloads/right-information-act/02%20_CIC_PartII_ MG_NREGA(F).pdf.

forest to gather such resources also reduces the chances of encounters with tiger and thus has the potential to reduce conflict. Based on the recommendations of this study this scheme has been launched in all the corridor areas that has been modelled in this study along with the already existing villages earmarked in the bugger zones of tiger reserves[4]. This scheme will also be applied to villages relocated from inside wildlife areas, irrespective of whether their relocated spot is in a wildlife area or not.

Recently due to a ban on cow slaughter in the state of Maharashtra[5] the cattle population in the state has increased dramatically[6]. This has led distressed farmers to abandon their unproductive cattle thereby increasing the number of unattended cattle which are venturing into forest areas to graze. Consequently, this high amount of uncontrolled grazing is leading to degradation of the corridor forests. A new initiative of the State Government of Maharashtra is to set up cow shelters in selected districts to mitigate this problem. These shelters are being called the "Govardhan Govansh Raksha Kendra."[7] This scheme will be conducted through local NGOs, where abandoned unproductive and non-lactating cattle will be contained inside the walls of these shelters and cattle excreta will be used to manufacture organic manure[8]. When implemented in villages near tiger corridors, this initiative helps triage with its 2-fold benefits: reduction of grazing pressure in corridor habitats and promotion of the use of organic fertilizers.

**5.6. Conclusion**

We believe that our approach is more than just focusing on single species conservation, but more broadly prioritizing of conservation actions when resources are scarce. We argue that funds can be funneled from diverse sectors when dedicated funding available for conservation may not be enough and provide an example of how this may work using the Indian tiger conservation challenge. Adoption of this novel approach provides us with a logical and intuitive approach for efficiently distributing available resources among management actions to achieve a targeted conservation goal. By explicitly choosing among available resources using a transparent prioritization approach, we may be able to highlight

[4] https://timesofindia.indiatimes.com/city/nagpur/jan-van-vikas-scheme-to-be-implemented-in-tiger- corridors-too/articleshow/60182124.cms
[5] http://bombayhighcourt.nic.in/libweb/acts/Stateact/2015acts/2015.05.PDF
[6] http://goo.gl/eqphXu
[7] http://goo.gl/utbEQ4
[8] http://goo.gl/hRkBVU

any deficit in available funds which otherwise may go unnoticed (Bottrill et al., 2008). The practice of conservation is a human socio-political process since conservation is driven or constrained by legislation and politics (Buckley 2016). Adoption of a transparent decision-making process through prioritization will rule out the possibility of charismatic taxa or emotive causes diverting funding from a more rationally valid cause (Metrick and Weitzman, 1996). Conservation efforts that follow the principle of prioritization are logical, can be duplicated across time and space (Bottrill et al., 2009).

The novel approach that we suggest can clearly and objectively apportion funds from peripheral sources for corridor conservation that have been hitherto invisible and/or seldom tapped into. If meticulously pursued, our approach may become the best means of safeguarding tiger corridors in India. The crux lies in intelligently formulating policies and schemes to mainstream conservation for agencies without conservation mandates.

# REFERENCES

# REFERENCES


Anderson, R. P. and Gonzalez Jr, I. 2011. Species-specific tuning increases robustness to sampling bias in models of species distributions: an implementation with Maxent. Ecological Modelling, 222(15): 2796-2811.

Aryal, A., Shrestha, U. B., Ji, W., Ale, S. B., Shrestha, S., Ingty, T., Maraseni, T., Cockfield, G. and Raubenheimer, D. 2016. Predicting the distributions of predator (snow leopard) and prey (blue sheep) under climate change in the Himalaya. Ecology and evolution, 6(12): 4065-4075.

Barlow, A. C. 2009, The Sundarbans tiger: adaptation, population status and conflict management, Ph.D. thesis, University of Minnesota: 170 pp.

Beier, P., Spencer, W., Baldwin, R. F. and Mcrae, B. 2011. Toward best practices for developing regional connectivity maps. Conservation Biology, 25(5): 879-892.

Borah, J., Jena, J., Yumnam, B. and Puia, L. 2016. Carnivores in corridors: estimating tiger occupancy in Kanha–Pench corridor, Madhya Pradesh, India. Regional Environmental Change, 16(1): 43-52.

Bottrill, M. C., Joseph, L. N., Carwardine, J., Bode, M., Cook, C., Game, E. T., Grantham, H., Kark, S., Linke, S., Mcdonald-Madden, E., Pressey, R. L., Walker, S., Wilson, K. A. and Possingham, H. P. 2008. Is conservation triage just smart decision making? Trends in Ecology & Evolution, 23(12): 649-654.

Bottrill, M. C., Joseph, L. N., Carwardine, J., Bode, M., Cook, C., Game, E. T., Grantham, H., Kark, S., Linke, S., Mcdonald-Madden, E., Pressey, R. L., Walker, S., Wilson, K. A. and Possingham, H. P. 2009. Finite conservation funds mean triage is unavoidable. Trends in Ecology & Evolution, 24(4): 183-184.

Buckley, R. C. 2016. Triage Approaches Send Adverse Political Signals for Conservation. Frontiers in Ecology and Evolution, 4(39).

Carbone, C., Christie, S., Conforti, K., Coulson, T., Franklin, N., Ginsberg, J. R., Griffiths, M., Holden, J., Kawanishi, K., Kinnaird, M., Laidlaw, R., Lynam, A., Macdonald, D. W., Martyr, D., Mcdougal, C., Nath, L., O'brien, T., Seidensticker, J., Smith, D. J. L., Sunquist, M., Tilson, R. and Wan Shahruddin, W. N. 2001. The use of photographic rates to estimate densities of tigers and other cryptic mammals. Animal Conservation, 4(1): 75-79.

Cardillo, M., Purvis, A., Sechrest, W., Gittleman, J. L., Bielby, J. and Mace, G. M. 2004. Human Population Density and Extinction Risk in the World's Carnivores. PLOS Biology, 2(7): e197.

Carroll, C., Mcrae, B. and Brookes, A. 2012. Use of linkage mapping and centrality analysis across habitat gradients to conserve connectivity of gray wolf populations in western North America. Conservation Biology, 26(1): 78-87.

Ceia-Hasse, A., Borda-De-Água, L., Grilo, C. and Pereira, H. M. 2017. Global exposure of carnivores to roads. Global Ecology and Biogeography, 26(5): 592-600.

Champion, S. H. and Seth, S. K. 1968. A revised survey of the forest types of India. Government of India Press, New Delhi, 404 pp.

Chandramouli, C. 2011. Census of India 2011. In: Registrar General (ed.). New Delhi: Ministry of Home Affairs.

Chundawat, R. S., Sharma, K., Gogate, N., Malik, P. K. and Vanak, A. T. 2016. Size matters: Scale mismatch between space use patterns of tigers and protected area size in a Tropical Dry Forest. Biological Conservation, 197: 146-153.

Clauzel, C., Bannwarth, C. and Foltete, J.-C. 2015. Integrating regional-scale connectivity in habitat restoration: An application for amphibian conservation in eastern France. Journal for nature conservation, 23: 98-107.

Department of Land Resources 2013. Draft National Land Utilisation Policy. Ministry of Rural Development, Government of India, New Delhi.

Devi, B. S., Murthy, M., Debnath, B. and Jha, C. 2013. Forest patch connectivity diagnostics and prioritization using graph theory. Ecological modelling, 251: 279-287.

Dhanwatey, H. S., Crawford, J. C., Abade, L. a. S., Dhanwatey, P. H., Nielsen, C. K. and Sillero-Zubiri, C. 2013. Large carnivore attacks on humans in central India: a case study from the Tadoba-Andhari Tiger Reserve. Oryx, 47(2): 221-227.

Dinerstein, E. and Wikramanayake, E. D. 1993. Beyond “Hotspots”: How to Prioritize Investments to Conserve Biodiversity in the Indo-Pacific Region. Conservation Biology, 7(1): 53-65.

Dinerstein, E., Loucks, C., Wikramanayake, E., Ginsberg, J., Sanderson, E., Seidensticker, J., Forrest, J., Bryja, G., Heydlauff, A. and Klenzendorf, S. 2007. The fate of wild tigers. AIBS Bulletin, 57(6): 508-514.

Divyabhanusinh 1999. The end of a trail: the cheetah in India. New Delhi, India, 248 pp.

Doerr, V. A., Barrett, T. and Doerr, E. D. 2011. Connectivity, dispersal behaviour and conservation under climate change: a response to Hodgson et al. Journal of Applied Ecology, 48(1): 143-147.

Duque-Lazo, J., Van Gils, H., Groen, T. and Navarro-Cerrillo, R. 2016. Transferability of species distribution models: The case of *Phytophthora cinnamomi* in Southwest Spain and Southwest Australia. Ecological modelling, 320: 62-70.

Dutta, T., Sharma, S., Mcrae, B. H., Roy, P. S. and Defries, R. 2016. Connecting the dots: mapping habitat connectivity for tigers in central India. Regional Environmental Change, 16(1): 53-67.

Espinosa, S., Celis, G. and Branch, L. C. 2018. When roads appear jaguars decline: Increased access to an Amazonian wilderness area reduces potential for jaguar conservation. PLOS ONE, 13(1): e0189740.

Fahrig, L. 2007. Non-optimal animal movement in human-altered landscapes. Functional ecology, 21(6): 1003-1015.

Fahrig, L. and Merriam, G. 1994. Conservation of fragmented populations. Conservation biology, 8(1): 50-59.

FAO 2006. Rapid growth of selected Asian economies: lessons and implications for agriculture and food security. Synthesis report. Regional Office for Asia and the Pacific. Food and Agriculture Organization of the United Nations, Bangkok

Gara, T. W., Wang, T., Skidmore, A. K., Ngene, S. M., Dube, T. and Sibanda, M. 2017. Elephants move faster in small fragments of low productivity in Amboseli ecosystems: Kenya. Geocarto international, 32(11): 1243-1253.

Goodrich, J. M. 2010. Human–tiger conflict: a review and call for comprehensive plans. Integrative Zoology, 5(4): 300-312.

Habib, B., Rajvanshi, A., Mathur, V. and Saxena, A. 2016. Corridors at Crossroads: Linear Development-Induced Ecological Triage as a Conservation Opportunity. Frontiers in Ecology and Evolution, 4(132).

Habib, B., Saxena, A., Mondal, I., Rajvanshi, A., Mathur, V. B. and Negi H.S. 2015. Proposed Mitigation Measures for Maintaining Habitat Contiguity and Reducing Wild Animal Mortality on NH 6 & 7 in the Central Indian Landscape. Wildlife Institute of India, Dehradun and National Tiger Conservation Authority, Govt. of India, New Delhi. TR 2015/006

Hanski, I. 1991. Single-species metapopulation dynamics: concepts, models and observations, 17-38: In Metapopulation Dynamics: Empirical and Theoretical Investigations, Gilpin, M. and Hanski, I. (eds.) Academic Press, London.

Hanski, I. 1994. A practical model of metapopulation dynamics. Journal of animal ecology, 63: 151-162.

Hanski, I. 1998. Metapopulation dynamics. Nature, 396: 41.

Harrison, S. 1991. Local extinction in a metapopulation context: an empirical evaluation, 73-88: In Metapopulation dynamics: empirical and theoretical investigations, Gilpin, M. and Hanski, I. (eds.) Academic Press, London.

Hilty, J. A., Lidicker, W. Z., Merenlender, A. and Dobson, A. P. 2012. Corridor Ecology: The Science and Practice of Linking Landscapes for Biodiversity Conservation. Island Press, Washington, DC, 344 pp.

Hockings, M. 2003. Systems for Assessing the Effectiveness of Management in Protected Areas. BioScience, 53(9): 823-832.

Inskip, C., Ridout, M., Fahad, Z., Tully, R., Barlow, A., Barlow, C. G., Islam, M. A., Roberts, T. and Macmillan, D. 2013. Human–tiger conflict in context: risks to lives and livelihoods in the Bangladesh Sundarbans. Human ecology, 41(2): 169-186.

Jackson, S. F. and Gaston, K. J. 2008. Incorporating Private Lands in Conservation Planning: Protected Areas in Britain. Ecological Applications, 18(4): 1050-1060.

Jenks, G. F. 1967. The data model concept in statistical mapping. International yearbook of cartography, 7: 186-190.

Jhala, Y. V., Qureshi, Q. and Gopal, R. (eds.) 2015. The status of tigers, co-predators & prey in India. National Tiger Conservation Authority, New Delhi & Wildlife Institute of India, Dehradun. TR2015/021.

Joshi, A. R., Dinerstein, E., Wikramanayake, E., Anderson, M. L., Olson, D., Jones, B. S., Seidensticker, J., Lumpkin, S., Hansen, M. C., Sizer, N. C., Davis, C. L., Palminteri, S. and Hahn, N. R. 2016. Tracking changes and preventing loss in critical tiger habitat. Science Advances, 2(4).

Joshi, A., Vaidyanathan, S., Mondol, S., Edgaonkar, A. and Ramakrishnan, U. 2013. Connectivity of Tiger (Panthera tigris) Populations in the Human-Influenced Forest Mosaic of Central India. PLoS ONE, 8(11): e77980.

Karanth, K. K. and Defries, R. 2011. Nature-based tourism in Indian protected areas: New challenges for park management. Conservation Letters, 4(2): 137-149.

Karanth, K. U. and Chellam, R. 2009. Carnivore conservation at the crossroads. Oryx, 43(1): 1-2.

Karanth, K. U. and Gopal, R. 2005. An ecology-based policy framework for human-tiger coexistence in India: In People and Wildlife, Conflict or Co-existence?, Woodroffe, R., Thirgood, S. and Rabinowitz, A. (eds.) Cambridge University Press.

Karanth, K. U. and Sunquist, M. E. 1995. Prey selection by tiger, leopard and dhole in tropical forests. Journal of Animal Ecology, 64: 439-450.

Karanth, K. U., Nichols, J. D., Kumar, N. S., Link, W. A. and Hines, J. E. 2004. Tigers and their prey: predicting carnivore densities from prey abundance. Proceedings of the National Academy of Sciences of the United States of America, 101(14): 4854-4858.

Kolowski, J. and Holekamp, K. 2006. Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border. Biological conservation, 128(4): 529-541.

Krishnamurthy, R., Cushman, S. A., Sarkar, M. S., Malviya, M., Naveen, M., Johnson, J. A. and Sen, S. 2016. Multi-scale prediction of landscape resistance for tiger dispersal in central India. Landscape ecology, 31(6): 1355-1368.

Ladle, R. and Whittaker, R. J. 2011. Conservation Biogeography. Wiley, 256 pp.

Laurance, W. F. and Arrea, I. B. 2017. Roads to riches or ruin? Science, 358(6362): 442-444.

Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. American Entomologist, 15(3): 237-240.

Loveridge, A., Wang, S. W., Frank, L. and Seidensticker, J. 2010. People and wild felids: conservation of cats and management of conflicts, 161-195: In The Biology and Conservation of Wild Felids, Macdonald, D. and Loveridge, A. (eds.) Oxford University Press.

Marino, J., Bennett, M., Cossios, D., Iriarte, A., Lucherini, M., Pliscoff, P., Sillero-Zubiri, C., Villalba, L. and Walker, S. 2011. Bioclimatic constraints to Andean cat distribution: a modelling application for rare species. Diversity and Distributions, 17(2): 311-322.

Mcdougal, C. 1987. The man-eating tiger in geographical and historical perspective: In Tigers of the world: the biology, biopolitics, management, and conservation of an endangered species, Tilson, R. L. and Seal, U. S. (eds.) Noyes Publications, New Jersey.

Mcrae, B. and Kavanagh, D. 2011. Linkage mapper connectivity analysis software. The Nature Conservancy.

Mcrae, B. H. 2006. Isolation by resistance. Evolution, 60(8): 1551-1561.

Mcrae, B. H. and Beier, P. 2007. Circuit theory predicts gene flow in plant and animal populations. Proceedings of the National Academy of Sciences, 104(50): 19885-19890.

Mcrae, B. H., Dickson, B. G., Keitt, T. H. and Shah, V. B. 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. Ecology, 89(10): 2712-2724.

Mcrae, B. H., Hall, S. A., Beier, P. and Theobald, D. M. 2012. Where to restore ecological connectivity? Detecting barriers and quantifying restoration benefits. PloS one, 7(12): e52604.

Merow, C., Smith, M. J. and Silander, J. A. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. Ecography, 36(10): 1058-1069.

Metrick, A. and Weitzman, M. L. 1996. Patterns of behavior in endangered species preservation. Land Economics, 72(1): 1-16.

Mi, C., Huettmann, F., Guo, Y., Han, X. and Wen, L. 2017. Why choose Random Forest to predict rare species distribution with few samples in large undersampled areas? Three Asian crane species models provide supporting evidence. PeerJ, 5: e2849.

Michalski, F., Boulhosa, R., Faria, A. and Peres, C. 2006. Human–wildlife conflicts in a fragmented Amazonian forest landscape: determinants of large felid depredation on livestock. Animal Conservation, 9(2): 179-188.

Miller, J. R. B., Jhala, Y. V. and Schmitz, O. J. 2016. Human Perceptions Mirror Realities of Carnivore Attack Risk for Livestock: Implications for Mitigating Human-Carnivore Conflict. PLoS ONE, 11(9): e0162685.

Ministry of Finance 2016. Economic Survey 2015–2016 Vol I. Government of India, New Delhi.

Ministry of Law and Justice 2007. Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act.

Miquelle, D., Nikolaev, I., Goodrich, J., Litvinov, B., Smirnov, E. and Suvorov, E. 2005. Searching for the coexistence recipe: a case study of conflicts between people and tigers in the Russian Far East: In People and Wildlife, Conflict or Co-existence?, Woodroffe, R., Thirgood, S. and Rabinowitz, A. (eds.) Cambridge University Press.

MoEF 2012. India's Submission to the CBD on Assessment of Funding Support for Biodiversity Conservation in India. Ministry of Environment & Forests, Government of India, New Delhi.

MoEF 2014. India's Fifth National Report to the Convention on Biological Diversity. Fifth National Report, Ministry of Environment &Forests, Government of India, New Delhi.

Mondal, I., Habib, B., Nigam, P. and Talukdar, G. 2016. Tiger Corridors of Eastern Vidarbha Landscape. National Tiger Conservation Authority, New Delhi & Wildlife Institute of India, Dehradun. TR 2016/009

Muscarella, R., Galante, P. J., Soley-Guardia, M., Boria, R. A., Kass, J. M., Uriarte, M. and Anderson, R. P. 2014. ENMeval: An R package for conducting spatially independent evaluations and estimating optimal model complexity for Maxent ecological niche models. Methods in Ecology and Evolution, 5(11): 1198-1205.

Nagendra, H., Pareeth, S. and Ghate, R. 2006. People within parks—forest villages, land-cover change and landscape fragmentation in the Tadoba Andhari Tiger Reserve, India. Applied Geography, 26(2): 96-112.

Nowell, K. and Jackson, P. 1996. Wild cats: status survey and action plan. IUCN, Gland, Switzerland.

NTCA 2013. Standard Operating Procedure to Deal with Emergency Arising Due to Straying of Tigers in Human Dominated Landscapes. National Tiger Conservation Authority, Government of India, New Delhi.

Nyhus, P. J. and Tilson, R. 2010. Panthera tigris vs Homo sapiens: conflict, coexistence, or extinction?, 125-141: In Tigers of the World: The Science, Politics, and Conservation of Panthera tigris, Tilson R. and Nyhus P. J. (eds.) Academic Press, Burlington, USA.

Oriol-Cotterill, A., Macdonald, D., Valeix, M., Ekwanga, S. and Frank, L. 2015. Spatiotemporal patterns of lion space use in a human-dominated landscape. Animal Behaviour, 101: 27-39.

Phillips, S. J. and Dudík, M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography, 31(2): 161-175.

Qiao, H., Soberón, J. and Peterson, A. T. 2015. No silver bullets in correlative ecological niche modelling: insights from testing among many potential algorithms for niche estimation. Methods in Ecology and Evolution, 6(10): 1126-1136.

Qureshi, Q., Saini, S., Basu, P., Gopal, R., Raza, R. and Jhala, Y. V. 2014. Connecting Tiger Populations for Long-term Conservation. National Tiger Conservation Authority, New Delhi & Wildlife Institute of India, Dehradun. TR 2014/02.

Rabinowitz, A. 1993. Estimating the Indochinese tiger *Panthera tigris carbetti* population in Thailand. Biological Conservation, 65(3): 213-217.

Radosavljevic, A. and Anderson, R. P. 2014. Making better Maxent models of species distributions: complexity, overfitting and evaluation. Journal of biogeography, 41(4): 629-643.

Rathore, C. S., Dubey, Y., Shrivastava, A., Pathak, P. and Patil, V. 2012. Opportunities of Habitat Connectivity for Tiger (*Panthera tigris*) between Kanha and Pench National Parks in Madhya Pradesh, India. PLoS ONE, 7(7): e39996.

Ravan, S., Dixit, A. and Mathur, V. 2005. Spatial analysis for identification and evaluation of forested corridors between two protected areas in Central India. Current Science, 88(9): 1441-1448.

Reddy, P. A., Cushman, S. A., Srivastava, A., Sarkar, M. S. and Shivaji, S. 2017. Tiger abundance and gene flow in Central India are driven by disparate combinations of topography and land cover. Diversity and Distributions, 23(8): 863-874.

Ricketts, T. H. 2001. The matrix matters: effective isolation in fragmented landscapes. The American Naturalist, 158(1): 87-99.

Ripple, W. J., Estes, J. A., Beschta, R. L., Wilmers, C. C., Ritchie, E. G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M. P., Schmitz, O. J., Smith, D. W., Wallach, A. D. and Wirsing, A. J. 2014. Status and Ecological Effects of the World's Largest Carnivores. Science, 343(6167).

Rodgers W. and Panwar H. S. 1988. Biogeographical classification of India. New Forest, Dehra Dun.

Rodrigues, A. S. L., Andelman, S. J., Bakarr, M. I., Boitani, L., Brooks, T. M., Cowling, R. M., Fishpool, L. D. C., Da Fonseca, G. a. B., Gaston, K. J., Hoffmann, M., Long, J. S., Marquet, P. A., Pilgrim, J. D., Pressey, R. L., Schipper, J., Sechrest, W., Stuart, S. N., Underhill, L. G., Waller, R. W., Watts, M. E. J. and Yan, X. 2004. Effectiveness of the global protected area network in representing species diversity. Nature, 428(6983): 640-643.

Sanderson, E. W., Forrest, J., Loucks, C., Ginsberg, J., Dinerstein, E., Seidensticker, J., Leimgruber, P., Songer, M., Heydlauff, A. and O'brien, T. 2010. Setting priorities for tiger conservation: 2005–2015, 143-161: In Tigers of the World (Second Edition), Tilson, R. and Nyhus, P. J. (eds.) Elsevier.

Sankar, K., Qureshi, Q., Nigam, P., Malik, P., Sinha, P., Mehrotra, R., Gopal, R., Bhattacharjee, S., Mondal, K. and Gupta, S. 2010. Monitoring of reintroduced tigers in Sariska Tiger Reserve, Western India: preliminary findings on home range, prey selection and food habits. Tropical Conservation Science, 3(3): 301-318.

Sawyer, S. C., Epps, C. W. and Brashares, J. S. 2011. Placing linkages among fragmented habitats: do least-cost models reflect how animals use landscapes? Journal of Applied Ecology, 48(3): 668-678.

Seidensticker, J. 1987. Bearing witness: Observations on the extinction of *Panthera tigris balica* and *Panthera tigris sondaica*. Tigers of the World: 1-8.

Shah, V. B. and Mcrae, B. Circuitscape: a tool for landscape ecology. In: Varoquaux G., Vaught T. and Millman J., eds. Proceedings of the 7th Python in Science Conference, 2008. 62-66.

Sharma, S., Dutta, T., Maldonado, J. E., Wood, T. C., Panwar, H. S. and Seidensticker, J. 2013a. Spatial genetic analysis reveals high connectivity of tiger (*Panthera tigris*) populations in the Satpura–Maikal landscape of Central India. Ecology and Evolution, 3(1): 48-60.

Sharma, S., Dutta, T., Maldonado, J. E., Wood, T. C., Panwar, H. S. and Seidensticker, J. 2013b. Forest corridors maintain historical gene flow in a tiger metapopulation in the highlands of central India. Proceedings of the Royal Society of London B: Biological Sciences, 280(1767): 20131506.

Stevens, V. M., Verkenne, C., Vandewoestijne, S., Wesselingh, R. A. and Baguette, M. 2006. Gene flow and functional connectivity in the natterjack toad. Molecular Ecology, 15(9): 2333-2344.

Tarkesh, M. and Jetschke, G. 2012. Comparison of six correlative models in predictive vegetation mapping on a local scale. Environmental and ecological statistics, 19(3): 437-457.

Thatte, P., Joshi, A., Vaidyanathan, S., Landguth, E. and Ramakrishnan, U. 2018. Maintaining tiger connectivity and minimizing extinction into the next century: Insights from landscape genetics and spatially-explicit simulations. Biological Conservation, 218: 181-191.

Treves, A., Naughton-Treves, L., Harper, E. K., Mladenoff, D. J., Rose, R. A., Sickley, T. A. and Wydeven, A. P. 2004. Predicting human-carnivore conflict: A spatial model derived from 25 years of data on wolf predation on livestock. Conservation Biology, 18(1): 114-125.

Van Gils, H. and Kayijamahe, E. 2010. Sharing natural resources: mountain gorillas and people in the Parc National des Volcans, Rwanda. African journal of ecology, 48(3): 621-627.

Vasudev, D. and Fletcher Jr, R. J. 2015. Incorporating movement behavior into conservation prioritization in fragmented landscapes: an example of western hoolock gibbons in Garo Hills, India. Biological Conservation, 181: 124-132.

Verboom, J., Lankester, K. and Metz, J. a. J. 1991. Linking local and regional dynamics in stochastic metapopulation models, 39-55: In Metapopulation Dynamics: Empirical and Theoretical Investigations, Gilpin, M. and Hanski, I. (eds.) Academic Press, London.

Wall, J., Wittemyer, G., Klinkenberg, B., Lemay, V. and Douglas-Hamilton, I. 2013. Characterizing properties and drivers of long distance movements by elephants (*Loxodonta africana*) in the Gourma, Mali. Biological Conservation, 157: 60-68.

Warren, D. L. and Seifert, S. N. 2011. Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. Ecological applications, 21(2): 335-342.

Wikramanayake, E. D., Dinerstein, E., Robinson, J. G., Karanth, U., Rabinowitz, A., Olson, D., Mathew, T., Hedao, P., Conner, M. and Hemley, G. 1998. An Ecology-Based Method for Defining Priorities for Large Mammal Conservation: The Tiger as Case Study. Conservation Biology, 12(4): 865-878.

Wikramanayake, E., Dinerstein, E., Forrest, J., Loucks, C., Seidensticker, J., Klenzendorf, S., Sanderson, E. W., Simons, R., Heydlauff, A. and Ginsberg, J. 2010. Roads to Recovery or Catastrophic Loss: How Will the Next Decade End for Wild Tigers?, 493-506: In Tigers of the World (Second Edition), Tilson, R. and Nyhus, P. J. (eds.) Elsevier.

Wolf, C. and Ripple, W. J. 2016. Prey depletion as a threat to the world's large carnivores. Royal Society Open Science, 3(8).

Woodroffe, R. and Frank, L. G. Lethal control of African lions (*Panthera leo*): local and regional population impacts. Animal Conservation forum, 2005. Cambridge University Press, 91-98.

World Bank 2013. World Development Report 2014: Risk and Opportunity - Managing Risk for Development. World Bank, Washington, DC.

Yumnam, B., Jhala, Y. V., Qureshi, Q., Maldonado, J. E., Gopal, R., Saini, S., Srinivas, Y. and Fleischer, R. C. 2014. Prioritizing Tiger Conservation through Landscape Genetics and Habitat Linkages. PLoS ONE, 9(11): e111207.

Zeller, K. A., Mcgarigal, K. and Whiteley, A. R. 2012. Estimating landscape resistance to movement: a review. Landscape Ecology, 27(6): 777-797.

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# Triage of Means: Options for Conserving Tiger Corridors beyond Designated Protected Lands in India

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The latest tiger census conducted in India during the year 2014 shows that it harbors 57% of the global tiger population in 7% of their historic global range. At the same time, India has 1.25 billion people growing at a rate of 1.7% per year. Protected tiger habitats in India are geographically isolated and collectively holds this tiger population under tremendous anthropogenic pressure. These protected lands are in itself not enough to sustain the growing tiger population, intensifying human-tiger conflict as dispersing individuals enter human occupied areas. These factors—isolation and inadequate size of the protected lands harboring tiger meta-populations, highlight the need to connect tiger habitats and the importance of corridors beyond protected lands. It is imperative to conserve such corridors passing through private lands to safeguard the long-term survival of the tigers in India. The goal of long-term tiger conservation in India lies in smartly integrating tiger conservation concerns in various sectors where tiger conservation is not the priority. To effectively tap into all these resources, we propose a "Triage of Means" strategy. Here we do not prioritize species, populations or sites due to the non-availability of conservation resources. Instead, we aim to channel from available resources (means to achieve conservation) from other sectors where tiger conservation is not the focus. We outline how to prioritize resources available from various sectors into conservation by prioritizing issues hampering tiger conservation beyond protected habitats.

**Keywords: triage of means, corridors, conservation, tiger, Central Indian landscape, India**

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## INTRODUCTION

India harbors over half the global tiger (*Panthera tigris tigris*) population within just 7% of their historic range (Jhala et al., 2015). These tigers are distributed in geographically isolated populations (Qureshi et al., 2014), being separated by landscapes of intensive human occupation, such as expanding agriculture, urbanization and an aggressive infrastructural development fuelled by a national aspiration to achieve 8% economic growth (Ministry of Finance, 2016). However, India does not have a comprehensive landuse policy (Department of Land Resources, 2013), which may lead to unchecked land conversion near forest fringes. Moreover, most of the reserves that contain these isolated tiger populations are not large enough to sustain the steadily growing tiger population (Chundawat et al., 2016). This leads to an intensification of conflict between the growing tiger population and a human population of 1.25 billion increasing at a rate of 1.7% annually (Chandramouli, 2011). Dispersing tigers from protected reserves are prone to confrontations with humans, resulting in human-tiger conflict (Dhanwatey et al., 2013). Isolation and inadequate reserve size (average size is 486 km$^2$, Karanth and Defries, 2011) amongst sites that harbors the fragmented tiger populations highlight the need of connecting these forest patches and the importance of corridors in doing so.

## CORRIDORS: CONNECTING LINKS FOR LONG TERM CONSERVATION

The last decade in conservation research has illustrated that habitat corridors are an important conservation intervention to offset negative impacts of habitat fragmentation and to maintain meta-population dynamics (Hilty et al., 2012). The Central Indian Landscape which roughly covers an area of 76,913 km$^2$ (Yumnam et al., 2014), sets a perfect example of the importance of connecting fragmented tiger populations by corridors (Dutta et al., 2016). Deforestation, road widening, mining, aggressive urbanization and unchecked human activity in corridors are major concerns about the viability of corridors in the Central Indian landscape (Sharma et al., 2013a; Yumnam et al., 2014; Borah et al., 2016). Most studies unanimously suggest that reducing anthropogenic pressure (Joshi et al., 2013) and restoring habitat (Yumnam et al., 2014) are solutions for the long term sustainability of corridors. In addition, others have suggested involving local communities through community centered conservation programmes and eco-tourism (Ravan et al., 2005; Rathore et al., 2012), which may ensure that local communities are still able to derive their livelihood from the corridor forests. Elevating the legal status of corridors lands (Ravan et al., 2005; Yumnam et al., 2014) and use of smart green infrastructure in critical corridor habitats (Yumnam et al., 2014; Habib et al., 2015) has also been advocated as an alternative solution to safeguard corridors in the landscape. In areas where corridors span across multiple states, co-operation between different state agencies has been suggested (Ravan et al., 2005).

## TRIAGE: IS IT THE WAY TO GO?

Conservation "is about conserving" (Harcourt, 2000); it's about making things happen on the ground. Carrying out one research project after another, proposing laws, drafting policies, and holding meetings, may not provide the desired outcomes if it cannot transform into any conservation action on the ground (Knight et al., 2006, 2008; Boreux et al., 2009; Braunisch et al., 2012).

Recommendations emanating from scientific studies need hard implementation on the ground for corridor conservation to benefit from all the scientific efforts being invested in it. On the ground, implementation of the above recommendations face numerous hurdles and requires extensive negotiations and prioritization of conservation actions. The negotiation and prioritization process often takes the form of a to and fro dialogue between the advocates (conservation agencies) and the opponents (developmental agencies) of conservation. This increases the time lag between a management recommendation made in a scientific study and its implementation on the ground (Arlettaz et al., 2010). We may need to focus conservation efforts in areas or on issues which are of more pressing nature or where negotiations may yield better results or follow implementation pathways which best suits available funds or alternatives.

Derived from the French word *trier* or "to sort," the word Triage has been popularly used to connote this process of prioritization (Random House, 1997). The term originated from battlefields and hospital emergency rooms, which casts its analogy on conservation biology as a "crisis discipline," a target oriented science where decisions need to be taken rapidly, often without the availability of complete knowledge and limited resources (Soulé, 1985). It echoes the political saying "choose the battles that you can win" (Ochoa-Ochoa et al., 2011).

There have been varying reactions from different quarters regarding the triage approach of conservation (Bottrill et al., 2008, 2009; Jachowski and Kesler, 2009; Parr et al., 2009; Ochoa-Ochoa et al., 2011; Rappaport et al., 2015). The argument for or against triage so far seems balanced as there are almost an equal number of publications supporting each view. Buckley (2016) has argued that when triage is followed to allocate scarce resources for conservation efficiently, it may send negative political signals by implying that global or local scale extinction of some species is acceptable. In the process, the damage caused far outweighs the attempted good that the triage approach may have achieved. In addition, Buckley (2016) states that the practice of conservation is a human socio-political process since conservation is driven or constrained by legislation and politics. In the triage approach, the process of prioritization may need the establishment of a threshold value and drawing a threshold is unscientific, leading to inevitable species extinction (Buckley, 2016). Furthermore, others argue that the triage approach which was adapted from battlefield and hospitals cannot fit scenarios applicable to conservation (Jachowski and Kesler, 2009).

Extinction is unacceptable according to the fundamental concepts of conservation biology since the general inherent consideration is that all species have an inherent value (Soulé, 1985). Some suggest that the conservation triage paradigm rejects this fundamental belief by neglecting some species, since conserving all species is costly and so-called inefficient, and ultimately push these species toward extinction (Jachowski and Kesler, 2009). Some research groups have gone to the extent of comparing the cost of conservation to the expenses allocated for space exploration (Balmford et al., 2002), and they argue that since conservation is not the costliest affair on this planet, we can allocate sufficient resources to conserve most species. Parr et al. (2009) say that we should not choose from species while letting some go extinct in the process of efficiently allocating resources.

While the preceding authors have identified the limitations in adopting a triage approach, we advocate triage as a tool available to a conservationist, under penny scarce conservation scenarios. We cite an Indian scenario where triage need not mean choosing from species, populations or sites while neglecting others. We define it as a prioritization process which lets one accumulate conservation funds from unconventional but potential sources; sources who's main mandate is not conservation, but the funds available from them can be leveraged to assist conservation if channeled in the right direction.

## TRIAGE: AN OPTION FOR TIGER CORRIDOR CONSERVATION

Recommendations by various research groups to safeguard the tiger and its habitat in India often hits the same road block: the dilemma of triage. The importance of protected areas (PA) for conserving natural resources has been highly recognized worldwide (Hockings, 2003; Rodrigues et al., 2004) and successful conservation strategies often consider connectivity with adjacent PAs (Jackson and Gaston, 2008; Ladle and Whittaker, 2011). A recent corridor study has identified 9371 $km^2$ of area outside PAs that are crucial for the dispersal and movement of tigers in the Eastern Vidarbha Landscape (EVL) in Central India (Mondal et al., 2016). This area includes reserve forest, unprotected forests, and privately owned lands covered by forested or agricultural landuse. These areas come under the "Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act" (Ministry of Law Justice, 2007) enabling local communities to derive their livelihood from these lands, including the forest. Due to the proximity of intensive human use areas, these multiple use forest areas suffer from anthropogenic pressures like resource extraction, grazing, mining, infrastructural developments and noise, light and air pollution. Despite the plethora of impediments, these corridors are still functional to allow the movement of animals across the landscape (Joshi et al., 2013; Sharma et al., 2013b). Many areas along these corridors are in a critical state due to fragmentation, degradation, and resource extraction. Habitat connectivity is uncertain at these spots and loss of contiguity here may render the entire length of the corridor non-functional. Overlap of human use and tiger presence leads to the prevalence of human-tiger conflict, including direct attacks on humans and livestock depredation (Miller et al., 2016). Such events contribute to negative attitudes of the local community toward tiger conservation in the area. On multiple occasions, deforestation occurring along corridor habitats occur outside of notified forest boundaries (Joshi et al., 2016) and the forest administration, as an advocate of conservation, hardly has a say.

The above points highlight the magnitude of mitigation measures that need to be employed for successful conservation of tiger corridors in the EVL, which includes protecting corridor forests, restoring degraded habitats, buying lands along corridors, paying compensation to villagers suffering from human-tiger conflict. In the 3rd Asia Ministerial Conference on Tiger Conservation 2016 held in New Delhi, the Honorable Prime Minister of India stated that "conservation of tigers is not a choice, it is an imperative." He further added, "I believe Tiger Conservation and Conservation of Nature is not a drag on development, both can happen in a mutually complimentary manner, all we need is to reorient our strategy by factoring the concerns of the tiger in sectors, where tiger conservation is not the goal." At the same meeting, the Honorable Minister of Environment, Forests and Climate Change addressed the government's initiative to save tiger corridors: "We will incentivize project proponents to give land for compensatory afforestation in tiger corridors. By such measures, we can free tiger corridors from private incumbents, and it will become forest land. It will protect tiger corridors which will protect the growing tiger population." All this reflects a general positive public will toward tiger conservation, with further assurance being provided by available Government funds and above mentioned policies. To effectively tap into all these resources and public will, we must follow an unconventional triage approach as a means to prioritize alternative funding streams.

This we call, "triage of means": a process where we channel available resources by prioritizing from among various schemes of government ministries/departments for tiger corridor conservation. Under provisions of clause 135 of the Companies Act, 2013[1] funds are available from the corporate sector as well in the form of 2% of their average net profit in the previous 3 years toward Social Corporate Responsibility (CSR). Such CSR funds can also be used for tiger conservation. The merit of this proposed triage approach is its ability to draw resources from sectors, where tiger conservation is not the primary goal. Such indirect funds can be leveraged by mainstreaming the conservation agenda in these sectors.

## TRIAGE OF MEANS

The key strategy of the triage of means that we present is to harness resources available from several areas, which typically lie in the purview of different ministries of the Central Government of India (GoI)[2]. This can only be achieved if environmental concerns are internalized in policymaking in a large number of sectors. The major portion of funds available for conservation in India is under various programs of the Ministry of Environment, Forest and Climate Change (MoEF & CC). These funds are available in the form of core (direct and immediate biodiversity impact), and non-core funding (pollution, hazardous substances management, etc. which facilitate biodiversity conservation of river streams, wetlands) from MoEF & CC (MoEF, 2012). Out of the MoEF & CC's aggregate budget of USD 362.52 million for the year 2013–14, the core funding constitutes USD 233.38 million while the non-core accounts for USD 38.76 million (MoEF, 2014). Apart from MoEF & CC, states in India also allocate a part of their budget for biodiversity conservation. It amounts to USD 749.75 million as per their 2013–14 budget. The indirect peripheral funding amounting to USD 351.3 million is available from 77 schemes from 23 Ministries/Departments of
They support activities that benefit biodiversity but
biodiversity conservation is not the main focus. Co
part of non-core funding from MoEF & CC are dire
to be used in protected areas or lands, yet it fails to c
outside the purview of this protection and financi
Our triage of means is about opportunistically am
resources from peripheral funding sources (**Figure 1**).

## IMPLEMENTING TRIAGE OF MEANS

Corridor habitats in India often consist of degraded forest surrounded by human-dominated landscapes. Due to this

[1] www.mca.gov.in/Ministry/pdf/CompaniesAct2013.pdf
[2] www.cbd.int/financial/doc/india-assessment-funding-support-en.pdf

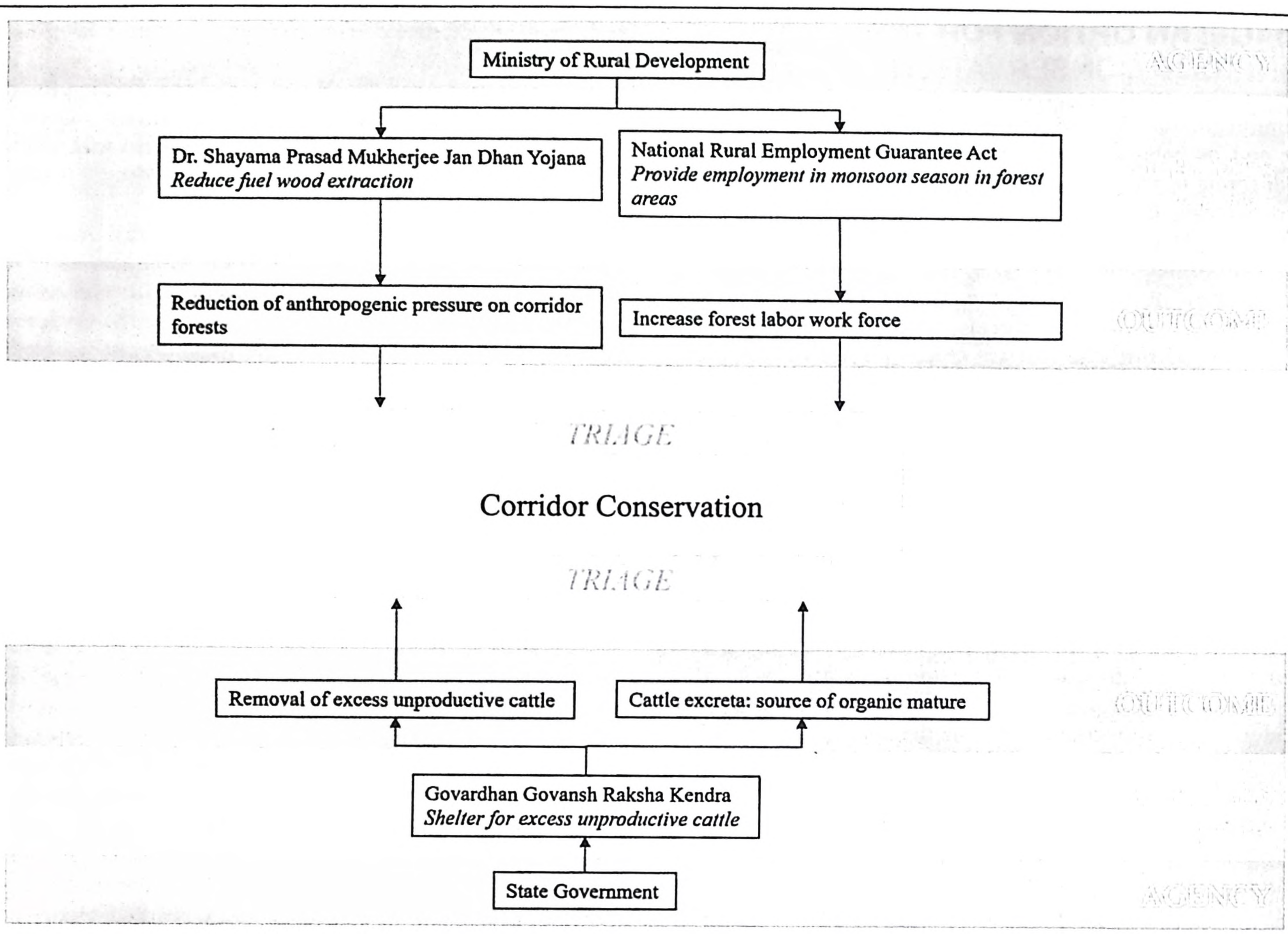


**FIGURE 1 | The figure is showing various tasks which can be carried out by the agencies from other Ministries of Govt. of India where conservation is not the goal (triage of means).**

close interface, the corridors are facing intense anthropogenic pressures, such as extraction of fuelwood and fodder, the presence of invasive species and excessive grazing. Here we try to suggest options how we can mobilize resources from other sectors to reduce these pressures on the corridors.

The National Rural Employment Guarantee Act (NREGA) 2005, under the Ministry of Rural Development, provides secure livelihood to rural populations in the form of 100 days of wage employment for unskilled manual labor.[3] It has been recognized as the most ambitious example of rural social security and public works programme in the World Development Report, 2014 by World Bank (2013). However, in the monsoon season, this scheme fails to provide any jobs to the local villagers due to flooding and muddy conditions. On the other hand, this workforce of thousands of manpower can be well employed in corridor forest areas in weed removal exercises and habitat restorations. This way the NREGA scheme picks up even in monsoon providing employment to thousands of villagers, and at the same time improve habitat quality in the corridor areas.

Dr. Shayama Prasad Mukherjee Jan Dhan Yojana (scheme) by the Ministry of Rural Development aims to provide the rural population with cooking gas (Liquid Petroleum Gas) or biogas (made from cattle dung) as an alternate source of daily household energy needs in the state of Maharashtra. Such schemes, when targeted in villages near corridor areas, can reduce their dependency on forests and reduce extraction of firewood and fodder. Lesser ventures into the forest to gather such resources also reduces the chances of encounters with tiger and thus has the potential to reduce conflict.

Recently due to a ban on cow slaughter in the state of Maharashtra[4] the cattle population in the state has increased dramatically.[5] This has led distressed farmers to abandon their unproductive cattle thereby increasing the number of unattended cattle which are venturing into forest areas to graze. Consequently, this high amount of uncontrolled grazing is

[3]http://rural.nic.in/sites/downloads/right-information-act/02%20_CIC_PartII_MG_NREGA(F).pdf.

[4]http://bombayhighcourt.nic.in/libweb/acts/Stateact/2015acts/2015.05.PDF

[5]http://goo.gl/eqphXu.

leading to degradation of the corridor forests. A new initiative of the State Government of Maharashtra is to set up cow shelters in selected districts to mitigate this problem. These shelters are being called the "Govardhan Govansh Raksha Kendra."[6] This scheme will be conducted through local NGOs, where abandoned unproductive and non-lactating cattle will be contained inside the walls of these shelters and cattle excreta will be used to manufacture organic manure.[7] When implemented in villages near tiger corridors, this initiative helps triage with its 2-fold benefits: reduction of grazing pressure in corridor habitats and promotion of the use of organic fertilizers.

## CONCLUSION

We believe that triage is more than just focusing on single species conservation, but more broadly prioritizing of conservation actions when resources are scarce. We argue that funds can be funneled from diverse sectors when dedicated funding available for conservation may not be enough and provide an example of how this may work using the Indian tiger conservation challenge. Adoption of triage provides us with a logical and intuitive approach for efficiently distributing available resources among management actions to achieve a targeted conservation goal. By explicitly choosing among available resources using a transparent triage approach, we may be able to highlight any deficit in available funds which otherwise may go unnoticed (Bottrill et al., 2008). The practice of conservation is a human socio-political process since conservation is driven or constrained by legislation and politics (Buckley 2016). Adoption of a transparent decision-making process through triage will rule out the possibility of charismatic taxa or emotive causes diverting funding from a more rationally valid cause (Metrick and Weitzman, 1996). Conservation efforts that follow the principle of triage are logical, can be duplicated across time and space (Bottrill et al., 2009).

The triage of means that we suggest can clearly and objectively apportion funds from peripheral sources for corridor conservation that have been hitherto invisible and/or seldom tapped into. If meticulously pursued, *Triage of Means* may become the best *means of triage* for safeguarding tiger corridors in India. The crux lies in intelligently formulating policies and schemes to mainstream conservation for agencies without conservation mandates.

[6]http://goo.gl/utbEQ4
[7]http://goo.gl/hRkBVU.

## AUTHOR CONTRIBUTIONS

IM, BH, GT, and PN designed, drafted and revised the paper, and approved the final version of the manuscript before submission.

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## REFERENCES

Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T. S., Sierro, A., Watson, J. E. M., et al. (2010). From publications to public actions: when conservation biologists bridge the gap between research and implementation. *Bioscience* 60, 835–842. doi: 10.1525/bio.2010.60.10.10

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R. E., et al. (2002). Economic reasons for conserving wild nature. *Science* 297, 950–953. doi: 10.1126/science.1073947

Borah, J., Jena, J., Yumnam, B., and Puia, L. (2016). Carnivores in corridors: estimating tiger occupancy in Kanha-Pench corridor, Madhya Pradesh, India. *Region. Environ. Change* 16, 43–52. doi: 10.1007/s10113-015-0904-0

Boreux, V., Born, J., and Lawes, M. J. (2009). Sharing ecological knowledge: opportunities and barriers to uptake. *Biotropica* 41, 532–534. doi: 10.1111/j.1744-7429.2009.00574.x

Bottrill, M. C., Joseph, L. N., Carwardine, J., Bode, M., Cook, C., Game, E. T., et al. (2008). Is conservation triage just smart decision making? *Trends Ecol. Evol.* 23, 649–654. doi: 10.1016/j.tree.2008.07.007

Bottrill, M. C., Joseph, L. N., Carwardine, J., Bode, M., Cook, C., Game, E. T., et al. (2009). Finite conservation funds mean triage is unavoidable. *Trends Ecol. Evol.* 24, 183–184. doi: 10.1016/j.tree.2008.11.007

Braunisch, V., Home, R., Pellet, J., and Arlettaz, R. (2012). Conservation science relevant to action: a research agenda identified and prioritized by practitioners. *Biol. Conserv.* 153, 201–210. doi: 10.1016/j.biocon.2012.05.007

Buckley, R. C. (2016). Triage Approaches Send Adverse Political Signals for Conservation. *Front. Ecol. Evol.* 4:39. doi: 10.3389/fevo.2016.00039

Chandramouli, C. (2011). *CENSUS OF INDIA 2011*, ed Registrar General. New Delhi: Ministry of Home Affairs.

Chundawat, R. S., Sharma, K., Gogate, N., Malik, P. K., and Vanak, A. T. (2016). Size matters: scale mismatch between space use patterns of tigers and protected area size in a Tropical Dry Forest. *Biol. Conserv.* 197, 146–153. doi: 10.1016/j.biocon.2016.03.004

Department of Land Resources (2013). *Draft National Land Utilisation Policy*, ed Ministry of Rural Development. New Delhi: Government of India.

Dhanwatey, H. S., Crawford, J. C., Abade, L. A. S., Dhanwatey, P. H., Nielsen, C. K., and Sillero-Zubiri, C. (2013). Large carnivore attacks on humans in central India: a case study from the Tadoba-Andhari Tiger Reserve. *Oryx* 47, 221–227. doi: 10.1017/S0030605311001803

Dutta, T., Sharma, S., Mcrae, B. H., Roy, P. S., and Defries, R. (2016). Connecting the dots: mapping habitat connectivity for tigers in central India. *Region. Environ. Change* 16, 53–67. doi: 10.1007/s10113-015-0877-z

Habib, B., Saxena, A., Mondal, I., Rajvanshi, A., Mathur, V. B., and Negi, H. S. (2015). *Proposed Mitigation Measures for Maintaining Habitat Contiguity and Reducing Wild Animal Mortality on NH 6 & 7 in the Central Indian Landscape*. Technical Report, Wildlife Institute of India, Dehradun and National Tiger Conservation Authority, Goverment of India, New Delhi. doi: 10.13140/RG.2.1.3853.0323

Harcourt, A. H. (2000). Conservation in practice. *Evol. Anthropol.* 9, 258–265. doi: 10.1002/1520-6505(2000)9:6<258::AID-EVAN1004>3.0.CO;2-T

Hilty, J. A., Lidicker, W. Z., Merenlender, A., and Dobson, A. P. (2012). *Corridor Ecology: The Science and Practice of Linking Landscapes for Biodiversity Conservation*. Washington, DC: Island Press.

Hockings, M. (2003). Systems for assessing the effectiveness of management in protected areas. *Bioscience* 53, 823–832. doi: 10.1641/0006-3568(2003)053[0823:SFATEO]2.0.CO;2

Jachowski, D. S., and Kesler, D. C. (2009). Allowing extinction: should we let species go? *Trends Ecol. Evol.* 24:180. doi: 10.1016/j.tree.2008.11.006

Jackson, S. F., and Gaston, K. J. (2008). Incorporating private lands in conservation planning: protected areas in Britain. *Ecol. Appl.* 18, 1050–1060. doi: 10.1890/07-0662.1

Jhala, Y. V., Qureshi, Q., and Gopal, R. (eds.). (2015). "The status of tigers, copredators & prey in India 2014," in *National Tiger Conservation Authority* (Dehradun: Wildlife Institute of India), 1–456.

Joshi, A. R., Dinerstein, E., Wikramanayake, E., Anderson, M. L., Olson, D., Jones, B. S., et al. (2016). Tracking changes and preventing loss in critical tiger habitat. *Sci. Adv.* 2:e150167. doi: 10.1126/sciadv.1501675

Joshi, A., Vaidyanathan, S., Mondol, S., Edgaonkar, A., and Ramakrishnan, U. (2013). Connectivity of Tiger (*Panthera tigris*) Populations in the Human-Influenced Forest Mosaic of Central India. *PLoS ONE* 8:e77980. doi: 10.1371/journal.pone.0077980

Karanth, K. K., and Defries, R. (2011). Nature-based tourism in Indian protected areas: New challenges for park management. *Conserv. Lett.* 4, 137–149. doi: 10.1111/j.1755-263X.2010.00154.x

Knight, A. T., Cowling, R. M., and Campbell, B. M. (2006). An operational model for implementing conservation action. *Conserv. Biol.* 20, 408–419. doi: 10.1111/j.1523-1739.2006.00305.x

Knight, A. T., Cowling, R. M., Rouget, M., Balmford, A., Lombard, A. T., and Campbell, B. M. (2008). Knowing but not doing: selecting priority conservation areas and the research–implementation gap. *Conserv. Biol.* 22, 610–617. doi: 10.1111/j.1523-1739.2008.00914.x

Ladle, R., and Whittaker, R. J. (2011). *Conservation Biogeography*. West Sussex: Springer.

Metrick, A., and Weitzman, M. L. (1996). Patterns of behavior in endangered species preservation. *Land Econ.* 72, 1–16. doi: 10.2307/3147153

Miller, J. R., Jhala, Y. V., and Schmitz, O. J. (2016). Human perceptions mirror realities of carnivore attack risk for livestock: implications for mitigating human-carnivore conflict. *PLoS ONE* 11:e0162685. doi: 10.1371/journal.pone.0162685

Ministry of Finance (2016). *Economic Survey 2015–2016 Vol. I*. New Delhi: Government of India.

Ministry of Law and Justice (2007). *Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act*. New Delhi: Ministry of Law and Justice.

MoEF (2012). *India's Submission to the CBD on Assessment of Funding Support for Biodiversity Conservation in India*. New Delhi: Ministry of Environment & Forests, Government of India.

MoEF (2014). *India's Fifth National Report to the Convention on Biological Diversity*. New Delhi: Fifth National Report, Ministry of Environment & Forests, Government of India.

Mondal, I., Habib, B., Nigam, P., and Talukdar, G. (2016). *Tiger Corridors of Eastern Vidarbha Landscape*. Dehradun: Wildlife Institute of India. doi: 10.13140/RG.2.1.4625.1766

Ochoa-Ochoa, L. M., Bezaury-Creel, J. E., Vázquez, L.-B., and Flores-Villela, O. (2011). Choosing the survivors? A GIS-based triage support tool for micro-endemics: application to data for Mexican amphibians. *Biol. Conserv.* 144, 2710–2718. doi: 10.1016/j.biocon.2011.07.032

Parr, M. J., Bennun, L., Boucher, T., Brooks, T., Chutas, C. A., Dinerstein, E., et al. (2009). Why we should aim for zero extinction. *Trends Ecol. Evol.* 24:181 doi: 10.1016/j.tree.2009.01.001

Qureshi, Q., Saini, S., Basu, P., Gopal, R., Raza, R., and Jhala, Y. V. (2014) *Connecting Tiger Populations for Long-term Conservation*. Dehradun: National Tiger Conservation Authority & Wildlife Institute of India.

Random House (1997). *Webster's Unabridged Dictionary*. New York, NY: Random House.

Rappaport, D. I., Tambosi, L. R., and Metzger, J. P. (2015). A landscape triage approach: combining spatial and temporal dynamics to prioritize restoration and conservation. *J. Appl. Ecol.* 52, 590–601. doi: 10.1111/1365-2664.12405

Rathore, C. S., Dubey, Y., Shrivastava, A., Pathak, P., and Patil, V. (2012). Opportunities of Habitat Connectivity for Tiger (*Panthera tigris*) between Kanha and Pench National Parks in Madhya Pradesh, India. *PLoS ONE* 7:e39996. doi: 10.1371/journal.pone.0039996

Ravan, S., Dixit, A., and Mathur, V. (2005). Spatial analysis for identification and evaluation of forested corridors between two protected areas in Central India. *Curr. Sci.* 88, 1441–1448.

Rodrigues, A. S. L., Andelman, S. J., Bakarr, M. I., Boitani, L., Brooks, T. M., Cowling, R. M., et al. (2004). Effectiveness of the global protected area network in representing species diversity. *Nature* 428, 640–643.

Sharma, S., Dutta, T., Maldonado, J. E., Wood, T. C., Panwar, H. S., and Seidensticker, J. (2013a). Forest corridors maintain historical gene flow in a tiger metapopulation in the highlands of central India. *Proc. R. Soc. Lond. B Biol. Sci.* 280:20131506. doi: 10.1098/rspb.2013.1506

Sharma, S., Dutta, T., Maldonado, J. E., Wood, T. C., Panwar, H. S., and Seidensticker, J. (2013b). Spatial genetic analysis reveals high connectivity of tiger (*Panthera tigris*) populations in the Satpura–Maikal landscape of Central India. *Ecol. Evol.* 3, 48–60. doi: 10.1002/ece3.432

Soulé, M. E. (1985). What is conservation biology? A new synthetic discipline addresses the dynamics and problems of perturbed species, communities, and ecosystems. *Bioscience* 35, 727–734. doi: 10.2307/1310054

World Bank (2013). *World Development Report 2014: Risk and Opportunity—Managing Risk for Development*. Washington, DC: World Bank. doi: 10.1596/978-0-8213-9903-3.

Yumnam, B., Jhala, Y. V., Qureshi, Q., Maldonado, J. E., Gopal, R., Saini, S., et al. (2014). Prioritizing tiger conservation through landscape genetics and habitat linkages. *PLoS ONE* 9:e111207. doi: 10.1371/journal.pone.0111207

**Conflict of Interest Statement:** The authors declare that the research was conducted in the absence of any commercial or financial srelationships that could be construed as a potential conflict of interest.

# CERTIFICATE

This is to certify that Mr. INDRANIL MONDAL of Wildlife Institute of India, Dehradun has participated in **The International Urban Wildlife Conference 2017** held at **San Diego State University, San Diego, California** from 4th to 7th June, 2017.

He has presented a paper titled Connectivity conservation for tigers in a human dominated landscape

Signed: ______________________

Seth P. D. Riley, PhD - Co-chair, Host Committee; Member, Program Committee

Society for Conservation GIS 20th Annual Conference, 2017

# CERTIFICATE

This is to certify that Mr. INDRANIL MONDAL of Wildlife Institute of India, Dehradun has participated in the **20th Annual Conference of the International Society for Conservation GIS, 2017** held at **Monterey, California** from 16th to 19th July, 2017.

He has presented a paper titled *Connectivity conservation for tigers in a human dominated landscape*

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