Title of the Project:- "Study on tiger presence and their dispersal movements in Ratapani-Kheoni landscape of Vindhyan range."

Why this Project:-

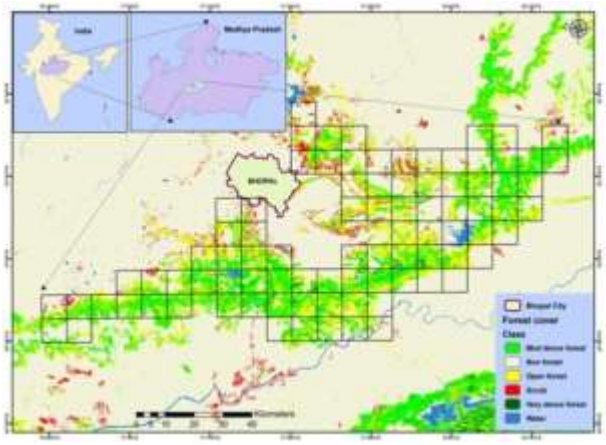
This project emerged due to the presence of dispersal tigers near Bhopal city, necessitating a scientific investigation to determine the reasons behind their proximity. The study aimed to identify the root causes and develop a strategic plan for sustainable wildlife management. The findings would support a decision-support system for demarcating critical tiger habitats using functional attributes and GIS mapping. Additionally, the project assessed landscape-level functionality through genetic analysis to manage human-animal interaction in urban areas. The study's results would aid the strategic green development of Bhopal and tiger conservation in the Ratapani-Kheoni landscape. By utilizing non-invasive genetics and camera traps, the project demonstrated cost-effective methods for long-term monitoring. It aimed to address the inadequate knowledge of tigers outside protected areas and improve the management of alternative tiger habitats in Madhya Pradesh

Research Methodology:-

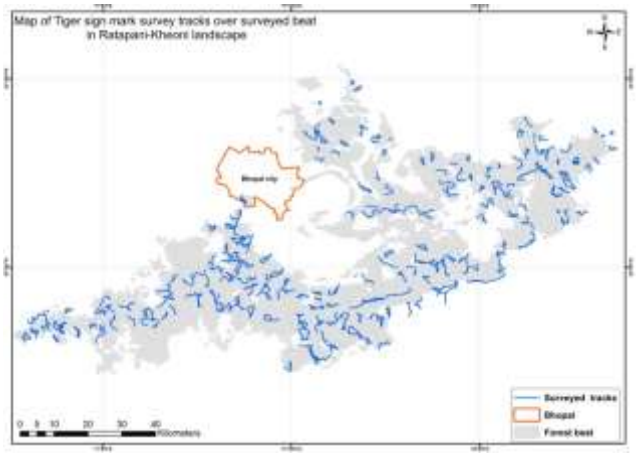
The study employed various methodologies for analyzing tiger occupancy, habitat suitability, and population genetics. Occupancy analysis was conducted using the PRESENCE program, while MaxEnt analysis was used to assess habitat suitability based on presence data collected from 234 survey beats. BMLR (Binomial Multiple Logistic Regression) analysis was employed to examine the relationship between tiger presence and habitat variables. Corridor designing in ArcGIS was performed using Linkage Mapper tools to support wildlife habitat connectivity analysis. Lastly, DNA analysis was carried out to determine the genetic diversity and population structure of tigers in the Ratapani-Kheoni landscape. The study design involved grid-based surveys for tiger sign marks and prey presence, and data collection was conducted through field surveys and DNA sampling.

Study Design:-

The tiger sign mark survey was conducted for tigers in the Ratapani-Kheoni landscape to determine the tiger-bearing area in the landscape from December 2018 to April 2019. Sampling unit large geographic grid cells at a scale appropriate to the study organism, depending on the biology of the species. For the sake of example, for the tiger in south-western India, the cell size was set based on the expected maximum home range size of ~200 (Karanth and Sunquist, 2000) and tiger in Panna tiger reserve in central India, the home range of male and female tigers were 132.7 and 73.6 (Sarkar et al., 2016). Initially, 8*8 grids were superimposed on the landscape geo-referenced map of the study area. A total of 5312 was initially surveyed which consisted of 337 forest beats within the 83 grids. Occupancy modeling framework, which accounts for imperfect detection, to identify the factors that affect the tiger distribution at the approximate scale of a female tiger's home range (Duangchatrasiri et al., 2019) 64 km2 -sized grid. We also surveyed the area for prey presence species. We used an occupancy survey method that explicitly accounted for spatial correlation recently designed to assess large-scale occupancy of tigers (Hines et al., 2010).



Georeferenced map of study site



Map showing GPS track evidence of survey

Objectives of Research:-

Non-invasive genetic analysis to establish tiger presence, minimum tiger numbers and their distribution.

Activities Undertaken:-

Data sorting, Geo-tagging and GIS mapping, Occupancy in Presence, Analysis of habitat suitability modelling including MaxEnt, Binomial multiple logistic regression (BMLR)etc. were performed. Linkage mapper was performed for corridor designing. Habitat suitability prediction was performed of different models viz. Generalized linear model (glm), Random Forest (RF), Support Vector Machine(SVM), MaxEnt(SDM), Boosted Regression Trees(BRT) in R language

Cost of the Project:- 43.07 lakhs

Outcome of Research

The objective based research question answers were find out below:

➢ **Where is the spatial distribution of tigers in the Ratapani-Kheoni landscape?**

- The analysis of tiger occupancy using presence software indicates that tigers are present in an area of 3762.48 km2 out of the total study area of 5312 km2.
- Based on the BMLR-based Habitat suitability index (HSI) for tigers, a suitable area of 2691 km2 is derived out of the 7225 km2 study area.
- The MaxEnt analysis predicts the probability of tiger occurrence in an area of 1409.08 km2 out of the total 7210 km2 study area.

➢ **What is the minimum tiger population?**

- The minimum number of tigers in the study area was determined to be nineteen based on NGS sequencing (DNA Test).

➢ **Which areas are priority areas for tiger conservation?**

- In the present study, five Tiger Conservation Priority Units (TCPUs) were identified using GIS mapping. These TCPUs are currently functioning as important habitats for tiger presence. Camera trap photographs of tigresses with their cubs were captured in TCPU_1 and TCPU_2, indicating their role as breeding source populations. The linkages between these TCPUs were demarcated using Linkage Mapper analysis in ArcGIS 10.1 software and depicted on a Geo-Referenced Map. The longest linkage is observed between TCPU_1 and TCPU_2, with a length of 26.53 km.
- The study area of 7210 km2 was mapped on a GIS platform using ArcGIS 10.1 software to identify tiger conservation prioritization areas (TCPUs). TCPU_1, TCPU_2, TCPU_3, TCPU_4, and TCPU_5 were identified using MaxEnt software within the landscape. The predicted probability of tiger occurrence was found to be 1409.08 km2 in the study area. The identified TCPUs were spatially distributed among five conservation units: TCPU_1 (50.99 km2), TCPU_2 (724.20 km2), TCPU_3 (104.43 km2), TCPU_4 (301.48 km2), and TCPU_5 (227.98 km2).

➢ **Which habitat is linked to priority areas with minimal resistance?**

- The analysis of linkage connectivity among all the tiger habitats is based on the measurement of resistance. The pinch point analysis was conducted to assess resistance within the linkage swath. The selected linkages have resistance values ranging from 18.98 to 0.06 CWD. Linkage_6 shows the highest Cost Weighted Distance (CWD) of 18.97 between TCPU_4 and Stepping Stone_9, while linkage_1 has the lowest CWD of 0.06, indicating a viable connecting linkage between TCPU_1 and TCPU_2.
- The Linkage Mapper analysis identified eight linkages within the study area, which are crucial for connecting the five TCPUs. The lengths of these linkages are as follows (in descending order): L_1 (26.27 km), L_6 (21.26 km), L_3 (18.40 km), L_4 (12.66 km), L_7 (9.14 km), L_5 (2.84 km), L_2 (2.13 km), and L_8 (1.06 km). The cost-weighted distances (CWD) of these linkages range from L-6_CWD_18.97 to L-1_CWD_0.06, indicating varying levels of resistance.

➢ **Where are the pinch point barriers located within the connecting linkages that create bottlenecks for tiger dispersal?**

- A total of 8 linkages were identified in the study area, with the shortest one being between TCPU_5 and the nearest stepping stone, SS_7. Although the stepping stones are positioned within the middle of the linkages, they play a crucial role in supporting tiger movement. A total of 10 stepping stones were found, providing safe passage for tigers between TCPU areas.
- Within a 3 km swath along the least cost path, seven villages fall under linkages 6, 7, and 8, while 20 villages fall under linkages 1, 2, 3, 4, 6, 7, and 8 within a 3-5 km swath. Among these villages, four (Gondra, Mahuakheda, Bhusibenta, and Umrai Bahara) are located within the 0-3 km swath of Linkage_6, two (Silpuri and Neemkheda) within Linkage_8, and one (Damdongri) within Linkage_7. Linkages 1-5 do not have any villages within their 0-3 km least-cost path.

➢ **How can we ensure the conservation of wildlife and its continued existence?**

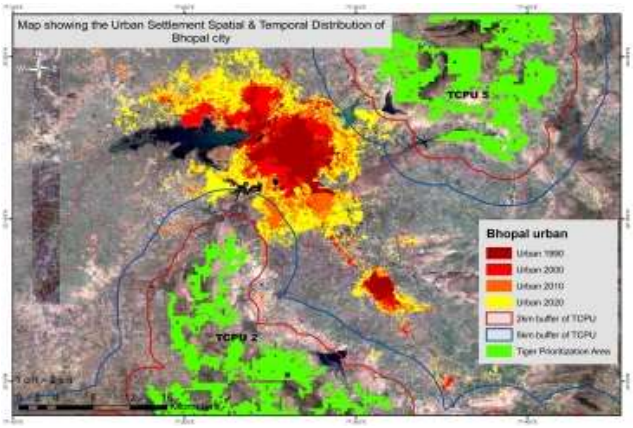
- The Mendora PPA, located in Kerwa Chowki in the Samardha Range, has been serving as a consistent breeding source area for tigers over the past decade. Therefore, it is crucial to establish a connection between Mendora PPA and Chichli beat by utilizing the revenue land in between. This land transfer is necessary because it functions as a valuable tiger habitat.
- To facilitate the establishment of a tiger safari, it is recommended to chain link fence the forest areas of Mendora PPA, revenue connecting linkage, and Chichli beat along their outer periphery. This enclosure will cover an area of 1744.7 hectares, ensuring the efficient utilization of land for the tiger safari. The establishment of a tiger safari can bring economic benefits through livelihood generation, social monitoring, and promoting long-term conservation programs. Ultimately, this strategy aims to prevent tigers from dispersing into the Bhopal Municipal Corporation areas from the Vindhya landscape.

➢ **How can the habitat of fragmented forest areas be improved to ensure a conducive habitat for wildlife?**

- The Jungle Safari has a range of potential beats including Bhanpura, Samaspura, Gol, Kathotiya, Charmandali, SewaniyaParihar, Jhiri, Tumdakheda, Veerpura, Chikalpani, Borpani, Khajuri, Jawra, Karmai, Mathar, Delawadi, Naharkola, Bhootpalasi, Diwatiya, and Bhiyanpur. These 20 beats, located in Bhopal, Sehore, and Obedullaganj divisions, offer significant opportunities for local people to engage in ecotourism practices and contribute to nature conservation efforts. They provide an ideal setting for exploring the wild natural habitat and promoting sustainable tourism practices.

➢ **Which areas of the landscape experience human-animal conflict, and what measures can be taken to mitigate it?**

- TCPU_2 and TCPU_5, located near the Bhopal capital region, have consistently shown evidence of tiger presence for seven years, making it a favorable area for tiger roaming and thriving wildlife.
- Bhopal's population has grown at an average rate of 31.47% over the past three decades, reaching an estimated 3,702,100 in the next three decades.
- The urban area of Bhopal has expanded by 46.76% in the last four decades, posing a disturbance to wildlife presence in TCPU_2 and TCPU_5. To address this, it is recommended to create a 2 km eco-sensitive buffer zone around the TCPUs and establish a green belt zone to foster co-existence.



Spatial and temporal distribution of Bhopal city

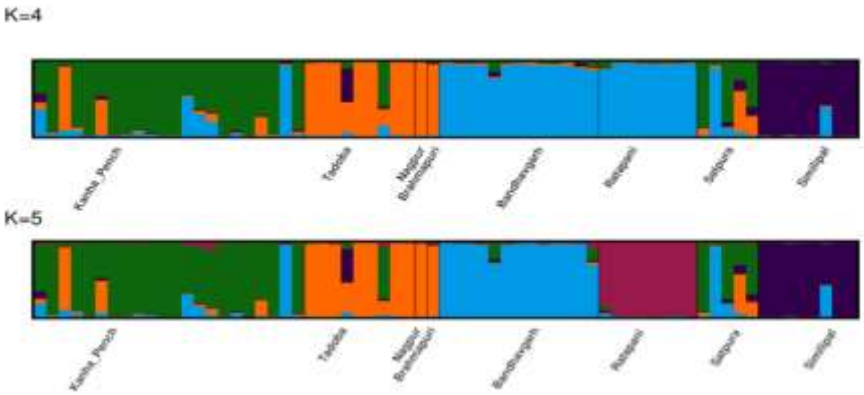
- Erecting a strong 32 km long and 12 feet high fence for the tiger safari is essential to enclose the 1744.7-hectare safari area. This will eliminate incidents of crop loss and potential harm to human life. Additionally, it will provide employment opportunities in ecotourism for nearby unemployed villagers. Eco-tourism-based monitoring will effectively combat wildlife hunting, create additional livelihoods, and promote harmony with wildlife conservation.
- The area surrounding TCPU_5 is rich in scenic natural beauty, featuring accessible grasslands at Prempura Beat for herbivore wildlife. However, there is a need to increase water sources' number and density. The presence of tigers, leopards, sloth bears, and wolves contributes to the thriving wildlife. The fertile soil, good site quality, and retained moisture further enhance the area's biodiversity, with great potential for butterfly parks in moist creek areas.
- The forest area connected to the capital of Madhya Pradesh offers a suitable location for forestry, wildlife research, and education. Educational activities can be conducted here for nature enthusiasts.
- Developing this area as a Forest Interpretation Center will strengthen tiger conservation efforts and provide livelihood opportunities for the forest-based community through ecotourism. By promoting eco-tourism-based monitoring, the vision of social fencing can be realized.
- Based on the present study, creating a nature reserve in TCPU_5 is necessary to conserve tigers and achieve the goal of co-existence.

➢ **Is the small tiger population in the sanctuary stable?**

- Yes, the small population in Ratapani is stable and experiencing continuous sustainable growth. However, it is important to note that the Ratapani population is distinct and isolated, with an adjacent tiger reserve.

➢ **What is the degree of genetic relatedness observed between the intra and inter-adjoining sub-metapopulations in the landscape?**

- Analysis of clustering of Ratapani, Satpura, Kanha-Pench and Bandhavgarh populations and assignment based on STRUCTURE indicate that there is some clustering of Kanha and Satpura populations, and these have the lowest Fst estimate. There is some shared ancestry between Satpura, Kanha, and Bandhavgarh, with some individuals sharing high proportions of ancestry based on the STRUCTURE plot.



- In addition, estimates of Fst between Bandhavgarh and Kanha and Satpura are relatively low. This suggests that there may be some movement of individuals among these populations. Ratapani has moderate Fst with all of the three other populations in the landscape (0.2-0.25). Based on STRUCTURE analysis, Ratapani has very little shared ancestry with any of the populations.
- Overall it does not appear that Ratapani is more closely related or connected to any of these three populations within the landscape. Further landscape-level analysis that assesses the impact of landscape features and distance across the landscape could help in explaining the apparent isolation or low connectivity of Ratapani with other populations within this landscape.

➢ **Which areas within the landscape have the capacity to support a resident tiger population, and which areas primarily facilitate the movement of transient tigers through connecting linkages?**

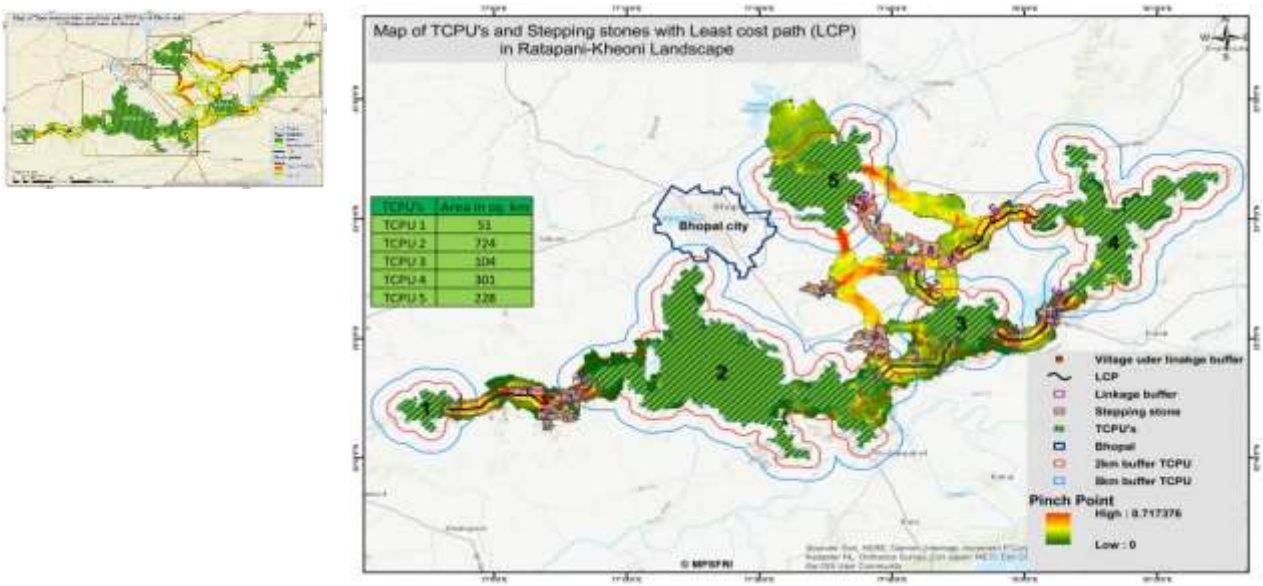


Figure: The five demarcated Tiger Conservation Prioritization Units (TCPUs)

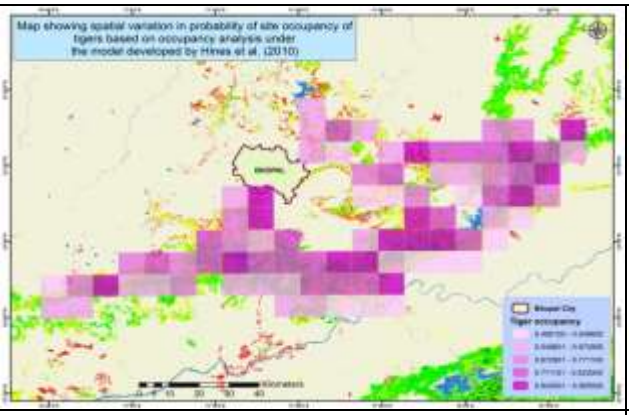
- Using ArcGIS 10.1 software, the entire 7210 km2 landscape was mapped to identify tiger conservation prioritization areas (TCPUs). Based on MaxEnt software analysis, five TCPUs were identified within the study area: TCPU_1, TCPU_2, TCPU_3, TCPU_4, and TCPU_5, with a predicted occurrence probability of 1409.08 km2.
- The total area of TCPUs is 1409.08 km^2, recognized as high-value conservation areas after GIS mapping. These areas require complete protection to ensure optimal ecological restoration and future wildlife coexistence. DNA Next-Generation Sequencing data from 2018-2019 identified a minimum of 19 tigers in the TCPUs. These findings are valuable for decision support systems (DSS) in demarcating critical tiger habitats based on functional attributes and their connecting linkages.
- • Eight linkages have been identified in the study area, with stepping stones located within these linkages. While the stepping stones are positioned in the middle of the linkages, their functionality and efficiency in supporting tiger movement surpass the linkages themselves. A total of 10 suitable tiger habitats, acting as stepping stones, provide safe passage for tigers moving between TCPUs, facilitating transient movement rather than supporting resident tiger populations.

➢ **What is the current status of geospatial tiger occupancy within the landscape?**

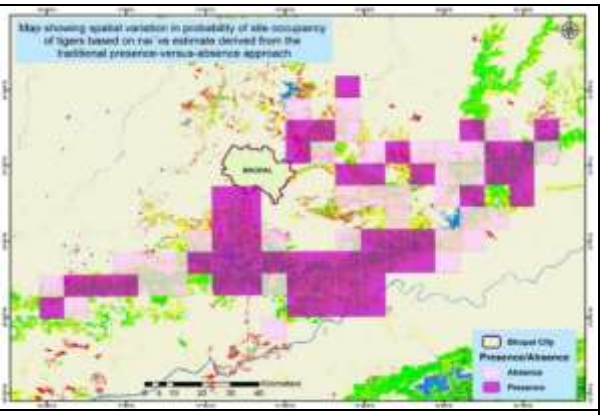
- Tiger occupancy survey was performed from Dec 2018 to Apr 2019 to estimate the overall occupancy rate Ψ on presence software version 13.6. In the occupancy survey across the study area of a total of 5312 (sq. km), segment distribution was 83 grid cells (size 64 sq. km). The detected tiger sign in 49 of 83 grid cells was confirmed, which yielded a naïve occupancy of 0.5904. The tiger-occupied estimated potential tiger habitat is 70.83% of the total study area, or an area of 3762.48 (SE=482.34) out of 5312(sq. km) Ratapani-Kheoni Landscape. In contrast, a naïve estimate derived from the traditional 'presence-versus-absence' approach is only 3136.20 sq. km and underestimated true occupancy by 59.04%.
- • The best-fitted model is the Hines model under which ψ (Cattle+Ruggedness),θ(.),θ'(.), pt(Nilgai+Water) model has shown the lowest AIC (value-1144.59) among 44 models. The model-specific β(beta) Coefficient estimate for covariates determining the Tiger occupancy in the Ratapani-Kheoni landscape is tiger β0(SE[β0])- 0.52(0.61).
- The rugged terrain, abundant perennial water availability, and Nilgai/Cattle presence were influencing the historical tiger population in the proximity of Bhopal by occupancy modelling . The Nilgai and Cattle presence was the main principal variable supporting the studied landscape's tiger population. Cattle and Nilgai share the habitat of tiger-occupied grids verified by our current study. However, a tiger was believed to not prefer large ungulate Nilgai as prey due to its night vision ability and highly nimble behaviour. However, some opportunistic

photographic evidence unambiguously supported that in the Ratapani-Kheoni landscape Nilgai population encountered predation.

- The findings of present occupancy modelling also support this fact as best fitted Hines model ψ(Cattle+Ruggedness), θ(.), θ'(.), pt(Nilgai+Water) is found. The detection probability of the Nilgai and water model gained the lowest AIC value. Cattle presence also influences the occupancy with high significance along with Nilgai, the feral cattle presence elsewhere in the elevated rugged terrain and providing easy prey for predation.
- The concerned forest divisions regularly reported and documented the cattle kill evidence by the tigers. The physical factor of rugged terrain also supports the tiger population by providing shelter, i.e. den, cliffs, and overhangs. So, we can say safely that the Ratapani-Kheoni landscape population is artificially supported by the presence of cattle due to anthropogenic reasons. The tiger presence also plays a critical role in habitat protection because rugged terrain is unsuitable for the sudden escape of forest dwellers during accidental encounters with carnivores. Patterns of spatial variation in probability of site occupancy of tigers in the Ratapani-Kheoni Landscape of Madhya Pradesh (RKL) were sown in Figure, page no. 25, (a) based on occupancy analysis under the model developed by Hines et al. (2010) (b) based on naïve estimate derived from the traditional presence-versus-absence approach.



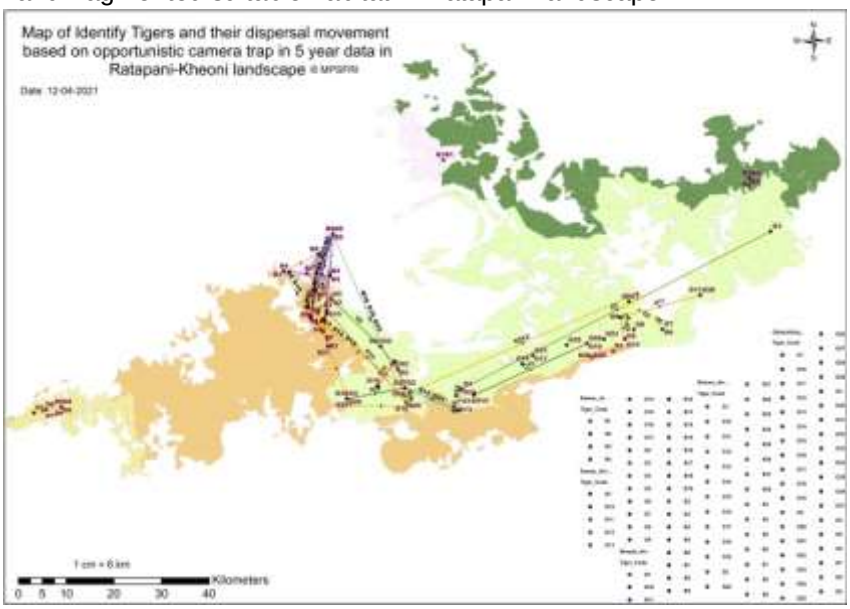
(A)The tiger occupied estimated potential tiger habitat is 70.83%, or an area of 3762.48 (SE=482.34) out of 5312(km2)



(B) In contrast, the traditional 'presence-versus-absence' approach is only 3136.20 km2 and underestimated true occupancy by 59.04%

➢ **What is the pattern of movement during dispersal in a landscape?**

In most cases, the Tiger dispersal movement overlaps the territorial forest of three divisions: Bhopal, Obbadlahganj and Sehore. Tigress T213 showing remarkably long-range behaviour is unique behaviour in thin and fragmented suitable habitat in Ratapani landscape.



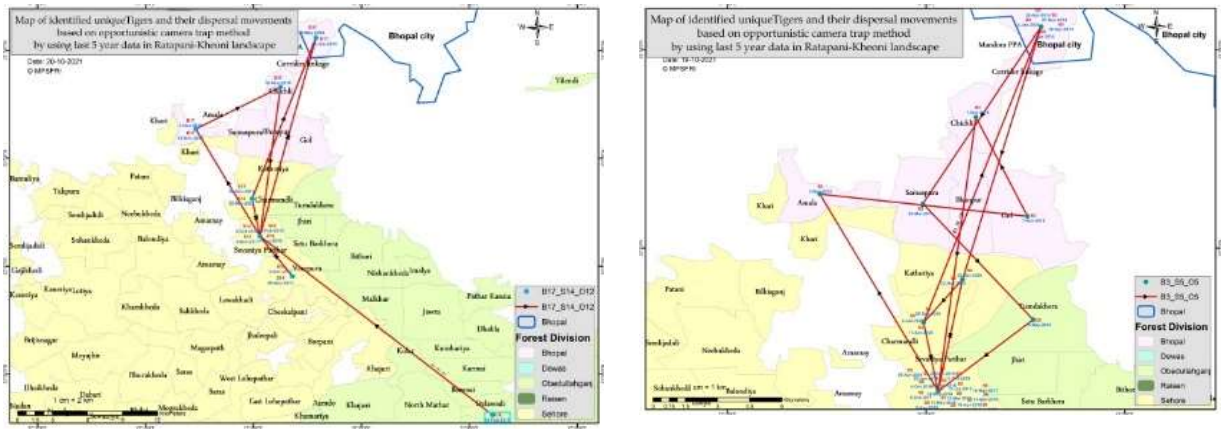
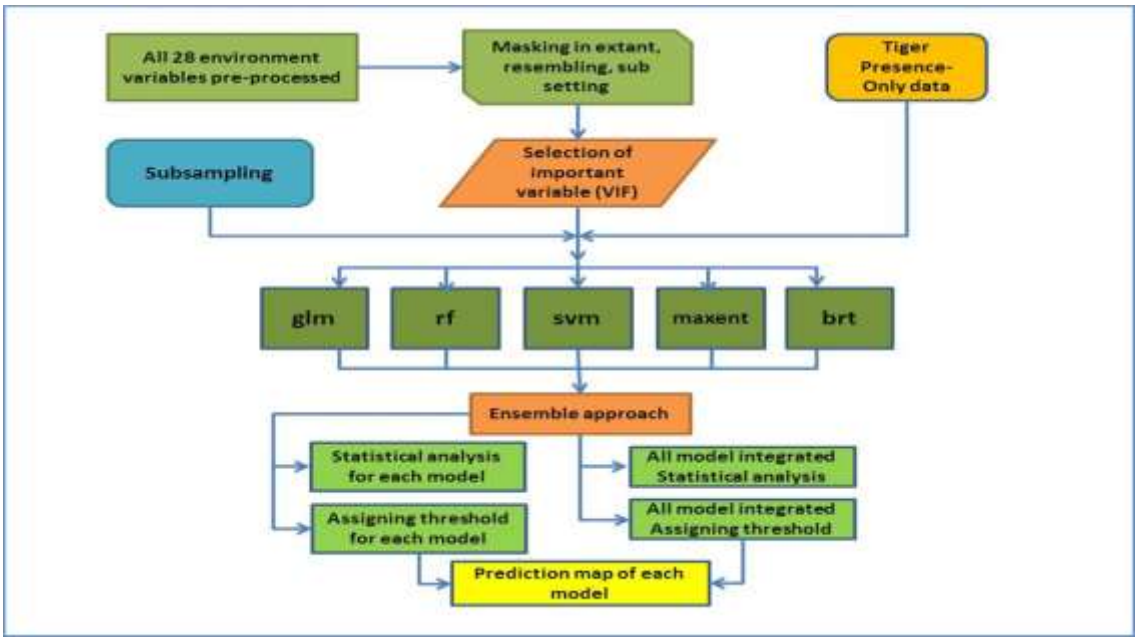


Figure shows the identified tigers & their dispersal movements, tiger movement has been showed equally overlapping in the areas of Bhopal, Obedullaganj and Sehore forest divisions.

6. Deliverable technologies developed in each project for stakeholders, forest professionals, field foresters and other beneficiaries.

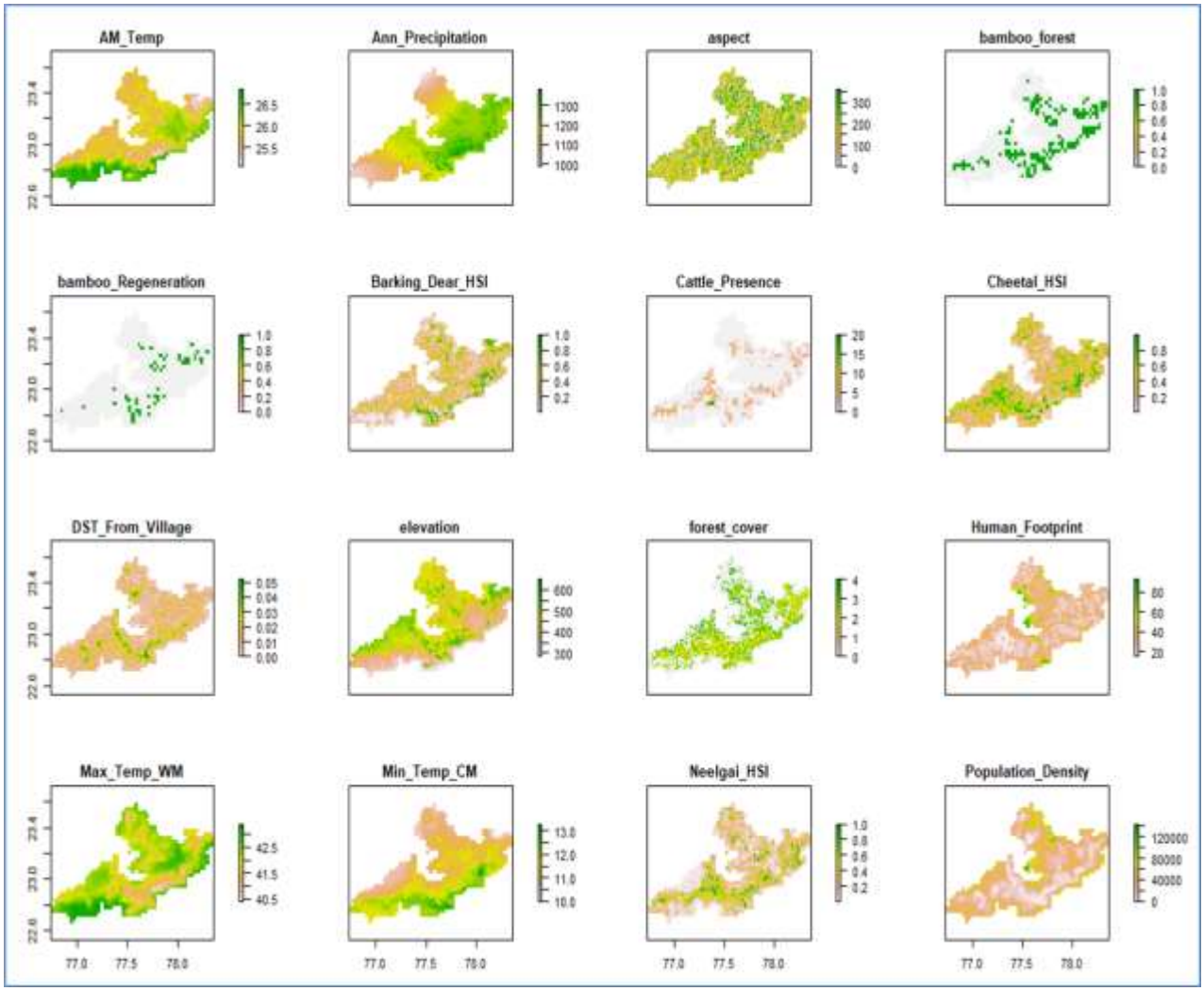
The methodology will be helpful for decision support in the prioritization of tiger conservation patches and also provide baseline information for a strategic conflict mitigation plan.

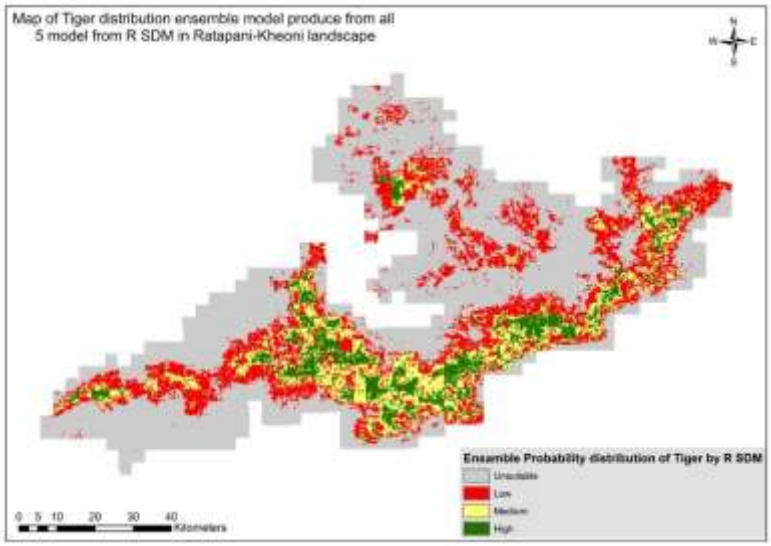
Species Distribution Modeling in R



SDM method overview flow diagram

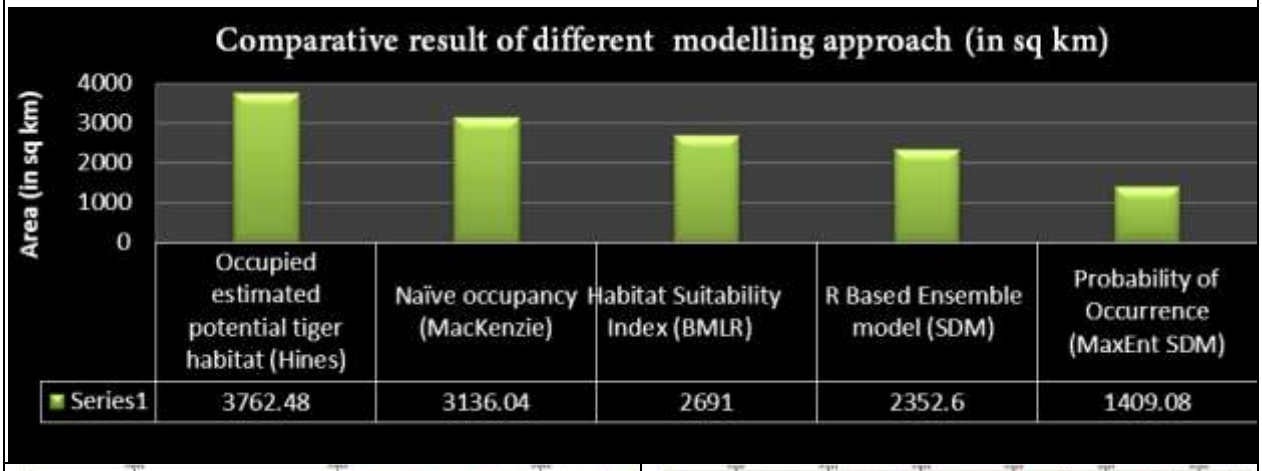
All Environment Variables used in R SDM model

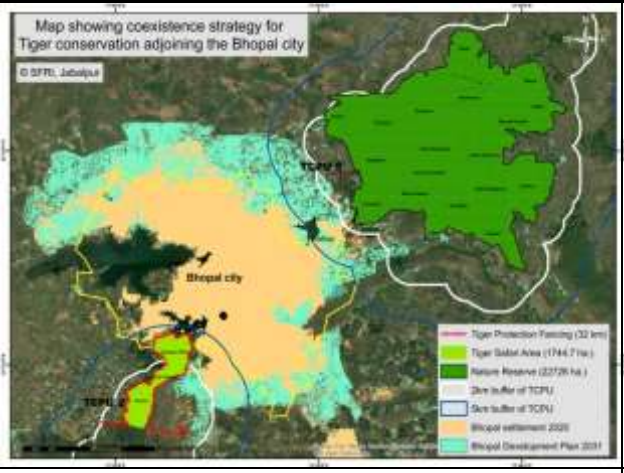




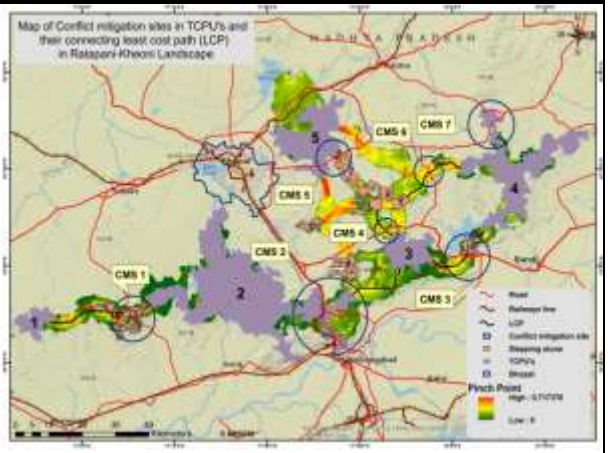
Methods	AUC	COR	TSS	Deviance
GLM	0.89	0.62	0.67	0.7
RF	0.93	0.71	0.72	0.61
SVM	0.91	0.67	0.72	0.67
MaxEnt	0.91	0.66	0.68	0.68
BRT	0.91	0.67	0.7	0.81

Figure: Ensemble model produced from GLM, RF, SVM, MAXENT and BRT, for modelling and mapping of Tiger habitat suitability distribution. The gray, red, yellow, and green colors describe "uninvaded," "low," "medium," and "high", respectively





Strategy to minimize conflict



Identification of mitigation sites