Title of the Project:- Study on tiger presence and dispersal movements in Ratapani-Kheoni landscape of Vindhya Range

Why this Project:-

The Ratapani-Kheoni landscape, situated on the peri-urban fringes of Bhopal, represents a critical but understudied interface between expanding human settlements and remnant tiger habitats. Despite frequent tiger sightings, breeding records, and conflict incidents, this region lacked a data-driven conservation framework. This study addresses that gap through an integrated approach combining occupancy modeling, habitat suitability analysis, genetic monitoring, and corridor mapping to assess tiger presence, dispersal, and habitat connectivity outside traditional Protected Areas. Its findings provide compelling evidence for formal conservation action, including the designation of a new Tiger Reserve, and offer a replicable model for managing large carnivores in human-dominated landscapes.

Study methodology and design

- Occupancy analysis:The present study was initiated with the aim of conducting occupancy modeling and ensuring the long-term conservation of tigers in the landscape. We utilized the single-species, single-season model in the PRESENCE 2.13.6 program (Hines, 2006) to analyze tiger occupancy and establish the framework for tiger presence in the landscape. The total study area encompassed approximately 4620.84 sq. km.
- MaxEnt analysis: MaxEnt analysis was conducted using tiger presence data from 234 surveyed beats in the Ratapani-Kheoni landscape, overlaid on 10 km² grid units. Environmental variable layers were standardized in ArcMap and converted to ASCII format, along with a bias layer for background correction. Species data were formatted in CSV with X-Y coordinates. MaxEnt was configured with 25% random test data, 15 replicates (subsample), and 5000 iterations. The model output included habitat suitability maps and statistical summaries stored in the designated path.
- BMLR Analysis: From Dec 2018 to June 2019, 357 tiger presence points were recorded in 3.17 km grids across Ratapani-Kheoni. Binomial Multiple Logistic Regression linked tiger presence to habitat variables after testing multicollinearity and model fit.

$$P = \frac{exp^{(\Sigma BX)}}{1 + exp^{(\Sigma BX)}} \ldots.$$

Habitat suitability across Ratapani-Kheoni was mapped using logistic regression in ArcGIS, classifying areas from most to non-suitable. A beta coefficient table supported the BMLR-based Habitat Suitability Index analysis.

- Corridor designing in ArcGIS 10.3.1 by using Linkage mapper tools:

  To prepare the resistance raster for the Linkage Mapper, we employed Gnarly landscape utility tools. These tools were utilized to generate a cumulative raster, incorporating the resistance values of features on the ground. We assigned resistance values to each feature within individual layers. An Excel spreadsheet was created to define the number of classes, provide class descriptions, and most importantly, specify resistance values. These resistance values were determined based on the negative impact of each feature with respect to suitable focal patches.

  Resistance habitat calculator: The Resistance and Habitat Calculator tool generated a resistance map using values from column F of the Excel sheet. For focal species analysis, maximum resistance across input layers was calculated to assess landscape integrity.

  Linkage Mapper tool: We utilized the Linkage Mapper GIS tools to enhance the analysis of regional wildlife habitat connectivity. This toolset comprises multiple Python scripts, bundled into an ArcGIS 10.1 toolbox, which automate the mapping of wildlife habitat corridors.
- **Population genetics through DNA analysis:**

Sampling: From December 2017 to June 2019, we collected samples in the Ratapani-Kheoni landscape and the Satpura Tiger Reserve in central India. A total of 359 scat samples were gathered

from the Ratapani-Kheoni landscape, and 267 scat samples were collected from locations within the Satpura Tiger Reserve, all presumed to be from tigers (Panthera tigristigris).

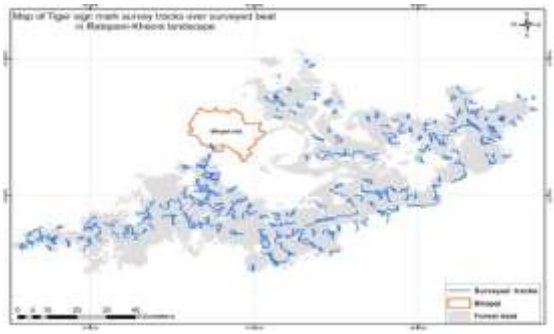
The objective of collecting these scat samples was to estimate the minimum number of tigers present in the forests, assess their relative genetic diversity, and determine whether there is a population genetic structure among these forest fragments in central India. This was achieved by comparing the genetic data from these samples with those from other locations, including the Kanha and Bandhavgarh tiger reserves.

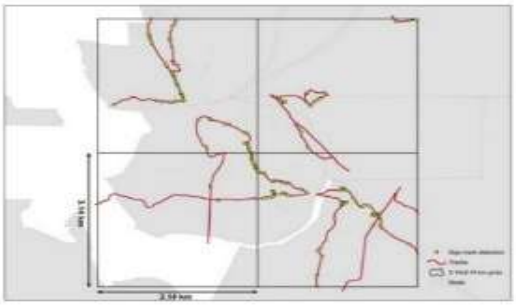
The DNA analysis for population genetics was carried out in the lab of Professor Uma Ramakrishnan at NCBS, Bengaluru, following these steps:

- Sample processing
- DNA extraction
- Species identification
- Genotyping using mPCR
- Individual identification
- Population genetic analysis

Study Design:

- From Dec 2018 to Apr 2019, a tiger sign survey was conducted over 5,312 km² in Ratapani-Kheoni using 8×8 km grids based on tiger home range estimates. Occupancy modelling assessed tiger distribution at 64 km² scale, accounting for imperfect detection. Prey presence was recorded, and spatial correlation was addressed using Hines et al. (2010).
- Field protocol: A tiger sign survey was conducted from Dec 2018 to Apr 2019 in Ratapani-Kheoni, recording tracks and scat along forest trails. Signs of key prey species were also noted. Trail segments were scored as “1” or “0” for detection and aggregated into 1 km spatial replicates. Occupancy was modeled using PRESENCE software, and overall tiger occupancy (Ψ) was estimated using AIC-based model comparison.





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

Objectives of Research

Monitoring of tigers through non-invasive DNA sampling; non-invasive genetic analysis to establish tiger presence, minimum tiger numbers, sex, and their distribution.

Short-term objectives:-

- Spatial distribution of Tigers.
- Minimum numbers of Tigers along with sex ratio.
- Habitat improvement strategy for fragmented forest areas.
- Make certain the wildlife conservation and its continuity.
- Identification of priority areas for tiger conservation.
- Identification of linking corridor with minimum resistance for Tiger movement.
- Identification of pinch point barrier (bottleneck) within the connecting linkage.

- Identification of landscape areas facing human-animal conflict along with the prescription of mitigation strategy.

Long term objectives:-

- Tiger population stability in the sanctuary.
- Degrees of genetic relatedness exists between the landscape's intra and inter-adjoining sub-metapopulation.
- Identification of areas of the landscape can support the residential and transient population.
- Tiger occupancy in the landscape.
- The pattern of movement during dispersal in the landscape.

Cost of the project : Rs. 43.07 lakhs

Outcome of the project :

Objective-Based Research Findings:

1. Spatial Distribution of Tigers

- Recent ecological modeling across the 7,210 km² Ratapani–Kheoni landscape in central India provides a multi-scale understanding of tiger distribution.
- Occupancy Modeling using PRESENCE software indicates tiger presence across 3,762.48 km² of the 5,312 km² surveyed (True Occupancy: 70.83%).
- Habitat Suitability Index (HSI) via BMLR modeling identified 2,691 km² of suitable habitat.
- MaxEnt Species Distribution Modeling predicts high tiger occurrence probability in 1,409.08 km².

2. Minimum Tiger Population

Non-invasive DNA analysis (NGS sequencing) confirmed a minimum of 19 individual tigers in 2018–19, indicating a small but viable population.

3. Priority Conservation Areas (TCPUs)

Using MaxEnt and GIS, five Tiger Conservation and Protection Units (TCPUs) were delineated:

TCPU	Area (km²)	Notable Feature
1	50.99	Confirmed breeding site
2	724.20	Core source population& Interface with urban expansion
3	104.43	Dispersal corridor node
4	301.48	Transitional habitat
5	227.98	Interface with urban expansion

Together, these TCPUs cover the 1,409.08 km² core habitat area and serve as conservation focal points.

4. Corridor Connectivity and Resistance

- Eight key linkages connect TCPUs and stepping stones (n=10).
- Linkage_1 (26.27 km) between TCPU_1 and TCPU_2 has lowest resistance (0.06 CWD), offering the best dispersal corridor.
- Linkage_6 shows the highest resistance (18.97 CWD), reflecting anthropogenic fragmentation.
- Village intersections are notable in Linkages 6–8 (0–3 km buffer), highlighting potential conflict zones.

5. Pinch Points and Stepping Stones

- Ten stepping stones were identified as critical microhabitats supporting tiger dispersal.
- Pinch points in Linkages 6, 7, and 8 are vulnerable to bottlenecks due to village proximity (e.g., Gondra, Silpuri).
- Strategic habitat restoration in these zones is essential to sustain movement pathways.

6. Conflict Mitigation and Urban Interface

- TCPU_2 and TCPU_5 lie adjacent to Bhopal city and are human-wildlife conflict hotspots.
- Urban expansion (projected +381.45 km² in 30 years) threatens habitat continuity.
- A 2 km eco-sensitive buffer zone, greenbelt planning, and 32 km protective fencing around the proposed 1,744.7 ha Tiger Safari can mitigate conflict and promote coexistence.

7. Sustainable Habitat Management and Livelihood Integration

- The safari zone includes 20 forest beats across Bhopal, Sehore, and Obedullaganj divisions.
- These areas are ideal for community-based ecotourism, research, and biodiversity education.
- Proposed development includes a Forest Interpretation Centre and Butterfly Park in moist creek zones of TCPU_5, enhancing both ecological value and local livelihoods.

8. Population Viability and Genetic Connectivity

- Genetic analysis shows the Ratapani tiger population is stable but isolated.
- STRUCTURE analysis reveals limited shared ancestry with Satpura, Kanha, and Bandhavgarh (Fst = 0.20–0.25), emphasizing the need for landscape-level genetic connectivity interventions.

9. Resident vs. Transient Use

- The 1,409.08 km² core area (TCPUs) can sustain resident tigers.
- Linkages and stepping stones serve as transient routes, underscoring the importance of maintaining functional corridors.

10. Geospatial Occupancy Trends

- Naïve occupancy = 0.5904 (49/83 grids).
- Best-fit model: ψ(Cattle + Ruggedness), pt(Nilgai + Water), AIC = 1144.59.

11. Key findings:

- Tigers are using rugged terrains with cattle and Nilgai presence.
- Photo evidence supports tiger predation on Nilgai.
- Tigers aid forest protection in inaccessible terrains.

12. Recommendations

- Enhance protection in TCPU_1 and TCPU_2 as source populations.
- Implement targeted habitat restoration in corridor pinch points.
- Promote community engagement through ecotourism-based livelihoods.
- Monitor urban expansion near TCPU_5 with a dedicated greenbelt and conflict mitigation framework.
- Integrate Ratapani into broader Central Indian Tiger Landscape Conservation Planning through genetic corridor design.

Key Facts of the Report - The principal facts on which project report is based are as follows:

Population genetics:

- The minimal unique tiger population is 19 in 2018-19 based on DNA genotyping (NGS)
- Ratapani individuals form their own cluster (STRUCTURE analysis)
- Ratapani has very little shared ancestry with Satpura, Kanha –Pench and Bandhavgarh populations, Not closely related or connected to any within the landscape
- Analysis of the four focal populations using structure indicates K=4 best explains the genetic clustering of these populations.
- Ratapani individuals form their cluster and do not show this pattern of shared variation.
- Analysis of clustering of these 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.

Relative movement pattern in different Geo-spatial scales:

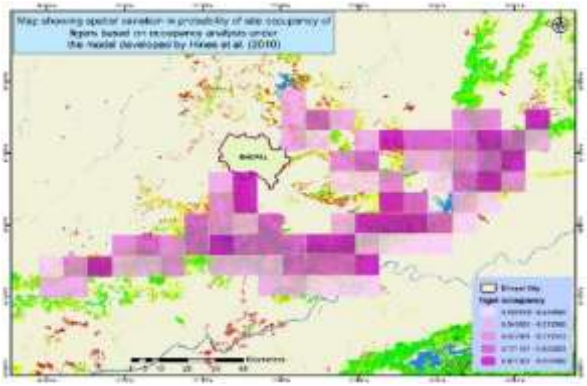
The relative temporal dispersal movements of all individually identified Unique Strip Pattern (IUSP) tigers were derived from opportunistic camera trap data spanning Bhopal, Sehore, Dewas, Obedullaganj, and Raisen divisions. These IUSPs were correlated with camera trap data from all mentioned divisions to integrate the movement patterns of tigers.

In the study area, tiger dispersal movements often overlap across the territorial forests of three divisions: Bhopal, Obedullaganj, and Sehore. The tigress exhibiting remarkably long-range behavior demonstrates unique behavior within the thin and fragmented suitable habitat of the Ratapani landscape.

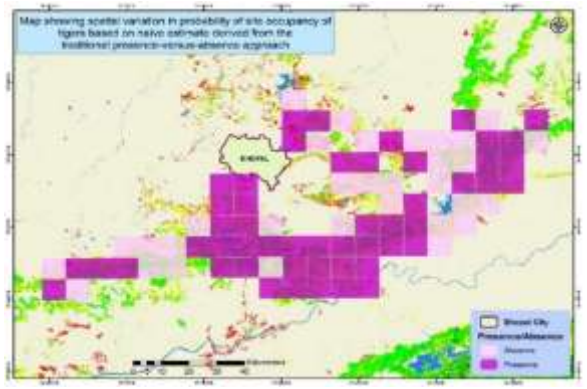
Occupancy estimates:

- The occupancy survey covered a total study area of 5312 sq. km, segmented into 83 grid cells of 64 sq. km each.
- Tiger signs were confirmed in 49 out of the 83 grid cells surveyed, resulting in a naïve occupancy rate of 0.5904.

(A) The estimated tiger-occupied habitat covers approximately 70.83% of the total study area, equating to an area of 3762.48 sq. km (SE=482.34) out of 5312 sq. km.



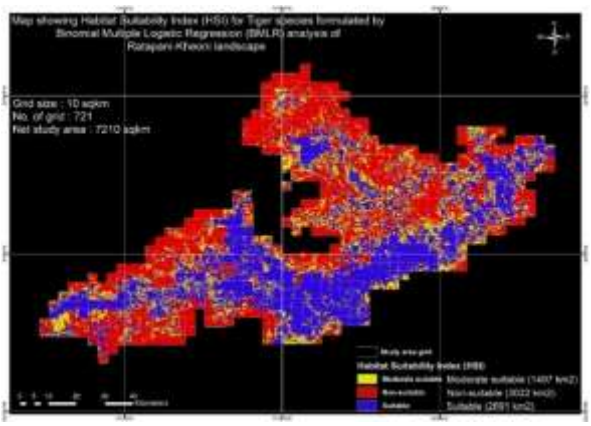
(B) In contrast, the traditional 'presence-versus-absence' approach covers only 3136.20 sq. km, underestimating true occupancy by 59.04%.



The best-fitted model identified through occupancy analysis is the Hines model, where the ψ(Cattle+Ruggedness), θ(.), θ'(.), pt(Nilgai+Water) configuration exhibited the lowest AIC value of 1144.59 among 44 models. The model-specific β(beta) coefficient estimate for covariates influencing tiger occupancy in the Ratapani-Kheoni landscape (RKL) is β0(SE[β0]) - 0.52(0.61).

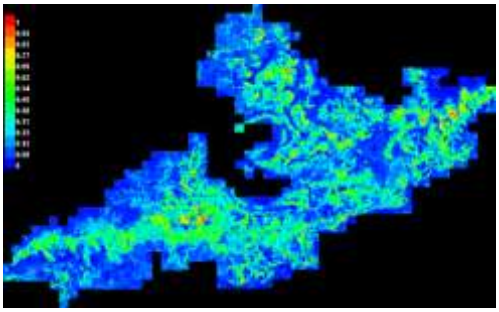
The historical tiger population persists near the city in the Vindhyan landscape due to rugged terrain, abundant water availability, and the presence of prey, primarily Bluebull/Cattle.

BMLR Output: Based on BMLR-based Habitat Suitability Index (HSI), the suitable area for tigers is estimated to be 2691 sq. km out of the total 7210 sq. km study area.



❖ **MaxEnt Output:** The total 7210 km^2 area was mapped on the GIS platform ArcGIS 10.1 by MaxEnt SDM analysis to find out the tiger conservation prioritization areas (TCPUs). TCPU_1, TCPU_2, TCPU_3, TCPU_4 and TCPU_5 were identified using MaxEnt software within a studied landscape area.

The predicted probability of occurrence covered an area of 1409.08 sq. km within the study landscape. The identified TCPUs were spatially distributed across five conservation units: TCPU_1 (50.99 sq. km), TCPU_2 (724.20 sq. km), TCPU_3 (104.43 sq. km), TCPU_4 (301.48 sq. km), and TCPU_5 (227.98 sq. km).



Percent Contribution for each variable of the model: The table below illustrates the percentage contribution of each variable in the model.

S. No.	Variable	Variable code	Percent contribution
1	B. tragocamelus probability of occurance	Nilgai_avg	28.1
2	Rusa unicolor probability of occurance	Sambar_avg	8.8
3	Topographic ruggedness Index	Ruggedness TRI	7.2
4	Village density	Village_Density	5.9
5	Annual mean temperature	AM_Temp	5
6	Minimum temperature of coldest month	Min_Temp_CM	4
7	Muntiacus muntjak probability of occurance	Barking_Deer_avg	3.6
8	Maximum temperature of warmest month	Max_Temp_WM	3.5
9	Melursus urcinus	Sloth_bear_presence	3.3
10	Slope	slope	3.2
11	Bamboo regeneration	Bamboo_Regeneration	3.2
12	DEM elevation	Elevation	3
13	Axis axis probability of occurance	Chital_avg	3
14	Bamboo forest	Bamboo_forest	2.9
15	Water availability upto March	Water_Availability_Upto_March	2.8
16	Human footprint	Human_footprint	2.7
17	Forest cover	Forest cover	2.4
18	Distance of village from forest compt.	DST_From_Village	2.3
19	Annual precipitation	Ann_Precipitation	1.9
20	Cattle count	Cattle_Presence	1.7
21	Human population density	Population_Density	0.8
22	Precipitation of Driest month	Precipitation_DM	0.7

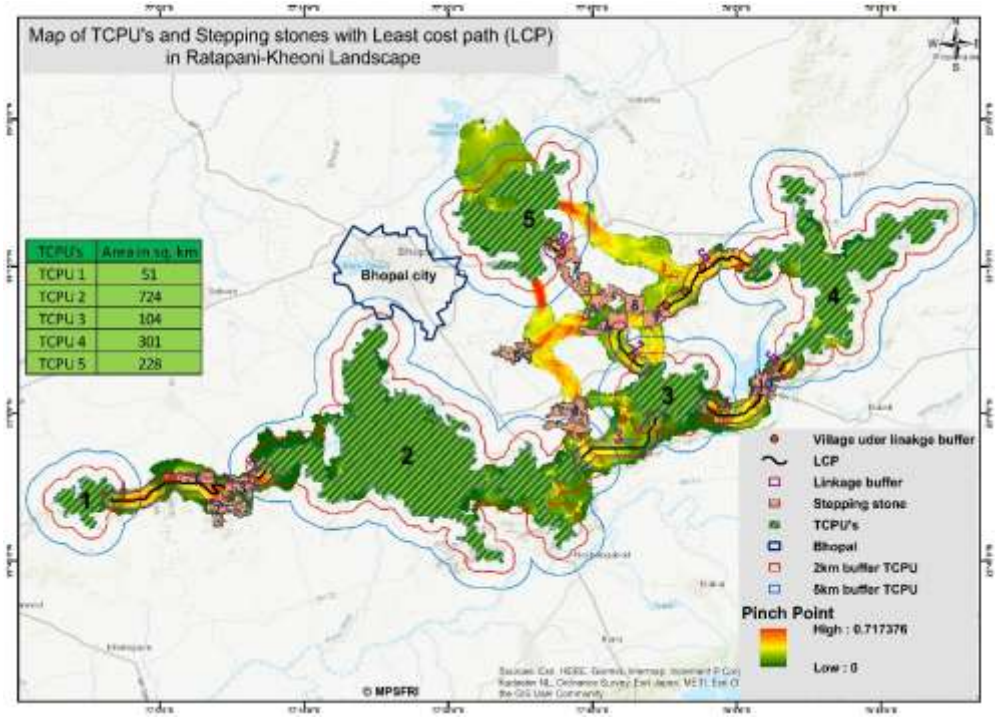
Our species distribution models effectively map tiger habitat needs across breeding seasons, accurately identifying core TCPUs and smaller stepping stone habitats. These stepping stones

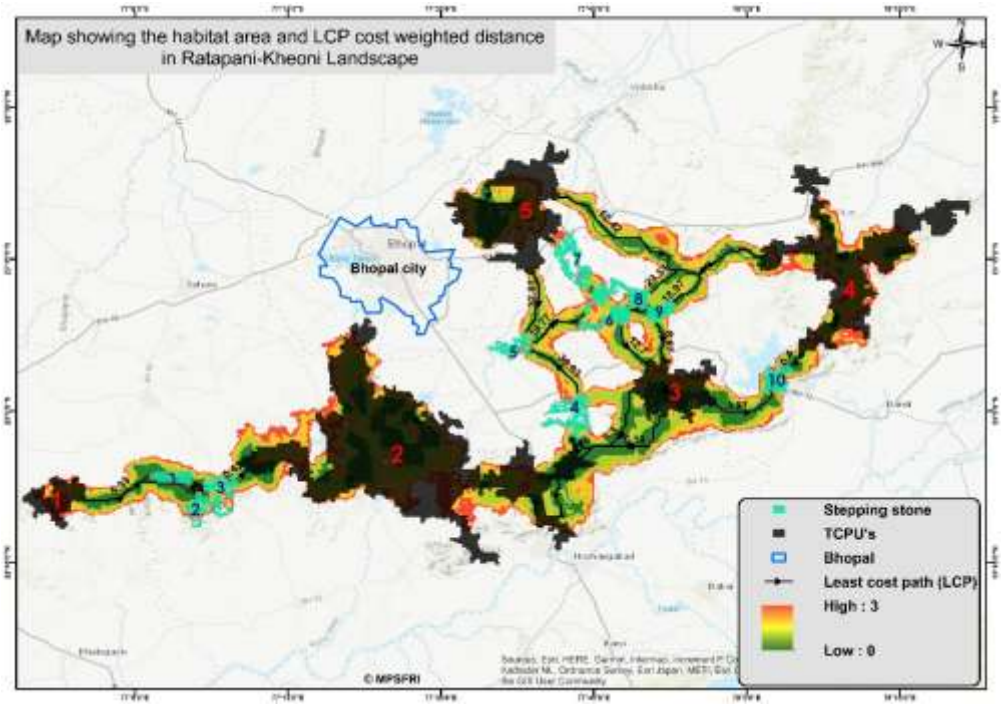
enhance connectivity by reducing travel distances between major TCPUs, serving as seasonal stopovers for dispersing tigers. While not supporting permanent breeding, they play a vital role in linking the habitat network. In total, ten stepping stones have been identified in the study area, with details summarized in the accompanying table.

Table showing Numbers of stepping stone, their area and the villages falling under the stepping stones

S.No.	Stepping Stone	Stepping stone area (in ha.)	Numbers of villages	Village area (in ha.)	Village population
1.	1	1173	0	-	-
2.	2	1959	1	712	869
3.	3	1411	1	1094.63	1109
4.	4	3033	6	1087.82	1083
5.	5	1504	3	957.18	1586
6.	6	1701	2	2093.08	1044
7.	7	2672	5	1606.02	2623
8.	8	2728	5	1766.35	4808
9.	9	1250	0	-	-
10.	10	1583	1	277.14	370

The map below illustrates the Tiger Conservation Priority Units (TCPUs), Stepping Stones, and Cost-Weighted Distance.





Linkage	Cost Weighted Distance (CWD)	Linkage length (in km.)	Village falling under 0-3 km swath	Village falling under 3-5 km swath	Total Villages
1	0.06	26.278	0	5	5
2	0.42	2.137	0	1	1
3	5.19	18.406	0	3	3
4	3.27	12.669	0	2	2
5	0.40	2.847	0	0	0
6	18.97	21.263	4	4	8
7	12.70	9.149	1	3	4
8	3.74	1.066	2	2	4

Result of SDM analysis in R:

Performances of Species Distribution Modelling

The results show that machine learning models (RF, BRT, MAXENT, SVM) outperformed the regression model (GLM) across all evaluation techniques. Random Forest (RF) had the highest accuracy, followed by SVM, MAXENT, BRT, and GLM. RF also led in AUC, TSS, and COR, while GLM performed well in Deviance after RF.

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	0.70	0.81

Tiger distribution in different models

Tiger occupancy based on max(se+sp) thresholds for GLM, RF, SVM, MAXENT, BRT, and Ensemble models were 34%, 43%, 21%, 36%, 29%, and 30.6%, respectively. RF performed best,

indicating 3,103 km² occupied out of 7,216.58 km². The ensemble model mapped occupancy levels, classifying 58.75% of the area as unsuitable. Of the remaining 41.24%, tiger presence was categorized as low (22.08%), medium (11.92%), and high (7.2%).

Model	AUC	Correlation	TSS	Threshold	Threshold Max (Spe+Sen)	persent of distribution	Suitable area in sq. km
glm	0.89	0.62	0.67	0.34	0.34	34	2453.64
RF	0.93	0.71	0.72	0.43	0.43	43	3103.13
SVM	0.91	0.67	0.72	0.21	0.21	21	1515.48
MaxEnt	0.91	0.66	0.68	0.36	0.36	36	2597.97
brt	0.91	0.67	0.7	0.29	0.29	29	2092.81
Ensemble	0.908	0.66	0.70	0.3060	0.32	32	2352.60

The relative contribution of predictor variables:

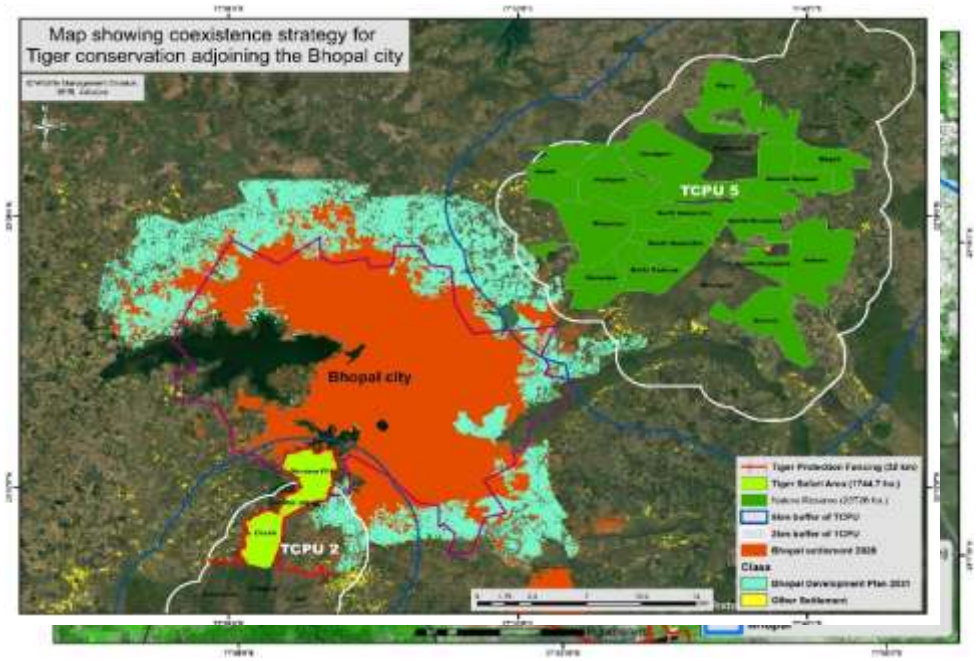
The relative influence of predictors is shown in Table 35. Some variables had a very high relative influence, while others were insignificant. The top three individual variables (Population_density, Barking_deer_HSI, Nilgai_HSI, Sambar_HSI, Cattle_Presence, Slothbear_Presence, Water_Upto_March) had relative influences for GLM, RF, SVM, MAXENT, and BRT of 37.8%, 16.7%, 20.2%, 21.5%, and 35.6%, respectively.

The relative variable importance (RVI) for population density was as follows: 22.4% (GLM), 7.5% (RF), 4.4% (SVM), 10.2% (MaxEnt), and 20.9% (BRT). The next most important factor was prey combinations: Barking deer + Nilgai (15.4% for GLM), Sambar + Nilgai (9.2% for RF), Cattle + Sambar (11.3% for SVM), Barking deer (5.5% for MaxEnt), and Cattle + Sambar (14.7% for BRT). The water variable ranked among the top three most important variables only in the MaxEnt model, where it was second with an RVI of 5.8%.

Financial output:-intangible climate change resistance benefits, contribution in carbon sink and effective ecotourism-based monitoring.

Application of research findings

Mendora PPA in Samardha Range has served as a tiger breeding area for a decade. To strengthen conservation, it is proposed to link it with Chichli beat via adjoining revenue land and develop the Raja Bhoj Tiger Safari. Enclosing Mendora PPA, the linkage, and Chichli beat with a chain-link fence (totaling 1,744.7 ha) will create a functional safari area. This initiative will support long-term tiger conservation while generating livelihoods and enabling social monitoring.

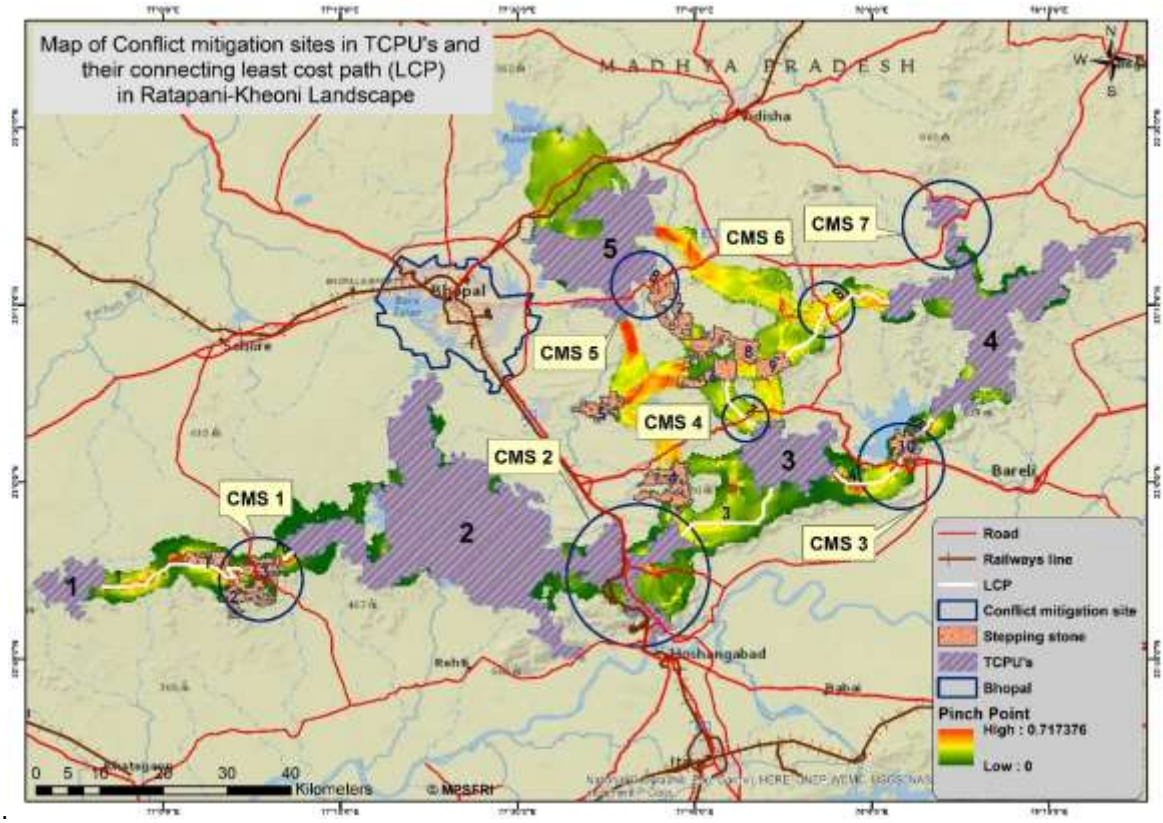


The proposed strategy aims to prevent tiger dispersal into Bhopal city by enclosing a 1,744.7-hectare area with a 32 km, 12-feet high fence as part of the Raja Bhoj Tiger Safari. This will reduce crop damage, loss of life, and poaching incidents. The safari will create ecotourism-based jobs for local villagers and promote wildlife conservation through community involvement. Located in a scenic forest near Bhopal, the area hosts rich biodiversity, including tigers, leopards, wolves, sloth bears, and various herbivores.

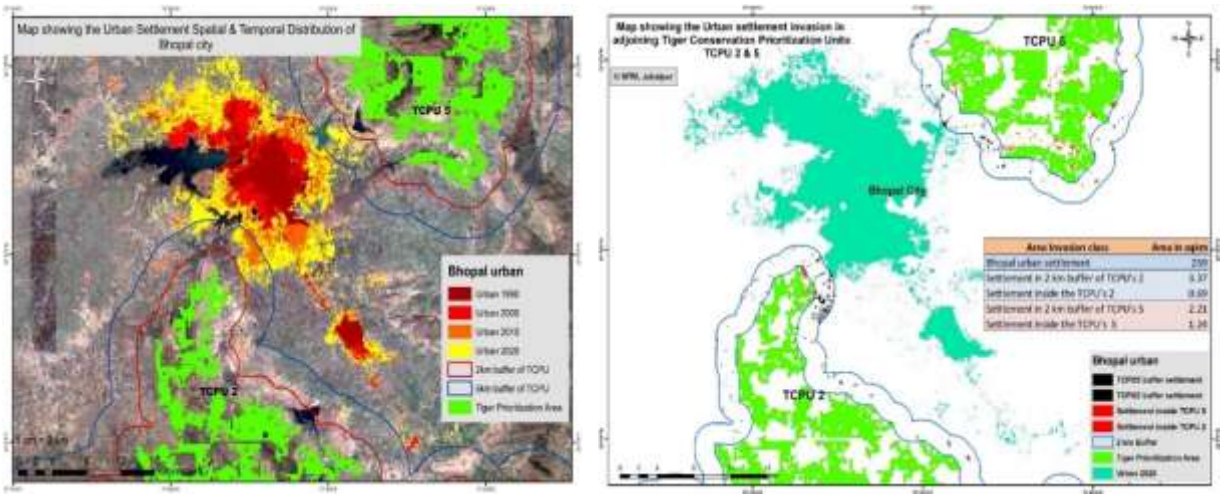
TCPU_2 and TCPU_5 near Bhopal offer high ecotourism potential. TCPU_2, adjacent to key water bodies like Kerwa and Kaliyasot dams, supports bird-watching and diverse wildlife. A 1,744.7-hectare Tiger Safari including Chichli and Mandora PPA, with a 32 km boundary, will enhance ecotourism and reduce conflict. Jungle Safari routes through 20 beats in Bhopal, Sehore, and Obedullaganj divisions will further expand opportunities. TCPU_5, rich in biodiversity and scenic grasslands, supports transient tigers and is ideal for reintroduction. It also offers scope for a Nature Interpretation Center and eco-education, creating livelihoods and supporting tiger conservation.
Enhanced conservation and surveillance will boost biodiversity and ensure safety near Bhopal's outskirts. This strategy offers a model for balancing wildlife coexistence with urban growth.

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

The selected methodology will serve as a critical decision-support tool for prioritizing key tiger conservation areas and will also provide essential baseline data for formulating a strategic human–wildlife conflict mitigation plan

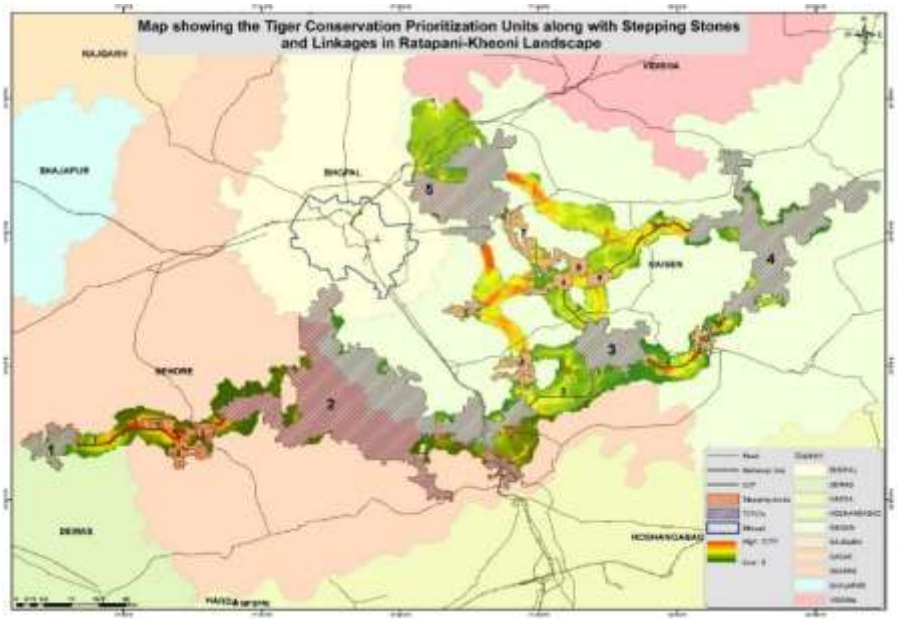


Urban expansion near Bhopal poses a growing threat to adjacent tiger habitats. To safeguard these ecosystems, it is essential to redirect human settlements away from forests through strategic green development. A 2 km green buffer around Tiger Conservation Prioritization Units (TCPUs) in the Bhopal Development Plan is recommended to reduce conflict and preserve habitat integrity. A detailed micro-plan for this buffer is critical for managing human–wildlife interactions and ensuring long-term conservation.



Tiger habitat suitability in the Vindhya range near Bhopal was assessed using the MaxEnt model, identifying 1,409 sq km of highly suitable habitat within a 5,312 sq km study area. This habitat spans the Bhopal, Sehore, Obedullaganj, and Raisen forest divisions. Next-Generation Sequencing (NGS) confirmed the presence of 19 unique tigers. Five Tiger Conservation Prioritization Units (TCPUs) have been delineated, connected by 8 linkages, including 10 stepping stones and pinch-point barriers.

Genetic analysis reveals limited relatedness between the Ratapani tiger population and other Central Indian populations like Kanha, Pench, and Satpura, with only some affinity to Bandhavgarh. Structure analysis indicates minimal shared ancestry. To enhance genetic exchange and population viability, strengthening corridor connectivity between Ratapani and areas like Nauradehi and Omkareshwar is recommended.



Conclusion:

The Vindhyan landscape study spanned approximately 5,312 sq. km. Historical records from the 1983–1998 Bhopal circle working plan reported 19 tigers based on the 1980 wildlife census. After a 35-year gap, the State Forest Research Institute (SFRI), Jabalpur confirmed the presence of 9 tigers via camera trapping in 2016. In our recent study (2018–19), Next-Generation Sequencing (NGS) of faecal DNA identified a minimum of 19 individual tigers, reaffirming the long-term persistence of a tiger population near Bhopal.

Genetic analyses revealed limited relatedness between the Ratapani tiger population and those of Satpura, Kanha, and Bandhavgarh Tiger Reserves. Structure analysis indicated minimal

shared ancestry, suggesting that Ratapani tigers are genetically distinct within the Central Indian landscape.

From December 2018 to April 2019, a tiger occupancy survey was conducted using Presence software v13.6. The landscape was divided into 83 grid cells of 64 sq. km each. Tiger signs were detected in 49 grids, resulting in a naïve occupancy estimate of 0.5904. Advanced modeling estimated potential tiger habitat occupancy at 3,762.48 sq. km (70.83% of the total study area), with a standard error of 482.34.

Traditional presence–absence approaches significantly underestimated occupancy by 59.04%, identifying only 3,136.20 sq. km as occupied. Among 44 candidate models, the Hines model was the best fit (lowest AIC = 1144.59). It identified cattle presence and rugged terrain as the most influential covariates (ψ = Cattle + Ruggedness), while detection probability (pt) was best explained by the presence of Nilgai and water sources.

Key ecological factors contributing to tiger habitat suitability included elevated rugged terrain, perennial water availability, and the presence of prey species—particularly cattle and Nilgai. While Nilgai are not typically preferred prey due to their agility and nocturnal activity, opportunistic predation was confirmed via camera trap evidence. Cattle, by contrast, were frequently predated upon, with multiple forest division records supporting these incidents.

Rugged landscapes provided natural shelters such as cliffs, rock overhangs, and dens, supporting tiger habitation. The consistent availability of feral and domesticated cattle has created an anthropogenically supported prey base, reinforcing tiger presence in the Ratapani-Kheoni landscape.

In conclusion, this study highlights the ecological resilience of tigers near Bhopal, the importance of refined occupancy modeling, and the critical role of anthropogenic factors—especially cattle—in sustaining the population. Enhanced conservation efforts should focus on managing livestock-wildlife interactions and improving habitat connectivity to ensure long-term viability.Wildlife-friendly, science-based land-use planning is essential for managing long-term human–wildlife interactions in the Vindhyan landscape near Bhopal. Key strategies include establishing buffer zones, modifying land use to support wildlife, and using guard animals or barriers to protect livestock and crops. Such measures can foster coexistence while preserving habitat integrity and biodiversity.

Details of Tiger Conservation Prioritization Units (TCPUs) GIS mapping of Ratapani Kheoni landscape:

1. TCPU with compartment and Villages TCPU_1, TCPU_2, TCPU_3, TCPU_4 and TCPU_5.

	TCPU	Area in sqe.km	Number of village	Name of village TCPU	Range	Beat	Compt.
1	TCPU1	50.99 km2	4	Khini Bujurg Dai Guwadiyabazyaft Nandakheda	Kheoni	Chikalpat, Doulatpur, Kalibai, Kheoni (E), Kheoni W, Kolari, Lalyakhedi, Nandadai, Roopadarh	RF-203,199,212,201, 200,209,213,214 210,204A, 208,198 204,205,207,191 206,195,194,196, 197,211
2	TCPU2	724.20 km2	32	Bhoot Palasi Nasipur Bawadiya Gondi Jabra Malkhar Karmoda Imaliya Gondi Loha Pathar Borda JhalPipali Kumhariya	Barkhera	Bagajhiri Barkhera Barrusot-I Barrusot-Ii Bhootpalasi Choka Divatiya Kairi Karmoda Pipaliya Kala	PF-982,983,980,981 965,970,975,976 977,978,979,940 941,942,943,944 948,949,950,945 946,947,971,974 964,966,967,968 951, RF-300,298,530,531 532,299,533,534

	TCPU	Area in sqe.km	Number of village	Name of village TCPU	Range	Beat	Compt.
				Chikalpani Magarpat Dhabla Khajuri Saras Semri Katkua Bineka Barkheda Harrai Sewaniya Parihar Khanpura Borda Kherichouka Bhura Kheda Goutampur Surai Dhaba Lawa Khadi Bamnai Mathar (Vangram) Jam Piplani Kalan Semra		Piplani Ratapani Tajpura	535
					Budhni	Bansapur Bhimkothi Budhani Jarrapur Saidganj Taalpura Uchakheda Yarnagar	PF643,641,642,640 RF623,624, PF639 RF634,635, PF637, 636,638,651,652 RF630,631,601,600 PF605, RF621
					Chilwaha	Uradmau Khamariya	RF492,493
					Dahod	Bamnai Bithori Dhabla Imalya Jawra Jhiri Karmai Kolar Kumhariya Malkhar Nishankheda PatharKansia Setu Barkhera Tumdakhera	PF 938,939,917,918,906 907,908,909,910,915 913,914,924,922,923 921,925,900,901,936 934,935,937,928,930 931,932,933,929,919 920,926,927,916,911 912,903,904,905,902 895,897,896 RF 536,301,302,305,306 307
					Delawari	Aamdo Bardha Delawadi Jamuniya Khajuri Naharkola North Mathar South Mathar	PF562,563,564,565,567 570,566B, 517,524,525 526,527,528 RF 529dw,531dw,532dw 577dw,551dw,552dw 553dw,554dw,548dw 549dw,550dw,555dw 556dw, 538,539dw 540dw,541dw,542dw 543dw,544dw,545dw 533dw, 537,534dw 535dw,536dw,546dw 547dw
					Icchawar	Dhaikheda	RF 267,253,266
					Ladkui	Bhurakheda Dabari Mograkheda Moyajhir Sirali	PF 460,459,458,461464, 462,466,468,465 RF 254,258,255,265,260 259,264,263,262,261
					Rehti	Banya Chatarkota Dhaba Khajuri Khanpura Ratanpur Semari	PF 488,490,489,491,523,521 522,520,519,518,571,572 573,575,574,568,569,566 RF 591,594,593,595,560,559
					Samardha	Bhanpur Chichli Gol Samaspura	PF 220,221,222,223 RF 214,215,216,217,218,219 210,212,213
					Sehore	Khari	RF 69

	TCPU	Area in sqe.km	Number of village	Name of village TCPU	Range	Beat	Compt.
					Veerpura	Amamay Borpani Charmandli Cheekalpani East Lohapathar Jhaleepali Kathotiya Lawakhadi Magarpath Saras Sevaniya Parihar Veerpura West Lohapathar	PF 63,507,511,510,509,508 502,506,505,503,504,342 349,341,340,343,348,346 347,345,344 RF 513,512,514,79,78,80,75,76 516,501,494,495,496,515 77,70,74,73,72,71,330,326 327,339,336,334,335,333 83,82,85,86,81,84,500 499,498,497
3	TCPU3	104.43 km2	5	Dant Kho MagardhaPipaliya Borkhadi Borpani Jaitpur	Barkhera	Mokalwada	RF 566,567,568,569,572,573
					Bineka	Bagaspur Borkhari East Dantkho Jaitpur Lulka Magardha North Dantkho Rampura Silari South Sajoli West Dantkho	PF 728,723,724,725 RF 446,441,477,461,462,463,454 455,456,457,440,452,453,442 443,458,459,460,444,448,450 451,470,471,472,473,474,475
					Goharganj	Karakwani	RF 565
4	TCPU4	301.48 km2	18	Khobi Kesali Kota Khajari Simariya Kalan Bhajiya Ghonti Bahra Suneti Ramgarh Borpani Mahalpur Patha Dagdaga Suagard Salahpur Surbarri Jaitgarh Patna Bhiladiya Gunjai Rajghati	Bamhori	Bajani Bhajiya Jaitgadh Kartoli Kukwara Pondri Ramgara Viran	RF 254,261,234,235,236,237,238 239,248,255,231,232,233,251 240,241,242,243,249,250,252 253
					Bari	Araskhera Bhartipur Chora Ghana Pali Dungariya Panjhirpa	PF 748 RF 524,521,517,518,519,520,522 523,276,277,278,279 UC -UC2
					Chilwaha	Behra Umrai	PF 765 RF 496
					Garhi	Borpani Dehganv Garhi A Garhi B Haidari Jamuniakala Jamuniakhas Karmodi Lilngava Mahalpurpatha Mudiyakhera Rampura Rasidpur Sarra Sehora	PF 107,101,988,989,102 RF 11,12,13,14,21,24,23,31,32,36 35,34,105,114,100,99,10,9,8,3 4,5,7,33,25,26,107,111,112 113,22,104,108,109,110,106

	TCPU	Area in sqe.km	Number of village	Name of village TCPU	Range	Beat	Compt.
					Sultanpur	Ghana(Berkhedi) GhotiBehra Santra	PF 743,744,755,756,757,751,752 754 RF 515,516
					West Silwani	Gajanda Khamaria Ramgarh Samnapur Simaria Singhpuri	RF 166,172,173,120,119,163,165 177,168,169,167,179,178
5	TCPU5	227.98 km2	19	Prempura Gopisur Satkunda Agriya Nayapura Agriya Choupda Bilarkhoh Sihora Imaliya Katsari Mushkabad Badoda Khamkheda Salera Bagod Bilkhiriya Kalan Geedgarh Sehadganj Silpuri Kharbai Sukasen Bankhedi	Chiklod	Makodiya	PF 770,771,772 RF 539
					Raisen West	Agaria Nayapura Bagod Baroda Sevasni Bhartipur Geedgarh Kharbai Mushkabad Piprai Sehatganj Sehora Tijalpur	PF 20,24,21,17,16,19,18,15,87 992,990,30,13,10,12,11,14,9 31,22,23,25,26,27,86A,86C RF 336,337,338,339,538,333 334,335,537,346,348,349
					Samardha	Amoni Kalyanpur Kanasiya North Padarya North Samardha Prampura South Samardha South Padariya	PF 194,195,190,191,197,198 RF 182,173,174,175,176,183,188 189,184,185,186,187,169,170 171,177,168,178,179,180,181

2. Stepping stones along with Compartment

Stepping stones	Division	Range	Compartment No.	LGL_STATUS	Beat Name
1	Sehore	Icchawar	238	RF	Dundalawa
			239	RF	Dundalawa
			240	RF	Dundalawa
			241	RF	Dundalawa
			231	RF	Balupat (East)
			232	RF	Balupat (W.)
			230	RF	Balupat (East)
			242	RF	Balupat (East)
			243	RF	Balupat (East)
			244	RF	Balupat (East)
			229	RF	Balupat (East)
2	Sehore	Ladkui	384	RF	Nayapura
			387	RF	Siradi
			388	RF	Siradi
			411	RF	Sankota
			385	RF	Sankota
			389	RF	Nayapura
			410	RF	Sankota
			412	RF	Rafikganj
			386	RF	Sankota

Stepping stones	Division	Range	Compartment No.	LGL_STATUS	Beat Name
			383	RF	Basantpur
			409	RF	Nayapura
			382	RF	Basantpur
			370	RF	Siradi
			372	RF	Ghutwani
			417	RF	Kosmi
3	Sehore	Icchawar	247	RF	Nadan
			250	RF	Nadan
			249	RF	Nadan
			248	RF	Nadan
			280	PF	Nadan
			251	RF	Dhaikheda
			252	RF	Dhaikheda
		Ladkui	418	RF	Durganayak
			421	RF	Durganayak
			419	RF	Durganayak
			417	RF	Kosmi
			420	RF	Durganayak
			416	RF	Kosmi
4	Obedullahganj	Barkhera	310	RF	Munhasa
			311	RF	Munhasa
			312	RF	Munhasa
			961	PF	Munhasa
			969	PF	Ratapani
		Goharganj	313	RF	Ghana
			314	RF	Ghana
			315	RF	Beelkheri
			316	RF	Beelkheri
			317	RF	Beelkheri
			318	RF	Sehora
			319	RF	Dhamdhusar
			843	PF	Sehora
5	Obedullahganj	Chiklod	816	PF	North Amarthon
			817	PF	North Amarthon
			818	PF	Bhojpur
			819	PF	Bhojpur
			330	RF	Ashapuri
			331	RF	Ashapuri
6	Obedullahganj	Chiklod	552	RF	Sonthar
			553	RF	Sonthar
			554	RF	Sonthar
			555	RF	Barbatpur
			796	PF	Maholi
			548	RF	Barbatpur
			549	RF	Barbatpur
			550	RF	Barbatpur
			797	PF	Maholi
7	Obedullahganj	Chiklod	543	RF	Barrukhar
			544	RF	Barrukhar
			768	PF	Maharmanga
	Raisen	Raisen East	34	PF	Neemkhera
			35	PF	Neemkhera
			37	PF	Neemkhera
			39	PF	Banchhod
			40	PF	Banchhod
			360	RF	Neemkhera

Stepping stones	Division	Range	Compartment No.	LGL_STATUS	Beat Name
			361	RF	Neemkhera
			362	RF	Neemkhera
			363	RF	Neemkhera
			364	RF	Neemkhera
8	Obedullahganj	Chiklod	546	RF	Barrukhar
			551	RF	Barbatpur
			552	RF	Sonthar
			547	RF	Barrukhar
	Raisen	Raisen East	41	PF	Banchhod
			42	PF	Banchhod
			43	PF	Veerpur
			44	PF	Veerpur
			46	PF	Veerpur
			47	PF	Veerpur
			48	PF	Veerpur
			365	RF	Nayapura
			366	RF	Nayapura
			368	RF	Nayapura
9	Obedullahganj	Chiklod	800	PF	Maholi
			801	PF	Maholi
		Chilwaha	426	RF	Karaghati
			427	RF	Arjani
			428	RF	Arjani
			429	RF	Arjani
			425	RF	Karaghati
	Raisen	Raisen East	50	PF	Gondra
			367	RF	Nayapura
10	Obedullahganj	Bari	286	RF	Bari
			287	RF	Bari
			288	RF	Bajeerganj
			289	RF	Bajeerganj
			290	RF	Bajeerganj
			527	RF	South Kandela

3. Linkage along with Compartment

Linkage	Division	Range		Compartment No.	LGL_STATUS	Beat Name
1	Sehore	Icchawar		214	RF	Bordikhurd
				235	RF	Bordikhurd
				213	RF	Bordikhurd
				236	RF	Bordikhurd
				237	RF	Dundalawa
				238	RF	Dundalawa
				212	RF	Bordikhurd
				239	RF	Dundalawa
				240	RF	Dundalawa
				241	RF	Dundalawa
				230	RF	Balupat (East)
				242	RF	Balupat (East)
				243	RF	Balupat (East)
				245	RF	Nadan
				244	RF	Balupat (East)
				247	RF	Nadan
				248	RF	Nadan
				246	RF	Nadan
	Dewas	Khategoan		233A	RF	Palasi
				225	RF	Ligapani

Linkage	Division	Range		Compartment No.	LGL_STATUS	Beat Name
				224	RF	Machwas
				230	RF	Ligapani
				231	RF	Khatamau
				232	RF	Palasi
				223	RF	Machwas
		Kheoni		215	RF	Patrani
				220	RF	Roopadarh
				222	RF	Roopadarh
				213	RF	Kheoni (E)
				221	RF	Roopadarh
				219	RF	Roopadarh
				214	RF	Kheoni (E)
				218	RF	Patrani
	Sehore	Ladkui		387	RF	Siradi
				366	RF	Pipilani
				368	RF	Pipilani
				369	RF	Pipilani
				370	RF	Siradi
				367	RF	Pipilani
				365	RF	Pipilani
2	Sehore	Icchawar		267	RF	Dhaikheda
				251	RF	Dhaikheda
				252	RF	Dhaikheda
				253	RF	Dhaikheda
				266	RF	Dhaikheda
		Ladkui		254	RF	Dabari
				255	RF	Dabari
				420	RF	Durganayak
				449	PF	Navalgaow
				450	PF	Navalgaow
3	Obedullahganj	Barkhera		573	RF	Mokalwada
				574	RF	Umariya
				575	RF	Umariya
				582	RF	Umariya
				583	RF	Umariya
				584	RF	Borpani
				585	RF	Borpani
				586	RF	Borpani
				588	RF	Pipaliyagoli
				589	RF	Amajhiri
				590	RF	Amajhiri
				591	RF	Amajhiri
				592	RF	Amajhiri
				594	RF	Amajhiri
				595	RF	Panjhir
				596	RF	Panjhir
				597	RF	Panjhir
				598	RF	Panjhir
				964	PF	Ratapani
				965	PF	Barrusot-I
				966	PF	Ratapani
				967	PF	Ratapani
				968	PF	Ratapani
				970	PF	Barrusot-I
				576	RF	Mokalwada
		Bineka		474	RF	West Dantkho

Linkage	Division	Range		Compartment No.	LGL_STATUS	Beat Name
	Sehore	Budhni		666	RF	Dungariya (B)
				667	RF	Dungariya (B)
				664	RF	Dungariya (A)
4	Obedullahganj	Bari		289	RF	Bajeerganj
				290	RF	Bajeerganj
				291	RF	Patni
				292	RF	Patni
				293	RF	Kevlajhir
		Bineka		463	RF	Jaitpur
				464	RF	North Neelgrah
				465	RF	North Neelgrah
				466	RF	North Neelgrah
				467	RF	South Neelgrah
				468	RF	South Neelgrah
				469	RF	South Neelgrah
				482	RF	South Dhunvani
				483	RF	South Dhunvani
				484	RF	South Dhunvani
				485	RF	North Dhunvani
				486	RF	North Dhunvani
				488	RF	Kamwali
				489	RF	Kamwali
				487	RF	North Neelgrah
5	Obedullahganj	Bari		285	RF	Bari
				286	RF	Bari
				287	RF	Bari
				524	RF	Araskhera
				525	RF	Araskhera
				526	RF	South Kandela
				528	RF	South Kandela
				284	RF	Bari
				527	RF	South Kandela
6	Obedullahganj	Chilwaha		496	RF	Behra
				400	RF	Umrai
				401	RF	Bharda
				402	RF	Bagwada
				403	RF	Bagwada
				404	RF	Bharda
				407	RF	Bhusimeta
				408	RF	Bhusimeta
				409	RF	Bhusimeta
				410	RF	Bhusimeta
				416	RF	Mahuakheda
				417	RF	Mahuakheda
				418	RF	Mahuakheda
				419	RF	Mahuakheda
				420	RF	Mahuakheda
				421	RF	Chandangora
				422	RF	Chandangora
				423	RF	Chandangora
				425	RF	Karaghati
				765	PF	Umrai
				766	PF	Bagwada
	Raisen	Garhi		4	RF	Mahalpurpatha
		Raisen East		50	PF	Gondra
				51	PF	Gondra

Linkage	Division	Range		Compartment No.	LGL_STATUS	Beat Name
				398	RF	Tikoda
				399	RF	Tikoda
7	Obedullahganj	Bineka		434	RF	Borkhari
				435	RF	Bineka
				437	RF	Bineka
				438	RF	Bineka
		Chiklod		554	RF	Sonthar
				325	RF	Dungariya
				326	RF	Dungariya
				796	PF	Maholi
				797	PF	Maholi
		Chilwaha		436	RF	Champaner
8	Raisen	Raisen East		35	PF	Neemkhera
				37	PF	Neemkhera
		Raisen West		27	PF	Sehora

Rani Kamlapati Fort is now a home of Delawadi tigers

Contiguous habitat of tiger around the Ginnor (Rani Kamlapati) Fort