Status and Distribution of Major Mammalian Fauna in the State of Madhya Pradesh

Final Report 2016

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

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Madhya Pradesh Forest Department

Wildlife Institute of India, Dehradun

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Madhya Pradesh Forest Department

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- Authors

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01

Introduction

Madhya Pradesh harbors more than 45 species of mammalian fauna (Wroughton 1913, Harshey and Chandra, 2001) which is about 10% of the India's wild mammals (Menon 2014). It broadly lies in Deccan Plateau, the largest biogeographic zone of India. Madhya Pradesh is the second largest state in India with an area of 3,08,245 km^2, covers almost 9.38% of geographical area of the country of which 25.13% is forested. It has the largest forest cover (77,462 km^2) among all the Indian states. It has 9 National Parks and 25 Wildlife Sanctuaries and 5 Tiger Reserves as Protected Areas which constitutes 3.25% of total geographic area.

It is home to several rare, endemic and endangered species, important from the conservation point of view. Madhya Pradesh shares some of the typical Indian fauna like chital, nilgai, black buck, four-horned antelope and the sloth bear along with some others like gaur, sambar and the barking deer that occur both in India and the South-East Asia (Prater 2005).

Apart from the forest and wildlife resources, Madhya Pradesh is also endowed with natural resources like minerals, fertile agro-climatic conditions and a network of rivers. There are ten river basins in Madhya Pradesh and the major rivers are Narmada, Tapti, Betwa, Chambal, Son, Mahanadi, Shipra, Kewai, and Johila. Madhya Pradesh has 11 different agro-climatic zones out of 25 Agro-climatic Zones in India. Madhya Pradesh has the only working diamond mine in India and has fourth position in coal production as well as third largest producer of cement in India. Being at the center of India, the state is well connected to the country's other corners, 425 trains pass through Madhya Pradesh daily with, 220 trains cross through the state capital Bhopal alone. Eighteen National Highways (5,193.57 km) traversing Madhya Pradesh along with the10,859 kms of State Highways.

Because of its diverse natural resources and good connectivity, Madhya Pradesh is rapidly developing as an industrial base for the economic growth of India. Madhya Pradesh is developing at an 11% economic growth rate (in 2013-14) when India recorded its second successive year of sub 5 % growth in GDP (gross domestic product). With the advent of the center's Smart Cities Mission, the Madhya Pradesh had proposed 7 cities (Bhopal, Indore, Gwalior, Jabalpur, Satna, Ujjain, and Sagar) to be far developed as smart cities of which Jabalpur, Ujjain, Gwalior had already been approved by the central government.

The state's forests and wildlife are threatened by human expansion, proliferation of urban sprawl, poaching of wild species, human wildlife conflict, unsustainable harvesting of the forest resources, human induced forest fires, mining, industrial development and infrastructure projects (Sharma *et al.* 2013, Dutta *et al.* 2015). These increasing developmental and infrastructural growth to support the growing economy posing a great threat of fragmentation and isolation of wild habitats in the

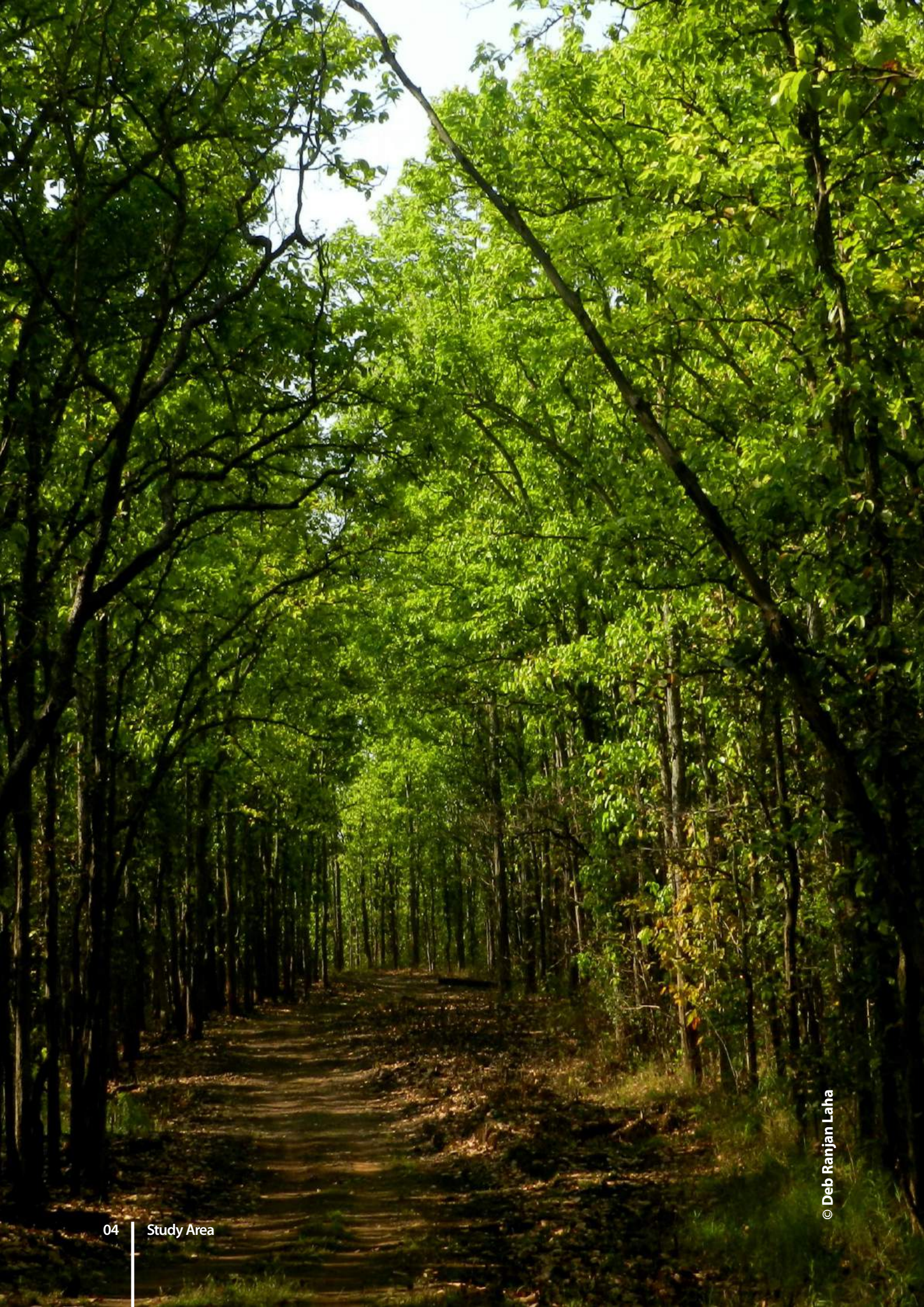
state (Dutta *et al.* 2015). The recent Indian State of Forest Report, 2015 stated that the forest cover of Madhya Pradesh has decreased by ~1% between 2013 and 2015 mainly because of encroachment, mining and felling of trees.

The state has three Class I and one Class III tiger conservation landscapes (TCL) of global priority for long term persistence of tigers (Dinerstein *et al*. 2006, Sanderson *et al*. 2006). The TCLs of Class I category, represent the best places to conserve tigers, which is meant for having more than or equal to 100 tigers with evident of breeding individuals, stable and diverse prey populations, minimal threats, and well connected between adjacent landscapes (Sanderson *et al*. 2006). And the Class III landscapes needs conservation effort above and beyond the next decade to bring them back to Class I status (Sanderson *et al*. 2006). These are Kanha- Phen, Pachmarhi - Satpura - Bori and Pench landscape (class I) and Panna East (Class III).

The state supports India's ~14% of tiger and ~23% of leopard population in the tiger range areas of the country (Jhala *et al*. 2015). The state has 15,156 km^2 tiger occupied forests which is about 17% of tiger occupied landscape in India. Few of the Protected Areas in Madhya Pradesh like Bandhavgarh, Kanha have tiger population with more than 50 individuals, which serve as major source populations ensuring the persistence of other metapopulations across the whole Central Indian Landscape. Since Madhya Pradesh is an important tiger range state hence the whole forested area of the state was sampled for all India tiger monitoring exercise during 2006, 2010 & 2014. This exercise provides the status of tiger and its prey in the forested landscape of the state.

Few other studies also had provided information on the status of large carnivores like tiger, leopard in some specific areas of the state. WWF- India has provided information on abundance of tiger and prey in the Kanha-Pench corridor (Jena *et al.* 2011), Phen Wildlife Sanctuary (Jena *et al.* 2014) and Panna landscape (Harsh *et al.* 2015). Wildlife Conservation Trust is working in Satpura Tiger Reserve, on the abundance tiger and its prey. The Wildlife Institute of India, Dehradun is conducting some long-term study on tiger and its prey at the source populations of Kanha, Pench, Panna and Sanjay Tiger Reserves. Apart from these areas, there is not much information available regarding the status, distribution and occupancy of other carnivores and ungulates across the state.

This report aims to provide the status and distribution of major mammalian carnivores and ungulates in the forests of Madhya Pradesh, through the information derived from Phase I, II, III and IV of the tiger monitoring exercises across the state. Unlike much of the previous research, we present the results on the abundance, distribution and status of all major ungulate and carnivore species and the underlying factors responsible for them on a fine spatial scale to directly assist on-going management practices.



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Study Area

The state is broadly divided into three biogeographic provinces viz., Gujarat-Rajputana (4B), Central Highlands (6A) and, Central Plateau (6D) (Rodgers and Panwar 1988). The Central Indian Highlands are a distinct province within the Deccan Peninsula zone, these highlands comprise of two parallel chains of hills viz., the Satpura and the Vindhya ranges, which run almost continuously from east to west and are separated by the river Narmada all along its course. The Satpura Maikal Landscape (SML) in the Central Indian Highlands is situated along the Satpura and Maikal hill ranges, between the Melghat Tiger Reserve in Maharashtra and the Achanakmar Tiger Reserve in Chhattisgarh. The landscape spans over 15 districts of three states, namely Madhya Pradesh, Maharashtra and Chhattisgarh.

Madhya Pradesh is administratively divided into 51 districts and these are further divided into 364 tehsils (Figure 1). Since civil administration e.g. Collectorate, Police etc. are in charge of revenue lands and law and order, it would prudent to know what wildlife resources are within the jurisdiction of each civil administrative units. The forests of Madhya Pradesh are administered as 72 forest divisions (Figure 2). Most of the source populations of endangered and threatened fauna are within the protected areas. However, the corridors that link the source populations often traverse territorial forests, revenue lands, and private lands (Figure 2). We therefore provide information of wildlife distribution and populations both at civil administrative units and within forest divisions.

2.1 Forest Types

The Central Highlands are primarily covered with tropical dry and moist deciduous forests. While teak *(Tectona grandis*) dominates the forest in the western and central parts of the region, an abundance of sal *(Shorea robusta*) forms the moist deciduous forests in the eastern ranges. North-eastern part of the Madhya Pradesh has forests dominated by stunted *Shorea robusta*, *Anogesius* spp. and *Acacia* spp. interspersed with several miscellaneous species. The southern half of the state has a Tectona grandis dominated drier forest association. Some of the natural grasslands, mostly those along river valleys, have now become agricultural lands while some other areas are of anthropogenic origin grasslands (e.g. old village sites or wastelands) being arrested by fire, tree cutting and livestock pressure (Qureshi *et al.* 2006).

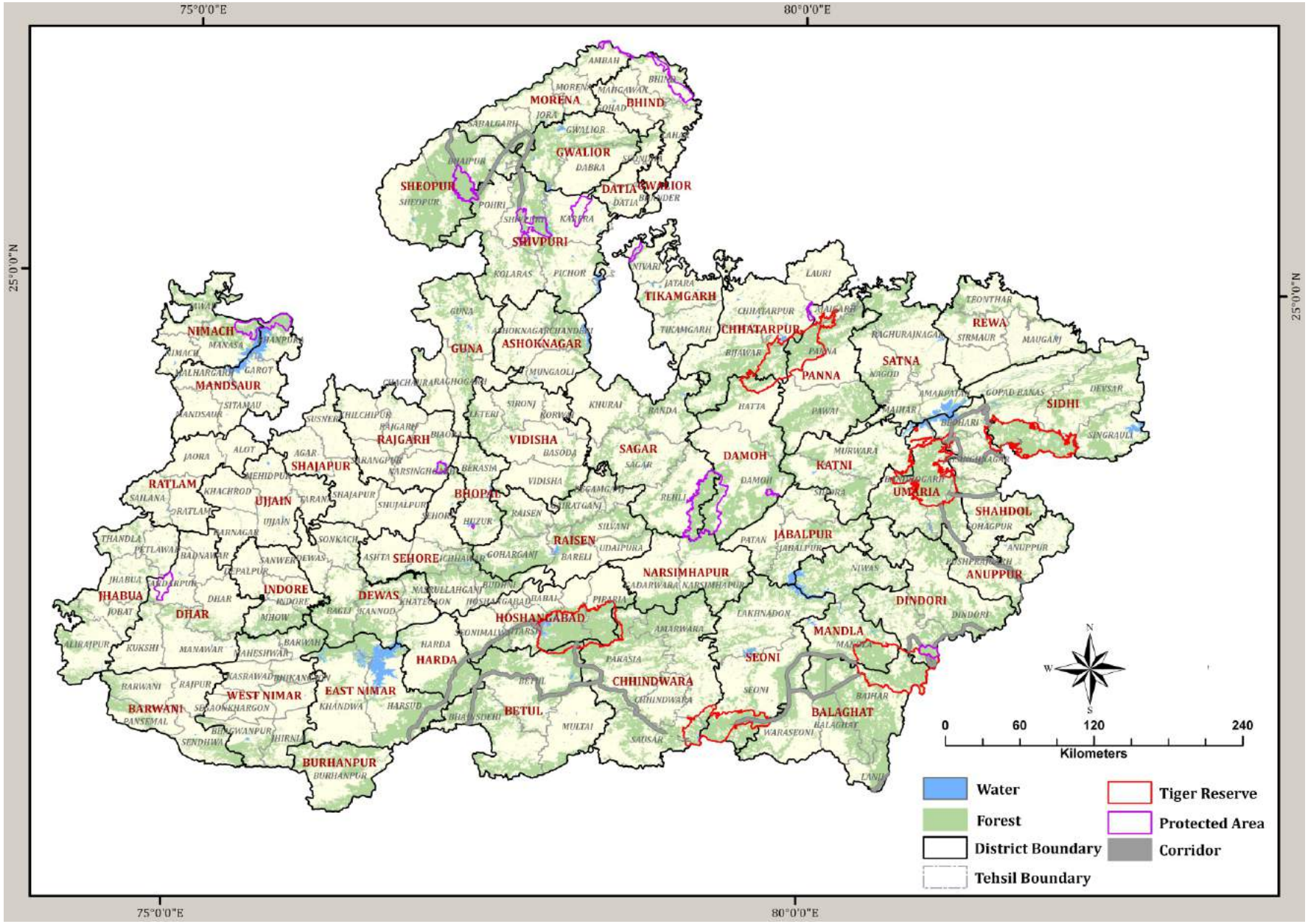

Figure 1 : Administrative boundary of districts & tehsils of Madhya Pradesh.

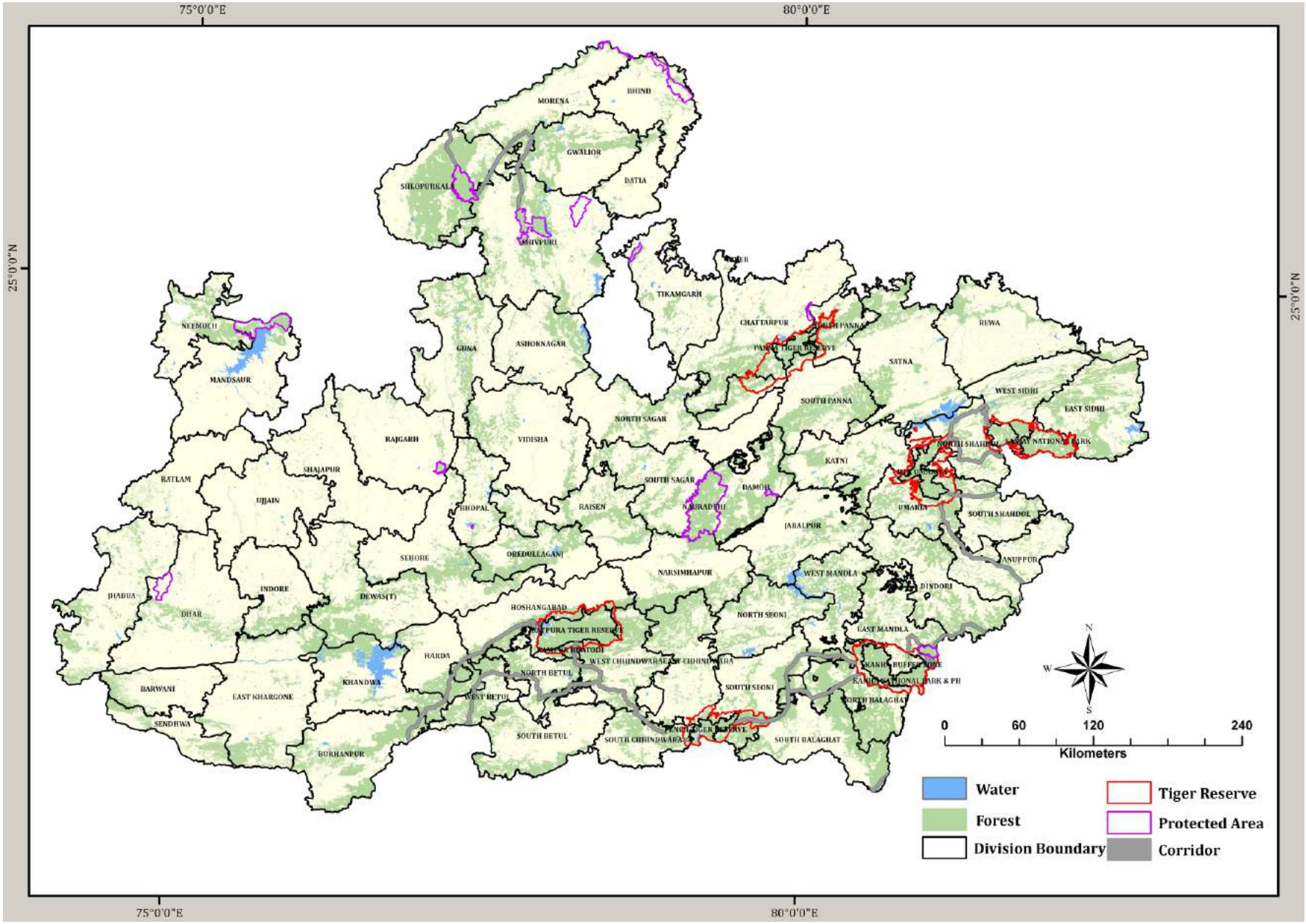

Figure 2: Administrative boundary map of forest divisions of Madhya Pradesh.

2.2. Forest Corridors

The forests corridors of Madhya Pradesh play a crucial role in maintaining biodiversity of central Indian landscape. Conservation of some endangered species is possible by maintaining metapopulation structure. Some important reserves that contribute to metapopulations of endangered species are Kanha-Pench, Pench-Satpura, Panna-Madhav-Kuno within the state of Madhya Pradesh, Kanha connects to Navegaon-Nagzira and Tadoba in Maharashtra and Achanakmar in Chattisgarh, Pench connects to Melghat in Maharashtra, Kuno connects to Ranthambore in Rajasthan, Satpura connects to Melghat in Maharashtra, and Bandhavgarh and Sanjay connects to Guru Ghasidas National Park in Chattisgarh. These corridors are vital for long term survival of wildlife population in Central India (Qureshi *et al.* 2014).

2.3 Mammalian Fauna

Madhya Pradesh is rich in mammalian biodiversity. The carnivore guild is large, consisting of the tiger *(Panthera tigris)*, leopard *(Panthera pardus)*, sloth bear *(Melursus ursinus)*, dhole *(Cuon alpinus)*, striped hyena *(Hyaena hyaena)*, jackal *(Canis aureus)*, wolf *(Canis lupus)*, jungle cat *(Felis chaus)*, wild cat *(Felis silvestris*), rusty spotted cat *(Prionailurus rubiginosus*), smooth coated otter *(Lutra percspicillata)*, Indian grey mongoose *(Herpestes edwardsii*), ruddy mongoose *(Herpestes smithii)*, common palm civet *(Paradoxurus hermaphrodites)* and oriental civet *(Viverricula indica)*. While the ungulate guild is comprised of gaur *(Bos gaurus)*, nilgai *(Boselaphus tragocamelus)*, sambar *(Rusa unicolor)*, chital *(Axis axis*), barking deer *(Muntiacus muntjak)*, blackbuck *(Antilope cervicapra)*, four horned antelope *(Tetracerus quadricornis)*, chinkara *(Gazella bennettii)*, mouse deer *(Moschiola indica*)and hard ground barasingha *(Rucervus duvaucelii branderi*). This report addresses some of these key species' fine scale distribution at 25 km^2 resolution and abundance.

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Methods

We followed the double sampling approach (Jhala *et al.* 2015) to estimate the distribution and abundance of tigers and leopard. The first component of the double sampling consists of ground surveys (Phase I) wherein the data is collected by the State Forest Department personnel: 1) trail surveys for occupancy of habitat patches by tiger, leopard and other carnivores 2) line transects to estimate prey abundance 3) sampling plots on the line transects to assess a) habitat characteristics, b) human impacts and c) prey dung density.

From recent remotely sensed data (Phase II) following variables a) landscape characteristics, b) human "foot-print", and c) habitat attributes were used to model tiger abundance and occupancy.

The second component (Phase III & IV) of the double sampling consists of scientifically rigorous abundance estimation in selected sampling units using a) remote camera trap based capture-recapture technique for estimating tiger and other carnivore abundance and b) line transect based Distance sampling for estimating prey abundance c) camera trap based habitat covariates and vegetation quantification on plots at each transect.

In the country wide status report (Jhala *et al.* 2015) distribution range of each species is provided as presence/ absence at 100 km^2 resolution. Here in we report relative abundance of each species at a 25 km^2 resolution by reanalysis of the data collected during Phase I.

3.1 Site specific camera trapping and line transect exercise

Camera trapping and line transect exercises conducted in Kuno and Phen Wildlife Sanctuaries, Kanha, Bandhavgarh, Pench, Panna and Satpura Tiger Reserves. The sampling details and individual site specific descriptions are given below.

Phen Wildlife Sanctuary: The Phen Wildlife Sanctuary spans across an area of 110.74 km^2 and was established in the year 1983. The sanctuary is located between 22^0 19' 11.6" N to 22^0 25' 15.2" N and 80^0 07' 19.2" E to 80^0 57' 26.0" E, known as a satellite micro core of the Kanha Tiger Reserve. The significance of Phen lies in that it provides a connective staging site for the corridor between the Kanha and Achanakmar Tiger Reserves. It's a home to the transient tigers of the Kanha-Achanakmar corridor.

Camera trapping operation was carried out from 16/02/2015 to 08/03/2015 in Phen which has an area of 110.74 km^2. A total of 96 camera trap stations were set up resulting in an effort of 1811 trap nights and to estimate prey density 19 transects were walked. Major carnivores photo captured were leopard, wild dog, sloth bear and jackal. Among ungulates chital, sambar, gaur, wild pig, and barking

deer are common. Additionally, here we found honey badger which was not recorded in Kanha Tiger Reserve earlier.

Kanha Tiger Reserve : Kanha is among the first nine Tiger Reserves launched during 1973-74, located between 22^0 01' 5.0" N to 27^0 27' 48.0" N and 80^0 26' 10" E to 81^0 04' 40.0" E , on the northern part of the Maikal hills of the Satpura in central Indian highlands. As per the biogeographic classification of India (Rodgers and Panwar, 1988), the area lies in zone 6A Deccan Peninsula-Central Highlands. It comes administratively in the Mandla and Balaghat districts of Madhya Pradesh. The tiger reserve harbours a mosaic of vegetation types including meadows and woodlands in the valleys, extensive grasslands on the plateaus, dense forests in the hilly tracts, and numerous perennial streams and ponds in the valley that supports swamp vegetation. The tiger reserve consists of a core zone, the critical tiger habitat of 917.43 km^2 which is a part of the national park (940 km^2) and the buffer zone (1134 km^2) is a multiple use area, consists of forest land, revenue land and private holdings (Negi and Shukla, 2010). The reserve is best known for conserving the three endangered species: tiger, hard ground barasingha, and wild dog.

A total of 1022 camera trap stations were set up in the core and buffer zones of Kanha Tiger Reserve between 19/02/2015 to 10/07/2015 (core) and 05/11/2014 to 14/02/2015 (buffer) in seven blocks, which has resulted in a cumulative effort of 23216 trap nights. A total of 230 transects (150 in core and 80 in buffer) were walked during this period.

Kuno Wildlife Sanctuary : Extended in the Vindhyan hill series, Kuno Wildlife Sanctuary situated in Sheopur district of Madhya Pradesh within the geographical extent 77^0 07' N to $77^0$26' N and 25^0 30' E to $25^0$53' E. It has two forest ranges, Palpur east and west with an area of 346.68 km^2 form the core area of the sanctuary. Six more ranges namely Moravan east and west, Sironi north and south, and Agara east and west surround the core, as buffer to the sanctuary. Kuno is connected to Ranthambore Tiger Reserve, Madhav National Park, and then to Panna Tiger Reserve through different corridor habitats.

Forest types are mainly Northern tropical dry deciduous forest (Champion and Seth, 1968) with the predominance of *Anogeissus pendula, Anogeissus latifolia, Acacia catechu, Boswelia serrata, Acacia leucophloea* etc.

Camera trapping and line transect exercise was conducted in June and July 2014 covering an area of 103.35 km^2 in Kuno Wildlife Sanctuary. A total of 117 camera-trap plots were sampled with the cumulative 2438 trap night efforts. Within the above said sampling period, photograph of an adult male tiger was obtained in six different trap locations. Thus, the density was not estimated for tiger in Kuno. Photographs of other fauna like sloth bear, golden jackal, striped hyena, honey badger, asian palm civet, spotted deer, nilgai, feral cattle, grey langur were also obtained during the sampling period. Total 78 transects were walked in Kuno for prey estimation.

Pench Tiger Reserve : Pench Tiger Reserve is located in the lower southern reaches of the Satpura hills and is named after the Pench River which is meandering through the Park from north to south. It is situated on the southern boundary of Madhya Pradesh in the districts of Seoni and Chhindwara. The core area of the tiger reserve includes Pench National Park (292.86 km^2) and Pench Mowghli Wildlife Sanctuary (118.47 km^2) and the buffer zone covers an area of 768.302 km^2. The total area of the reserve is 1179.632 km^2. It is located between $21^0$38' 55''N to 21^0 53' 52'' N and 79^0 08" 51'' E to 79^0 31' 55'' E. It lies along the border of Madhya Pradesh and Maharashtra, separated by a reservoir on the river Pench. The NH7 runs between Nagpur and Jabalpur along the eastern boundary of the reserve

for around 10 km and threatens to become a barrier for habitat connectivity with Kanha Tiger Reserve. Appropriate mitigation measures are needed for infrastructural development in this corridor to ensure maintenance of meta-population structure in this region. The mean annual rainfall is around 1400 mm and temperature varies from a minimum of 0°C in winters to 45°C in summers. The mean altitude is around 550 m above mean sea level.

Camera trapping operation was done in two blocks for a period of 67 days in an area of 299.69 km^2. A total of 234 camera trap stations were set up resulting in an effort of 8443 trap nights. Pench Tiger Reserve supports carnivores like tiger, leopard, wild dog, sloth bear, hyena, wolf and jungle cat. During this period, 60 line transects were also walked for ungulate density estimation. Among ungulates chital, sambar, gaur, wild pig, chowsingha and barking deer are common.

Satpura Tiger Reserve : Satpura Tiger Reserve comprising of Bori and Panchmari Wildlife Sanctuary is situated between 22^0 19' 28" N to 22^0 45' 30" N and $77^0$53' 48" E to 78^0 34' 0" E. Covering an area of more than 2100 km^2, this protected area is located in Hoshangabad district within Satpura hill ranges. Elevation of Satpura Tiger Reserve ranges from 320 m-1320 m above mean sea level (Borah *et al.* 2009).

Vegetation type of the reserve encompasses Southern moist mixed deciduous, Southern dry mixed deciduous, and Dry peninsular sal (Champion and Seth, 1968). A unique ecological phenomenon of that reserve is the occurrence of relict population of sal in predominant teak bearing area (Singh *et al.* 2001). Satpura proudly hosts 48 species of mammals, 258 species of avian fauna and 31 species of reptiles (Fellows 2015).

During December 2014 to March 2015 camera trapping and line transect exercises were conducted in two blocks. A total 276 camera locations were sampled over 77 occasions in both blocks with a cumulative sampling effort of 5868 trap nights. Major carnivores photo captured were tiger, leopard, wild dog, sloth bear and jackal. Small mammals like smooth coated otter and pangolin are also found here. Among the arboreal mammals, Indian Giant Squirrel and Indian Flying Squirrel are also present. Chital, sambar, gaur and wild pig are found common in 37 transects walked.

Bandhavgarh Tiger Reserve : Bandhavgarh Tiger Reserve lies between 23^0 30' 08" N to 23^0 57' 01" N and $80^0$47' 05" E to $81^0$11' 43" E with a total area of 1536.7 km^2. The core area is 716.46 $km^2$with a buffer of 820.15 km^2. Bandhavgarh Tiger Reserve consists of two conservation units: Bandhavgarh National Park (442.842 km^2) and the Panpatha Wildlife Sanctuary (245.842 km^2). The terrain of the tiger reserve is of rocky hills rising sharply from the swampy and densely forested valley in the low land. The Tiger Reserve has a diversity of herbivores and carnivore such as chital, sambar, nilgai, wild pig, barking deer, four-horned antelope, chinkara, tiger, leopard, dhole, sloth bear, stripe necked mongoose, etc. Gaur became locally extinct before 1995 due to loss of corridor. Last small population of gaur migrated out of Bandhavgarh before 1995 (Sankar *et al.* 2013). Fifty gaur were reintroduced from Kanha Tiger Reserve in 2011 (Sankar *et al.* 2013). The camera trapping was conducted in 580 km^2 area with an effort of 12836 trap nights. The quality of pictures was not good for leopard identification so further analysis was not done for leopard.

Panna Tiger Reserve : Panna Tiger Reserve is spread across Panna and Chhatarpur district and lies between 24^0 27' N to $24^0$46' N and 79^0 45' E to $80^0$09' E. With a core area of 542.66 km^2 this reserve is located in the Vindhyas within Central Highland biogeographic province (6A) (Rodgers *et al.* 2002).

Other than tiger, Panna sustains significant population of sloth bear, leopard, wild dog, striped hyena, sambar, chital, nilgai and numerous bird species and reptiles (Ramesh *et al.* 2013). The tiger population of Panna has been successfully reintroduced after the local extinction (WII 2009). Line transect exercise was done in Panna during December 2013 and January 2014. A total of 40 transects were walked during this period.

3.2 Occupancy Modelling

The problem of imperfect detection is addressed by carrying out the survey and the data analysis in an occupancy framework described by MacKenzie *et al.* (2002). The authors suggested a new method based on "detection-non-detection" of a species. The occupancy method allows the use of Proportion of area Occupied (POD) as a low-cost surrogate for species abundance. The occupancy model is based on the premise that changes in the proportion of area occupied by a species may be corresponding with changes in its population size. Presence/absence surveys can be conducted at a number of sites across a broad landscape, with the history of its presence/absence being maintained. The model allows building detection probability built over capture history of the species and also incorporates habitat covariates such as habitat types, forest type, vegetation composition and biotic influences to account for variation in detectability and occupancy. This also takes in to account variations in occupancy based on habitat characteristics. For a large-scale species survey, proportion of area occupied is a reasonable state variable to be used as suggested by Mackenzie *et al.* (2002, 2003, 2004) and Linkie *et al.* (2007).

Data from replicate ground surveys (Phase I) were transferred to 25 km^2 grids in a Geographic Information System. We used a grid of square cells to define survey sites for the occupancy model, and the objectives of our study were to estimate Probable Area Occupied (PAO) by animals. Since data from habitat, prey, and human foot print were likely to be correlated, we extracted Principal Components (PC's) from all covariates used in modelling occupancy of the target animals using IBM SPSS Statistics (Version 20). The PC's were then used as covariates to model occupancy which also accounted for imperfect detections (Yumnam *et al*. 2014). Detection probability of presence sign was likely to be a function of animal abundance and was therefore modelled with sign encounter rate as a covariate. Model selection and occupancy estimation was done in program PRESENCE (Version 10.9, MacKenzie *et al.* 2006) using Akaike Information Criterion (AIC). Since the grid size we used was small (25 km^2) in comparison to the home range of most large carnivores, our results of "occupancy" should be viewed as "habitat suitability". This analysis helps in understanding spatial extent of populations, factors that influence distribution and habitat connectivity between populations. Naive estimates of occupancy were also arrived at for major carnivores and herbivores.

Naive estimates of habitat occupied were calculated as the proportion of grid cells where tiger signs were recorded. Because occupancy methods explicitly estimate and account for the probability of detection (which is always <1), occupancy generated estimates are always greater than or equal to the naive estimate. Occupancy analysis focus on two parameters, *Psi* (Ψ) is the probability of a site is occupied by the target species, and *p* is the probability of detecting the species during the survey (Mackenzie *et al.* 2006). Detection histories were generated as a vector composed of a sequence of detections (1) and non-detection (0) for target animal presence in each spatial replicate. AIC was used to compare and select models (Burnham and Anderson, 1998).

3.3 Abundance Estimation of Carnivores

Tiger and leopard individuals were identified from the camera-trap pictures with the help of softwares (Extract-Compare for tigers and Hotspotter for leopard). The extracted flank photograph of an animal was used in these machine learning softwares to reliably and efficiently identify number of individuals. The matrix of tiger and leopard captures and the associated covariates were then used to model the density estimate in Spatially Explicit Capture Recapture (SECR) framework (Efford 2015).

Tiger and leopard density was estimated by using joint likelihood covariate model in SECR. Covariates used for the density estimation were tiger/leopard sign intensity, prey abundance, and human footprint index. The camera trapped sites where tiger and leopard densities were estimated by SECR as well as covariates were estimated (Phase I and Phase II) as training data to develop spatially explicit relationships in a joint likelihood framework between tiger/leopard spatial density and covariates. This model then predicted tiger/ leopard density in areas where camera trapping was not done but tiger/ leopard presence was detected.

Abundance estimates and density of tigers and leopards were provided at the country wide status report (Jhala *et al.* 2015). In this report we report density of tigers and leopards at a fine resolution of 5km x 5km (25 km^2) forested grids. For site specific management fine scale information is very important.

3.4. Abundance Estimation of Ungulates

We used distance sampling method to estimate the prey density of tiger in Madhya Pradesh. The data was analysed in two-step process. Initially, density and Effective Strip Width (ESW= W x P_a, where P_a is detection function) was calculated for each prey species in different habitats (sal, teak, grassland, scrubland and miscellaneous) by using the Phase III data (2014-15) collected by researchers from above mentioned Tiger Reserves and Wildlife Sanctuaries of Madhya Pradesh. This was estimated using Conventional Distance Sampling (CDS) approach (Buckland 2001) in program Distance (Version 6.2; Thomas 2010) for different habitat strata from the Phase III data collected by researchers. Data were grouped into appropriate intervals for each species to optimize the fit of detection function. The model with the lowest AIC value was selected as best fit model (Burnham and Anderson, 2002). An estimate of ESW is essential to convert the Encounter Rate (ER) to estimate abundance of ungulates (Jhala *et al.* 2008). Therefore, to calculate the final density of targeted prey species in respective habitat we used beat wise encounter rate of prey collected in the Phase I sampling. To estimate the final density, we used the formula $\hat{D}$= ER/ 2*ESW. Only beats present in 25 km^2 grid, which is occupied by targeted prey species were taken into account. Considering the principal prey species of tiger, density was estimated for chital, sambar, and gaur. Due to relatively less observations in sal and teak habitat, density of gaur is estimated only in miscellaneous habitat. To get reliable density estimate we removed the outliers that were more than 2 Standard Deviations (SD) from the data collected by the Forest Department.

In Results we report two estimates: those determined by 1) robust Distance Software analysis for transects where radial distance and animal bearing were recorded by a laser range finder and Suunto See through compass and 2) for transects where only encounter rates of ungulate species along with their group size were recorded (no distance and bearing recorded). The habitat specific ESW for each species obtained from (1) were used to compute density from (2). The results therefore provide crude estimates of abundance of ungulates across all forests of Madhya Pradesh.

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04

Occupancy and Abundance of Major Mammalian Fauna in Madhya Pradesh

4.1. Occupancy and Abundance Estimates of Carnivores

4.1.1 Occupancy and density estimates of tiger in Madhya Pradesh

The tiger, India's national animal, is a symbol that is an intrinsic part of our culture. Being at the top of the food chain, tigers are the specialized predators of large ungulates. Large carnivore species occur at naturally low densities which makes them particularly susceptible to extirpation and extinction (Lande 1988, Caughley 1994). Driven by synergistic impacts of habitat fragmentation, prey depletion and direct hunting (Karanth *et al.* 2004; Walston *et al.* 2010), tigers have suffered a global range contraction of 93% in the past two centuries (Dinerstein *et al.* 2007). The inclusion of the royal Bengal tiger to the list of endangered species in 1969 and later into the Red Data Book of the International Union for the Conservation of Nature and Natural Resources (IUCN) was due to an alarming decrease in numbers of free living tigers (Perry 1964, Gee 1964 and Seshadri 1968). The tiger has served as an effective flagship species in conserving wildlife and their habitats.

Occupancy estimate of tiger

To estimate the current status of tiger in Madhya Pradesh occupancy analysis was done from the Phase I data. Since many of the covariates are correlated with each other, principal components were extracted and the PC's were subsequently used as covariates for the occupancy models in PRESENCE. Seven principal components explained 62% of the variance of the original variables. The component loading were ecologically explainable as shown in the Table 1. The first component represents different covariates related to the abundance of major prey like chital, sambar. Second component represents terrain and vegetation of the area. Third component explains covariates related to human disturbance in that area. Fourth and fifth components involve abundance of minor prey like chinkara, nilgai, wildpig and barking deer. Sixth component represents the wilderness and protected habitat of the area and the last component includes abundance of forest prey species gaur.

Table 1: Principal component loadings after varimax rotation of covariates From Madhya Pradesh

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Pellet Count of Chital	0.832	0.067	-0.002	0.138	0.065	0.049	-0.022
Encounter Rate of Chital	0.825	0.03	0.007	0.038	0.062	0.008	-0.061
Pellet Count of Sambar	0.734	0.084	-0.044	0.109	0.116	0.113	0.263
Encounter Rate of Sambar	0.651	0.041	-0.029	0.072	0.127	0.04	0.337
Distance from Protected Areas	-0.453	-0.009	0.16	-0.148	-0.004	-0.436	-0.177
Ruggedness	-0.028	0.9	-0.009	-0.079	0.05	0.078	0.099
Elevation	-0.045	0.869	-0.097	-0.04	0.051	-0.115	0.054
Mean NDVI for Post-monsoon	0.256	0.69	0.01	-0.055	0.076	0.454	-0.014
Mean NDVI for Pre-monsoon	0.354	0.621	-0.023	-0.044	0.047	0.388	0.012
People Seen	-0.053	-0.031	0.865	0.025	-0.032	-0.092	0.022
Livestock Seen	-0.032	-0.074	0.848	0.091	0.011	-0.004	0.012
Human Tail	-0.016	0.025	0.802	0.119	0.087	0.064	-0.056
Pellet Count of Chinkara	0.091	0.029	-0.019	0.786	-0.03	0.05	-0.04
Encounter Rate of Chinkara	-0.042	-0.008	-0.02	0.745	-0.034	0.1	-0.065
Pellet Count of Nilgai	0.244	-0.191	0.244	0.64	0.128	0.082	0.036
Encounter Rate of Nilgai	0.087	-0.285	0.346	0.515	0.115	0.034	0.076
Pellet Count of Wild Pig	0.307	0.086	0.111	0.395	0.213	-0.177	0.135
Encounter Rate of Barking Deer	0.003	-0.004	0.036	-0.018	0.826	0.096	0.017
Pellet Count of Barking Deer	0.18	0.134	-0.015	0.057	0.711	0.065	0.081
Encounter Rate of Wild Pig	0.305	0.038	0.148	0.377	0.448	-0.051	0.062
Core Area	0.175	0.124	-0.033	0.081	0.099	0.7	0.117
Nightlights Area	0.076	-0.034	-0.02	-0.016	-0.008	-0.474	0
Canopy Cover	0.284	0.352	0.313	0.114	0.248	0.392	-0.043
Pellet Count of Gaur	0.097	0.039	-0.012	0.002	0.014	0.062	0.792
Encounter Rate of Gaur	0.155	0.063	0.006	-0.024	0.086	0.06	0.774
% Variance Explained	12.739	10.961	9.858	9.058	6.418	6.157	6.076
Cumulative % Variance	12.739	23.7	33.558	42.616	49.034	55.191	61.267

PC1 = Abundance of major prey like chital, sambar
PC2 = Terrain and vegetation of the area
PC3 = Human disturbance
PC4 = Abundance of minor prey like chinkara, nilgai,
PC5 = Abundance of minor prey like wildpig and barking deer
PC6 = Wilderness and protected habitat of the area
PC7 = Abundance of forest prey species gaur

As per best model for tiger occupancy Ψ (*Psi*) was best explained by PC1+PC2+PC3+PC5+PC6+PC7 variables while detection probability *p* was explained by encounter rate of tiger sign. The naïve occupancy (Ψ) that is generated without using the occupancy framework was found to be 6.65% of the sampled landscape was detected to have tigers. By correcting for non detection final parameter of occupancy (Ψ) was estimated to be 8.1 (±0.4). The probability of detecting (*p*) tiger presence, if

present at a replicate was estimated to be 0.08 (±0.005). From the coefficients of the best model it is clear that human disturbance had a negative effect on the presence of tiger while abundance of large prey and canopied forest had positive effect on tiger occupancy.

Table 2: Competing models tested and model selection using AIC for modelling tiger occupancy in Madhya Pradesh

Model	AIC	Δ AIC	AIC wgt	No. of Parameters	-2*Log (likelihood)
Ψ(PC1+PC2+PC3+PC5+PC6+ PC7), p(zlntigps)	4171	0	0.461	9	4153
Ψ(PC1+PC2+PC3+PC5+PC6), p(zlntigps)	4172.07	1.07	0.27	8	4156.07
Ψ(PC1+PC2+PC3+PC4+PC5+PC6+ PC7), p(zlntigps)	4173	2	0.1696	10	4153
Ψ(PC1+PC2+PC3+PC4+PC5+ PC6), p(zlntigps)	4174.07	3.07	0.0993	9	4156.07
Ψ(PC1+PC2+PC3+PC4+PC5), p(zlntigps)	4254.89	83.89	0	8	4238.89
Ψ(PC1+PC2+PC3),p(zlntigps)	4263.83	92.83	0	6	4251.83
Ψ(PC1+PC2+PC3+PC4),p(zlntigps)	4265.8	94.8	0	7	4251.8
Ψ(.),p(zlntigps)	4556.63	385.63	0	3	4550.63
Ψ(.),p(.)	6840.42	2669.42	0	2	6836.42

PC1 = Abundance of major prey like chital, sambar
PC2 = Terrain and vegetation of the area
PC3 = Human disturbance
PC4 = Abundance of minor prey like chinkara, nilgai,
PC5 = Abundance of minor prey like wildpig and barking deer
PC6 = Wilderness and protected habitat of the area
PC7 = Abundance of forest prey species gaur
zlntigps = Encounter rate of tiger sign

Table 3: Coefficient of the best model explaining tiger occupancy in Madhya Pradesh

Variables	Estimate	Standard Error (SE)
A1 Ψ	-1.77	0.158
A2 Ψ.PC1	1.727	0.176
A3 Ψ.PC2	0.51	0.108
A4 Ψ.PC3	-0.57	0.124
A5 Ψ.PC5	0.33	0.095
A6 Ψ.PC6	0.869	0.108
A7 Ψ.PC7	0.164	0.109
B1 P[1]	-2.584	0.089
B2 P[1].ZLNErTigPS	1.369	0.055

PC1 = Abundance of major prey like chital, sambar
PC2 = Terrain and vegetation of the area
PC3 = Human disturbance
PC5 = Abundance of minor prey like wildpig and barking deer
PC6 = Wilderness and protected habitat of the area
PC7 = Abundance of forest prey species gaur
ZLNErTigPS = Encounter rate of tiger sign

The spatial conditional occupancy model of tiger presence in the study area is as shown in Figure 3. In this map, the grid where the tiger sign was detected was assigned a score of 1 (red colour). In grids where tiger sign was not detected the occupancy probability Ψ value is plotted. This map needs to be interpreted as a habitat suitability map for tigers in Madhya Pradesh showing where tigers are present and the potential areas they can occupy as the resolution is much smaller than the average home range size of tigers i.e. 25 km^2.

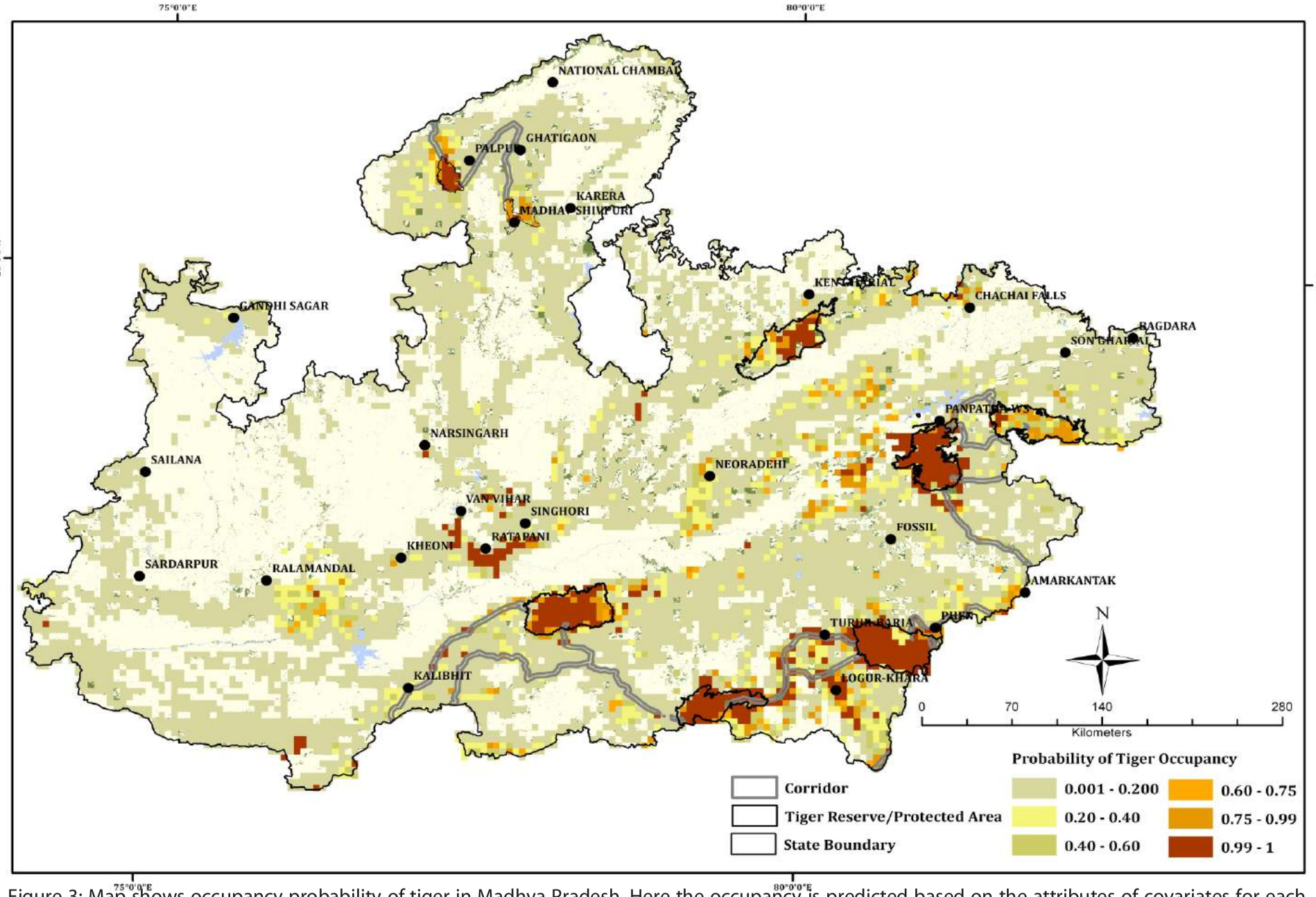

Figure 3: Map shows occupancy probability of tiger in Madhya Pradesh. Here the occupancy is predicted based on the attributes of covariates for each sampled grid after accounting for imperfect detection

Abundance estimate of tiger

The best model selected on the basis of AIC had tiger sign intensity, human disturbance index and prey abundance index as covariates (Table 4 & 5). Tiger density was higher in the southern districts of Madhya Pradesh (Figure 4). High tiger density was observed in Umaria, Shahdol, Sidhi, Mandla, Balaghat, Seoni, Chindwara, Hoshangabad, Raisen, Bhopal, Sehore, Panna, Chattarpur districts. Maximum tiger number was estimated in Bandhogarh tehsil of Shahdool district followed by Mandla tehsil of Mandla district. Tehsil-wise estimation also suggests large tiger population in Seoni tehsil of Seoni and Baihar tehsil of Balaghat district. Kanha-Pench corridor cut across these tehsils. Tiger presence was also recorded from Goharganj tehsil of Raisen, Budhni and Ichhawar of Sehore district. However no signs were recorded Bandhavgarh-Achanakmar corridor which spans through Anuppur district. This suggests poor functional connectivity of this corridor. Isolated presence of tiger was found in districts like Sheopur, Sagar, Jabalpur, Dewas and Burhanpur. Sheopur and Burhanpur are connected to neighboring state of Rajasthan and Maharashtra respectively, rest of the isolated occurrence of tigers is prone to risk extinction due to lack of connectivity. Tehsil-wise estimation of tiger is given in Table 6.

Table 4: Model selection for tiger density estimation using covariates in Spatially Explicit Capture Recapture (SECR) for Central Indian & Eastern Ghat Landscape

Model	Detection Function	No. of Parameters	Log Likelihood	AIC	ΔAIC
D~tigps + hl + PreyER	Halfnormal	6	-14181.55	28375.09	0
D~tigps + PreyDung + PreyER	Halfnormal	6	-14181.84	28375.69	0.6
D~tigps + PreyER	Halfnormal	5	-14183.21	28376.41	1.32
D~tigps + PreyDung	Halfnormal	5	-14188.58	28387.17	12.08

hl = Human disturbance index, tigps = tiger sign index, PreyER = Wild Prey Encounter rate
AIC= Akaike Information Criterion

Table 5: Model coefficients of best covariate model for estimating tiger density in Central Indian & Eastern Ghat Landscape.

Parameter	beta	SE.beta
Density	-8.882	0.082
tigps	0.258	0.028
hl	-0.229	0.138
preyER	0.194	0.051
g0	-4.452	0.025
Sigma	7.992	0.011

hl = Human disturbance index, tigps = tiger sign index, PreyER = Wild Prey Encounter rate

Table 6: Tiger numbers in Tehsils of Madhya Pradesh in 2014

District	Tehsil	Tiger Population	Lower SE limit	Upper SE limit
Balaghat	Baihar	36	31	40
Balaghat	Balaghat	9	6	12
Balaghat	Lanji	1	1	1
Balaghat	Waraseoni	5	5	5
Betul	Betul	3	3	4
Betul	Bhainsdehi	1	1	2
Bhopal	Huzur	1	1	1
Chhatarpur	Bijawar	4	3	4
Chhatarpur	Chhatarpur	1	1	1
Chhindwara	Amarwara	5	4	5
Chhindwara	Parasia	5	4	5
Chhindwara	Sausar	13	11	15
Dewas	Bagli	0	0	0
East Nimar	Burhanpur	2	2	2
Hoshangabad	Babai	0	0	0
Hoshangabad	Harda	4	3	5
Hoshangabad	Itarsi	0	0	0
Hoshangabad	Piparia	10	8	12
Hoshangabad	Seonimalwa	1	1	1
Hoshangabad	Sohagpur	14	12	17
Jabalpur	Jabalpur	0	0	0
Jabalpur	Murwara	4	3	4
Jabalpur	Patan	0	0	0
Mandla	Dindori	1	1	1
Mandla	Mandla	55	47	62
Morena	Bijaipur	1	0	2
Morena	Sheopur	0	0	0
Narsimhapur	Gadarwara	1	1	1
Narsimhapur	Narsimhapur	0	0	0
Panna	Ajaigarh	0	0	0
Panna	Panna	12	11	13
Panna	Pawai	0	0	0
Raisen	Bareli	0	0	0
Raisen	Goharganj	8	8	9
Raisen	Raisen	1	1	1

Table 6: Contd.

District	Tehsil	Tiger Population	Lower SE limit	Upper SE limit
Sagar	Banda	1	1	1
Sagar	Khurai	0	0	0
Sagar	Sagar	0	0	0
Sehore	Budhni	3	3	3
Sehore	Ichhawar	2	2	2
Sehore	Nasrullahganj	0	0	1
Sehore	Sehore	1	1	1
Seoni	Seoni	37	31	44
Shahdol	Bandhogarh	57	49	64
Shahdol	Beohari	2	2	2
Shahdol	Jaisinghnagar	1	1	2
Shahdol	Pushprajgarh	0	0	0
Sidhi	Gopad Banas	6	5	7
Sidhi	Singrauli	0	0	0
Total		**308**	**264**	**352**

Looking at the division-wise distribution of tiger (Table 7 & Figure 5), the scant presence of tiger in forests between Satpura, Kanha and Bandhavgarh Tiger reserves is a concern because of lack of connectivity. The forest patch of North Sagar and South Sagar, Damoh, South Panna and Satna are disjoint due to major settlements. A major focus on these forests is required to restore tiger habitat and provide connectivity between North and South of Narmada. The highest number of tiger was found in Kanha National Park.

Table 7: Tiger numbers in Forest Divisions of Madhya Pradesh

Division	Tiger Number	Lower SE limit	Upper SE limit
Anuppur	0	0	0
Bhopal	2	2	2
BTR Umariya	40	34	46
Burhanpur	2	2	2
Chattarpur	2	2	2
Dewas (T)	0	0	0
Dindori	1	1	1
East Chhindwara	3	3	3
East Mandla	7	5	8
East Sidhi	0	0	0
Harda	3	2	3
Hoshangabad	5	4	6
Jabalpur	0	4	0

Table 7: Contd.

Division	Tiger Number	Lower SE limit	Upper SE limit
Kanha Buffer Zone	11	16	12
Kanha National Park & Phen	62	45	69
Katni	3	2	4
Lamta Project	2	1	2
Mohgaon Project	1	1	1
Narsimhapur	1	1	1
Non Forest	3	3	3
North Balaghat	9	6	10
North Betul	1	1	1
North Panna	4	4	5
North Sagar	1	1	2
North Shahdol	3	3	4
Obedullaganj	9	8	10
Panna Forest Division	8	14	9
Pench Forest Division	25	13	30
Raisen	1	1	1
Rampur Bhatodi	1	1	1
Sanjay National Park	5	6	6
Satpura Forest Division	13	8	17
Sehore	5	4	6
Sheopurkala	1	1	2
South Balaghat	11	10	12
South Betul	2	3	3
South Chhindwara	3	2	3
South Panna	3	6	3
South Seoni	20	14	24
South Shahdol	1	7	1
Umaria	25	15	27
West Betul	0	1	0
West Chhindwara	6	5	6
West Mandla	2	2	3
West Sidhi	1	0	1
Total	**308**	**264**	**352**

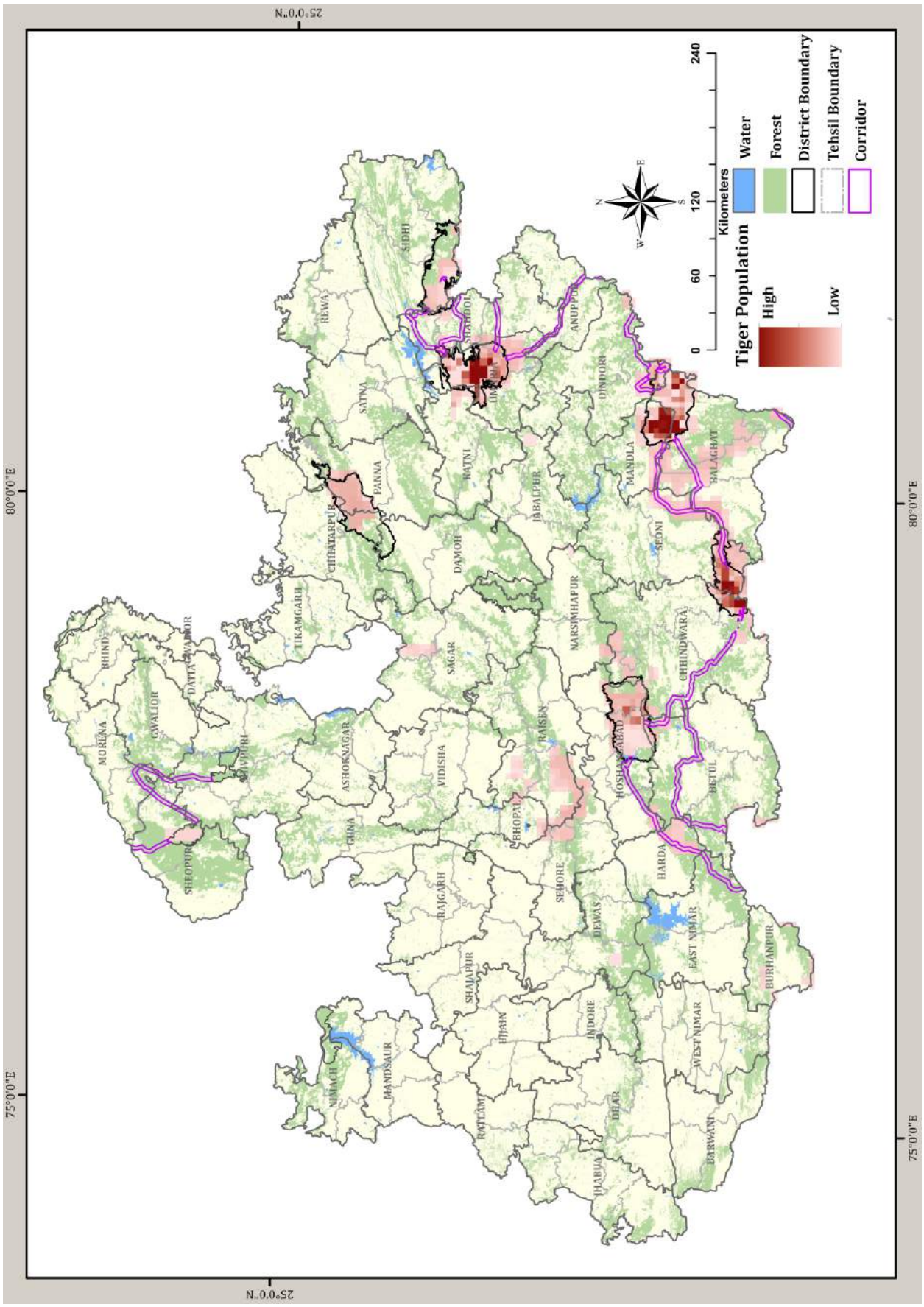

Figure 4: Tiger density overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh

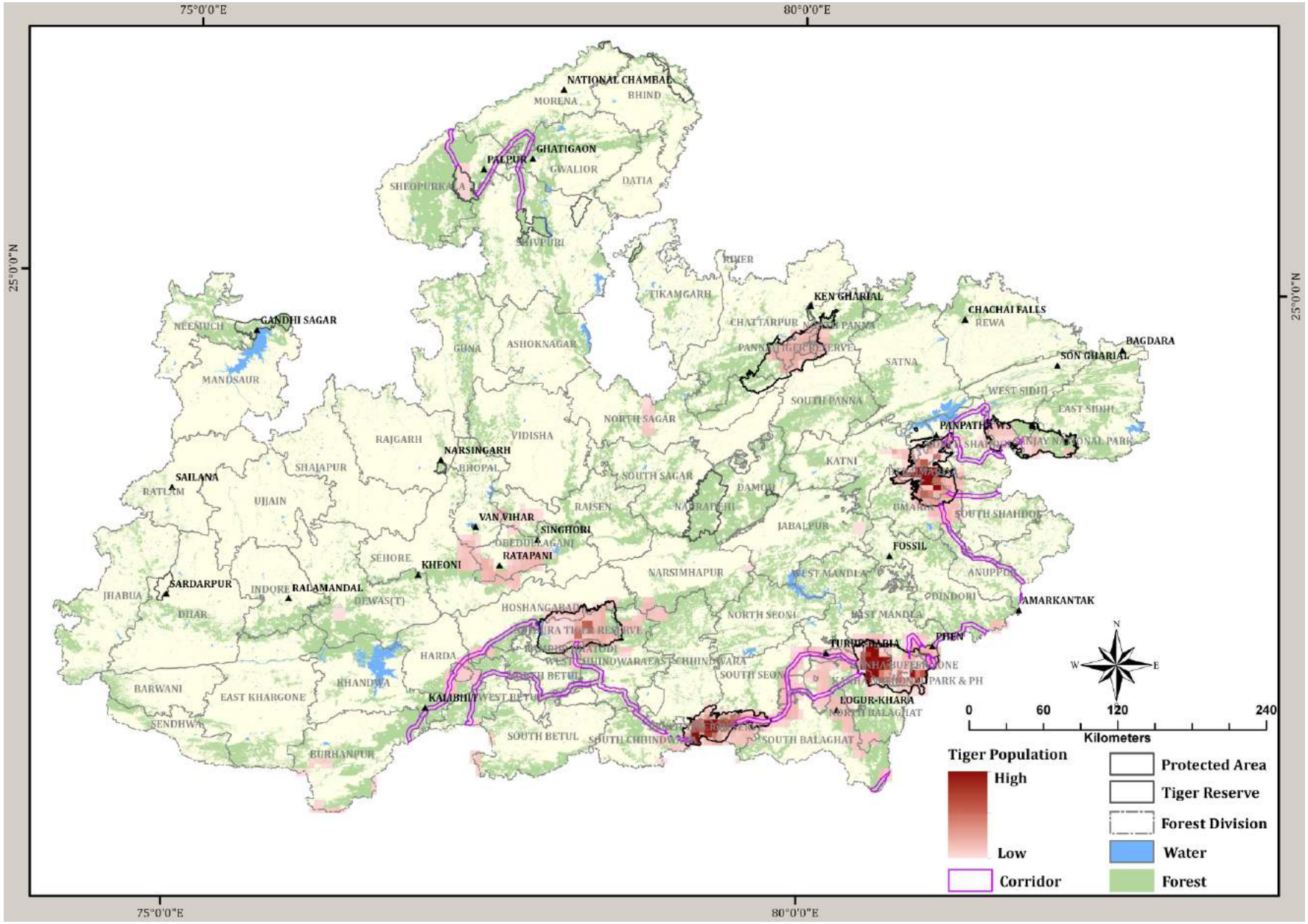

Figure 5: Tiger density overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

4.1.2 Occupancy and density estimates of leopard in Madhya Pradesh

The leopard has had the reputation of being one of the least studied of the large carnivores despite being the most abundant (Hamilton 1976). Leopards (*Panthara pardus*) have widest geographic distribution of all felids and achieve this feat by their flexibility of habitat choice (Boitani *et al.* 1999) and having a varied diet (Hayward *et al.* 2006b). The sparse information on leopards in the Indian subcontinent has mostly come from studies that focused on the tiger (Karanth & Sunquist 1995, 2000; Sunquist 1981) or the lion (Chellam 1993). The Indian subspecies, *Panthera pardus fusca*, is found in all forested habitats in the country, absent only in the arid deserts and above the timber line in the Himalayas (Prater 1980). The leopard is quite adaptable with respect to habitat and food requirements, being found in intensively cultivated and inhabited areas as well as near urban development (Nowell & Jackson 1996). There are frequent reports of leopards from many human dominated landscapes across India where it is involved in severe human-wildlife conflicts (Athreya *et al.* 2013). Leopards may not be as adversely affected as tigers under deteriorating habitat conditions (Ramakrishnan *et al.* 1999), the continual loss of habitat and intense poaching for illegal trade in body parts (Environmental Investigation Agency (EIA) and Wildlife Protection Society of India (WPSI) 2006) has caused a decline in their population. It is listed as a species of vulnerable by the IUCN red list. In India, however, it is listed in Schedule I of the Indian Wildlife (Protection) Act, 1972, under the highest level of protection. This is because poaching for skins, bones and claws, habitat destruction, loss of wild prey and poisoning carcasses of livestock killed by leopards are a significant threat to the species.

Occupancy estimate of leopard

Occupancy estimates of leopard in Madhya Pradesh done by using Phase I data in the software PRESENCE. Since there were many covariates which were correlated with each other, principal components were extracted and the PC's were used subsequently for the occupancy models. Seven principal components explained 61% variation of the original variables. The component loading were ecologically explainable as shown in the Table 8. The first component represents different covariates related to the abundance of major prey like chital, sambar. Second component represents terrain and vegetation of the area. Third component explains covariates related to human disturbance in that area. Fourth and fifth components involve abundance of minor prey like chinkara, nilgai, wildpig and barking deer. Sixth component represents the wilderness and protected habitat of the area and the last component includes abundance of a forest prey species gaur.


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Table 8: Principal component loadings after varimax rotation of covariates From Madhya Pradesh

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Pellet Count of Chital	0.832	0.067	-0.002	0.138	0.065	0.049	-0.022
Encounter Rate of Chital	0.825	0.03	0.007	0.038	0.062	0.008	-0.061
Pellet Count of Sambar	0.734	0.084	-0.044	0.109	0.116	0.113	0.263
Encounter Rate of Sambar	0.651	0.041	-0.029	0.072	0.127	0.04	0.337
Distance from Protected Areas	-0.453	-0.009	0.16	-0.148	-0.004	-0.436	-0.177
Ruggedness	-0.028	0.9	-0.009	-0.079	0.05	0.078	0.099
Elevation	-0.045	0.869	-0.097	-0.04	0.051	-0.115	0.054
Mean NDVI for Post-monsoon	0.256	0.69	0.01	-0.055	0.076	0.454	-0.014
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People Seen	-0.053	-0.031	0.865	0.025	-0.032	-0.092	0.022
Livestock Seen	-0.032	-0.074	0.848	0.091	0.011	-0.004	0.012
Human Tail	-0.016	0.025	0.802	0.119	0.087	0.064	-0.056
Pellet Count of Chinkara	0.091	0.029	-0.019	0.786	-0.03	0.05	-0.04
Encounter Rate of Chinkara	-0.042	-0.008	-0.02	0.745	-0.034	0.1	-0.065
Pellet Count of Nilgai	0.244	-0.191	0.244	0.64	0.128	0.082	0.036
Encounter Rate of Nilgai	0.087	-0.285	0.346	0.515	0.115	0.034	0.076
Pellet Count of Wild Pig	0.307	0.086	0.111	0.395	0.213	-0.177	0.135
Encounter Rate of Barking Deer	0.003	-0.004	0.036	-0.018	0.826	0.096	0.017
Pellet Count of Barking Deer	0.18	0.134	-0.015	0.057	0.711	0.065	0.081
Encounter Rate of Wild Pig	0.305	0.038	0.148	0.377	0.448	-0.051	0.062
Core Area	0.175	0.124	-0.033	0.081	0.099	0.7	0.117
Nightlights Area	0.076	-0.034	-0.02	-0.016	-0.008	-0.474	0
Canopy Cover	0.284	0.352	0.313	0.114	0.248	0.392	-0.043
Pellet Count of Gaur	0.097	0.039	-0.012	0.002	0.014	0.062	0.792
Encounter Rate of Gaur	0.155	0.063	0.006	-0.024	0.086	0.06	0.774
% Variance Explained	12.739	10.961	9.858	9.058	6.418	6.157	6.076
Cumulative % Variance	12.739	23.7	33.558	42.616	49.034	55.191	61.267

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PC5 = Abundance of minor prey like wildpig and barking deer
PC6 = Wilderness and protected habitat of the area
PC7 = Abundance of forest prey species gaur

As per best model for leopard occupancy *Psi* (Ψ) PC1+PC2+PC3+PC4+PC5+PC6 variables were considered and for detection probability *p*, encounter rate of leopard sign in that area was considered. The naïve occupancy (Ψ) that is generated without using the occupancy models was found to be 0.145, i.e. to say that 14.5% of the sampled landscape was detected to have leopards. Final parameter of occupancy (Ψ) was estimated to be 0.198 (±0.006). The probability of detecting

(*p*) leopard presence, by a single survey was estimated to be 0.095 (±0.003). From the coefficients of best model it is clear that human disturbance has a negative relation with the presence of leopard.

Table 9: Competing models tested and model selection using AIC for modelling leopard occupancy in Madhya Pradesh

Model	AIC	Δ AIC	No. of Parameters	-2*Log (likelihood)
Ψ(PC1+PC2+PC3+PC4+PC5+PC6), p(zlnleopps)	8731.64	0	9	8713.64
Ψ(PC1+PC2+PC3+PC4+PC5+PC6+ PC7), p(zlnleopps)	8731.82	0.18	10	8711.82
Ψ(PC1+PC2+PC3+PC4+PC5), p(zlnleopps)	8866.76	135.12	8	8850.76
Ψ(PC1+PC2+PC3+PC4), p(zlnleopps)	8895.64	164	7	8881.64
Ψ(.),p(.)	12608.29	3876.65	2	12604.29

PC1 = Abundance of major prey like chital, sambar
PC2 = Terrain and vegetation of the area
PC3 = Human disturbance
PC4 = Abundance of minor prey like chinkara, nilgai
PC5 = Abundance of minor prey like wildpig and barking deer
PC6 = Wilderness and protected habitat of the area
PC7 = Abundance of forest prey species gaur
zlnleopps = Encounter rate of leopard sign

Table 10: Coefficient of the best model explaining leopard occupancy in Madhya Pradesh

Variables	Estimate	Standard Error (SE)
A1 Ψ	0.371	0.17432
A2 Ψ.PC1	1.767191	0.262
A3 Ψ.PC2	0.908	0.138
A4 Ψ.PC3	-0.579	0.106
A5 Ψ.PC4	0.225	0.103
A6 Ψ.PC5	0.486	0.105
A7 Ψ.PC6	1.597	0.163
B1 P[1]	-2.553	0.05
B2 P[1].ZLNErLeo	1.349	0.034

PC1 = Abundance of major prey like chital, sambar
PC2 = Terrain and vegetation of the area
PC3 = Human disturbance
PC4 = Abundance of minor prey like chinkara, nilgai,
PC5 = Abundance of minor prey like wildpig and barking deer

PC6 = Wilderness and protected habitat of the area
PC7 = Abundance of forest prey species gaur
ZLNErLeo = Encounter rate of leopard sign

The spatial conditional occupancy model of leopard presence in the study area is as shown in Figure 6. In this map, the grid where the leopard sign was detected was assigned a score of 1 (red colour). In grids where the leopard sign was not detected the occupancy is considered as the probability of occupancy Ψ value estimated by the occupancy model. This map needs to be interpreted as a habitat suitability map for leopards in Madhya Pradesh showing where leopards are present and the potential areas they can occupy at a high spatial resolution of 25 km^2.

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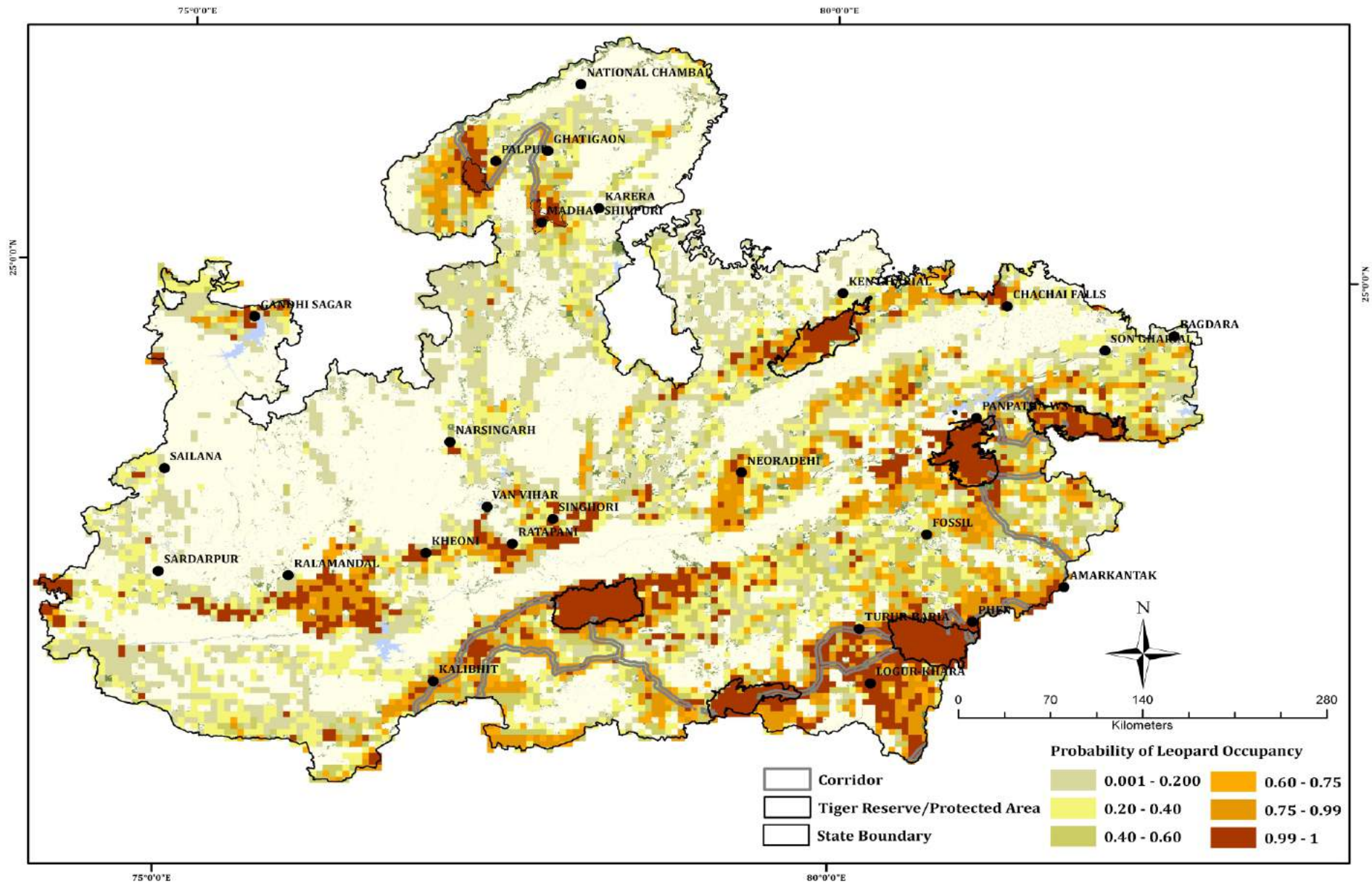

Figure 6: Map shows occupancy probability of leopard presence in Madhya Pradesh. Here the occupancy is predicted based on the attributes of covariates for each sampled grid after accounting for imperfect detection.

Abundance estimate of leopard

The best model that explained leopard density had human footprint index, prey abundance, canopied forest and leopard sign intensity as covariates (Table 11 & 12). Leopard density was found in most of the central and southern districts of Madhya Pradesh (Figure 7), though disjoint distribution was observed in Sagar, Damoh and Satna district. Leopard population seem to have lost its hold in districts like Ujjain, Shajapur, Rajgarh, Guna, Vidisha and Ashoknagar which in turn is breaking connectivity in leopard population between western and northern Madhya Pradesh with central and southern parts of the state. High density of leopard was observed in Dewar, Hoshangabad, Raisen, Chattarpur Panna, Mandla, Balaghat and Seoni, Chindwara. Maximum number of leopard was estimated for Baihar tehsil of Balaghat district. Beside Mandla tehsil of Mandla, Sohagpur tehsil of Hoshangabad, Panna tehsil of Panna, Bijapur tehsil of Chhatarpur and Bandhogarh tehsil of Shahdool district also have good leopard population (Table 13).

Table 11: Model selection for leopard density estimation using covariates in Spatially Explicit Capture Recapture (SECR) for Central Indian & Eastern Ghat Landscape

Model	Detection Function	No. of Parameters	Log Likelihood	AIC	ΔAIC
D~leops + hl + PreyER + ndvioct	Halfnormal	7	-9551.25	19116.51	0
D~leops + tigpst + hl + PreyDung + ndvioct	Halfnormal	8	-9550.75	19117.5	0.99
D~leops + hl	Halfnormal	5	-9576.58	19163.15	46.64
D~leops + ndvioct	Halfnormal	5	-10332.2	20674.4	1557.89
D~leops + rugg + PreyDung	Halfnormal	6	-10360.4	20732.82	1616.31
D~leops	Halfnormal	4	-10372.6	20753.28	1636.77

leops= Leopard sign index, hl = Human disturbance index, PreyER = Wild Prey Encounter rate ndvioct = NDVI post monsoon, AIC = Akaike Information Criterion

Table 12: Coefficients for the best covariate model in Spatially Explicit Capture Recapture (SECR) for estimating leopard density in Central Indian & Eastern Ghat Landscape.

Parameter	Beta	SE.beta
Density	-7.6	0.06
leops	0.09	0.02
hl	0.24	0.05
PreyER	0.05	0.05
ndvioct	-0.3	0.04
g0	-4.09	0.03
Sigma	7.71	0.01

leops = Leopard sign index, hl = Human disturbance index, PreyER = Wild Prey Encounter rate ndvioct = NDVI post monsoon.

Table 13: Leopard Number in Tehsils of Madhya Pradesh in 2014

District	Tehsil	Leopard Population	Lower SE limit	Upper SE limit
East Nimar	Burhanpur	14	13	15
Balaghat	Lanji	11	10	12
Betul	Bhainsdehi	12	11	13
West Nimar	Jhirnia	2	2	2
Balaghat	Balaghat	42	39	45
Balaghat	Baihar	145	131	157
Chhindwara	Sausar	29	25	33
Balaghat	Waraseoni	20	19	22
East Nimar	Harsud	41	37	46
Seoni	Seoni	74	64	83
West Nimar	Pansemal	2	2	3
Chhindwara	Chhindwara	2	2	2
Chhindwara	Amarwara	55	50	60
Betul	Betul	32	30	34
Chhindwara	Parasia	64	58	69
Hoshangabad	Harda	33	31	36
Betul	Multai	0	0	0
Jhabua	Alirajpur	35	27	43
West Nimar	Barwani	6	5	7
Dhar	Kukshi	1	1	1
Mandla	Mandla	106	95	117
East Nimar	Khandwa	17	16	19
Hoshangabad	Seonimalwa	7	6	7
West Nimar	Barwah	15	14	16
Hoshangabad	Itarsi	23	21	25
Hoshangabad	Sohagpur	92	82	102
Dewas	Bagli	50	41	59
West Nimar	Maheshwar	9	8	10
Dewas	Kannod	27	24	30
Hoshangabad	Piparia	39	36	42
Dhar	Manawar	5	4	5
Dhar	Dhar	11	10	12
Seoni	Lakhnadon	12	11	12
Indore	Mhow	20	18	21
Mandla	Dindori	8	8	9
Jhabua	Jobat	2	2	3

Table 13: Contd.

District	Tehsil	Leopard Population	Lower SE limit	Upper SE limit
Indore	Indore	4	4	4
Narsimhapur	Gadarwara	21	19	22
Hoshangabad	Babai	2	1	2
Narsimhapur	Narsimhapur	9	8	10
Sehore	Budhni	20	18	22
Hoshangabad	Hoshangabad	0	0	0
Mandla	Niwas	12	11	13
Dewas	Dewas	1	1	1
Dewas	Khategaon	8	7	8
Sehore	Nasrullahganj	6	5	6
Sehore	Ashta	5	4	6
Raisen	Goharganj	41	37	45
Sehore	Ichhawar	16	14	17
Jhabua	Jhabua	1	1	1
Jabalpur	Jabalpur	3	3	4
Dewas	Sonkach	4	3	4
Jabalpur	Patan	1	1	1
Shahdol	Pushprajgarh	0	0	0
Jhabua	Petlawad	1	1	1
Raisen	Bareli	23	21	25
Shahdol	Anuppur	3	2	3
Sehore	Sehore	6	5	7
Raisen	Udaipura	10	9	12
Bhopal	Huzur	5	5	6
Raisen	Silvani	28	25	31
Raisen	Raisen	9	7	11
Shahdol	Bandhogarh	64	58	71
Raisen	Gairatganj	3	3	3
Raisen	Begamganj	1	1	1
Damoh	Damoh	4	4	5
Jabalpur	Sihora	19	17	20
Sagar	Rehli	1	1	1
Ratlam	Sailana	2	2	2
Shahdol	Jaisinghnagar	11	10	12
Jabalpur	Murwara	16	14	18
Rajgarh	Narsinghgarh	5	4	5

Table 13: Contd.

District	Tehsil	Leopard Population	Lower SE limit	Upper SE limit
Bhopal	Berasia	1	0	1
Sidhi	Singrauli	14	13	15
Sidhi	Gopad Banas	57	53	61
Shahdol	Beohari	7	7	8
Sidhi	Devsar	13	12	14
Sagar	Khurai	5	4	5
Sagar	Banda	15	14	17
Chhatarpur	Bijawar	74	63	84
Damoh	Hatta	9	8	10
Mandsaur	Nimach	1	1	1
Panna	Pawai	0	0	0
Satna	Raghurajnagar	3	3	3
Panna	Panna	74	56	93
Mandsaur	Manasa	29	25	34
Chhatarpur	Chhatarpur	10	7	12
Mandsaur	Bhanpura	15	13	18
Satna	Nagod	3	3	4
Panna	Ajaigarh	3	3	3
Guna	Guna	0	0	0
Rewa	Sirmaur	11	10	13
Rewa	Mauganj	1	1	1
Rewa	Teonthar	4	3	4
Shivpuri	Shivpuri	29	26	32
Shivpuri	Karera	2	2	3
Morena	Sheopur	8	8	9
Morena	Bijaipur	29	26	33
Shivpuri	Pohri	3	3	3
Total		**1848**	**1643**	**2053**

Division wise, the leopard shows contiguous distribution in most of the forest division except South Sagar, Damoh and South Panna and Satna in central Madhya Pradesh and Vidisha and Guna in north Madhya Pradesh. A focus on Guna, Vidisha and Bhopal forest division would connect Sheopurkala-Shivpuri to Raisen and Obedullaganj. Also a focus on South Panna and South Sagar might connect leopard population of Chattarpur, North Sagar to Mandla and Narsimhapur (Figure 8). In Dewas, Kanha and Balaghat forest division highest number of leopard was found. The leopard number in forest divisions of Madhya Pradesh is mentioned in Table 8.

Table 14: Leopard Number in Forest Divisions of Madhya Pradesh

Division	Leopard Number	Lower SE limit	Upper SE limit
Anuppur	3	3	4
Barwani	6	5	7
Bhopal	8	7	9
BTR Umariya	30	27	33
Burhanpur	26	24	28
Chattarpur	65	58	72
Damoh	9	8	10
Dewas (T)	91	78	104
Dhar	16	15	18
Dindori	8	8	9
East Chhindwara	48	44	52
East Khargone	25	23	27
East Mandla	35	31	39
East Sidhi	27	24	29
Guna	0	0	0
Harda	24	22	26
Hoshangabad	58	52	63
Indore	25	23	27
Jabalpur	8	7	9
Jhabua	39	30	47.
Kanha Buffer Zone	41	37	45
Kanha National Park & Phen	89	80	98
Katni	31	28	34
Khandwa	46	41	50
Lamta Project	8	8	9
Mandsaur	34	29	40
Mohgaon Project	4	4	4
Narsimhapur	29	27	32
Nauradehi	5	5	6
Neemuch	12	10	13
Non Forest	20	18	22
North Balaghat	77	72	83
North Betul	12	11	13
North Panna	33	28	38
North Sagar	20	18	21
North Seoni	11	11	12

Table 14: Contd.

Division	Leopard Number	Lower SE limit	Upper SE limit
North Shahdol	19	17	21
Obedullaganj	76	69	84
Panna Forest Division	49	33	65
Pench Forest Division	37	29	45
Raisen	41	36	45
Rajgarh	5	4	6
Rampur Bhatodi	7	7	8
Ratlam	2	2	2
Rewa	16	14	18
Sanjay National Park	39	37	42
Satna	6	5	6
Satpura Forest Division	68	61	74
Sehore	46	41	51
Sendhwa	2	2	3
Sheopurkala	38	33	42
Shivpuri	34	30	37
South Balaghat	61	56	65
South Betul	22	20	24
South Chhindwara	15	13	16
South Panna	12	9	15
South Sagar	0	0	0
South Seoni	45	41	49
South Shahdol	10	10	11
Umaria	58	52	64
West Betul	8	8	9
West Chhindwara	72	65	78
West Mandla	19	17	20
West Sidhi	18	16	19
Total	**1848**	**1643**	**2052**

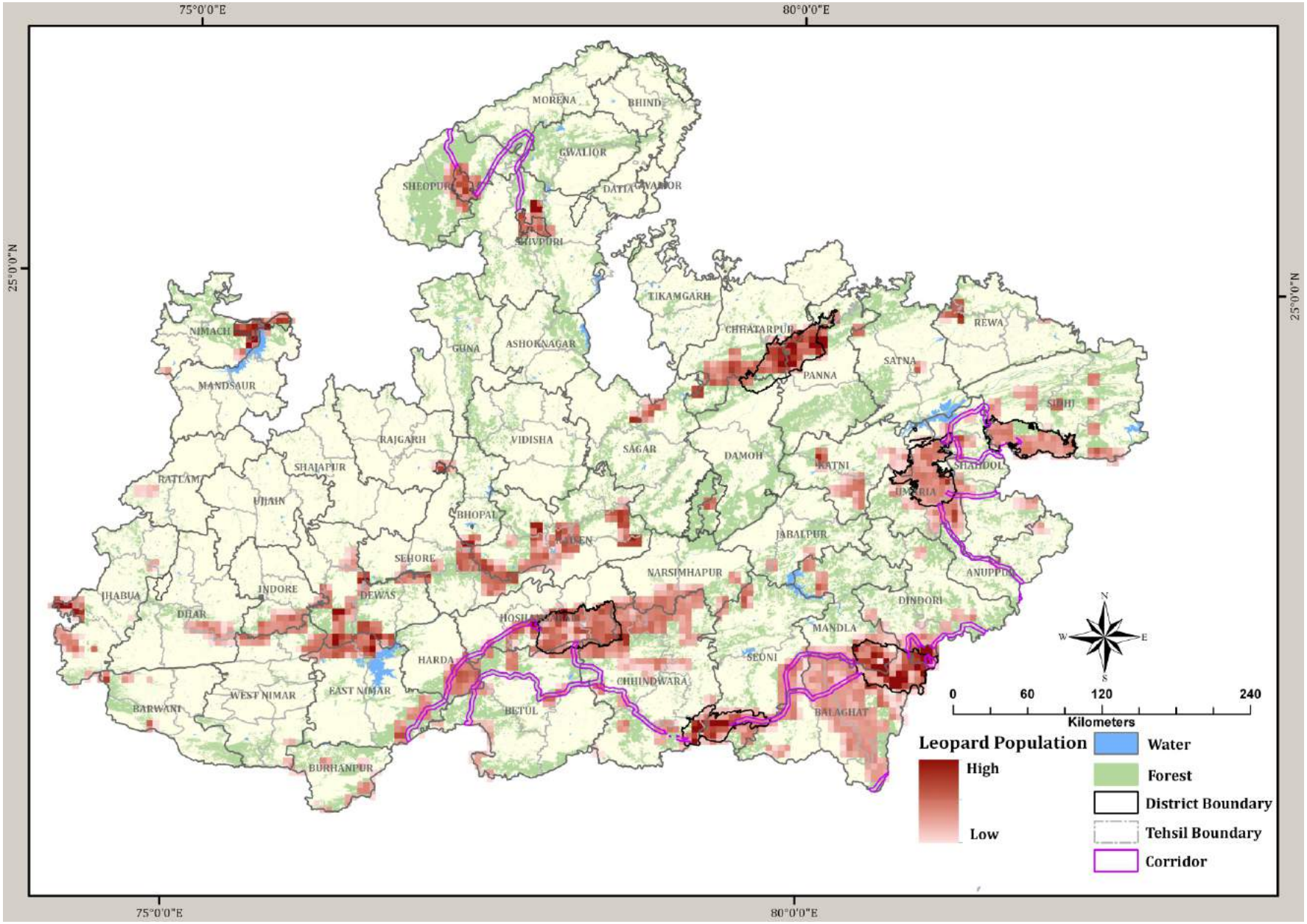

Figure 7: Leopard density overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

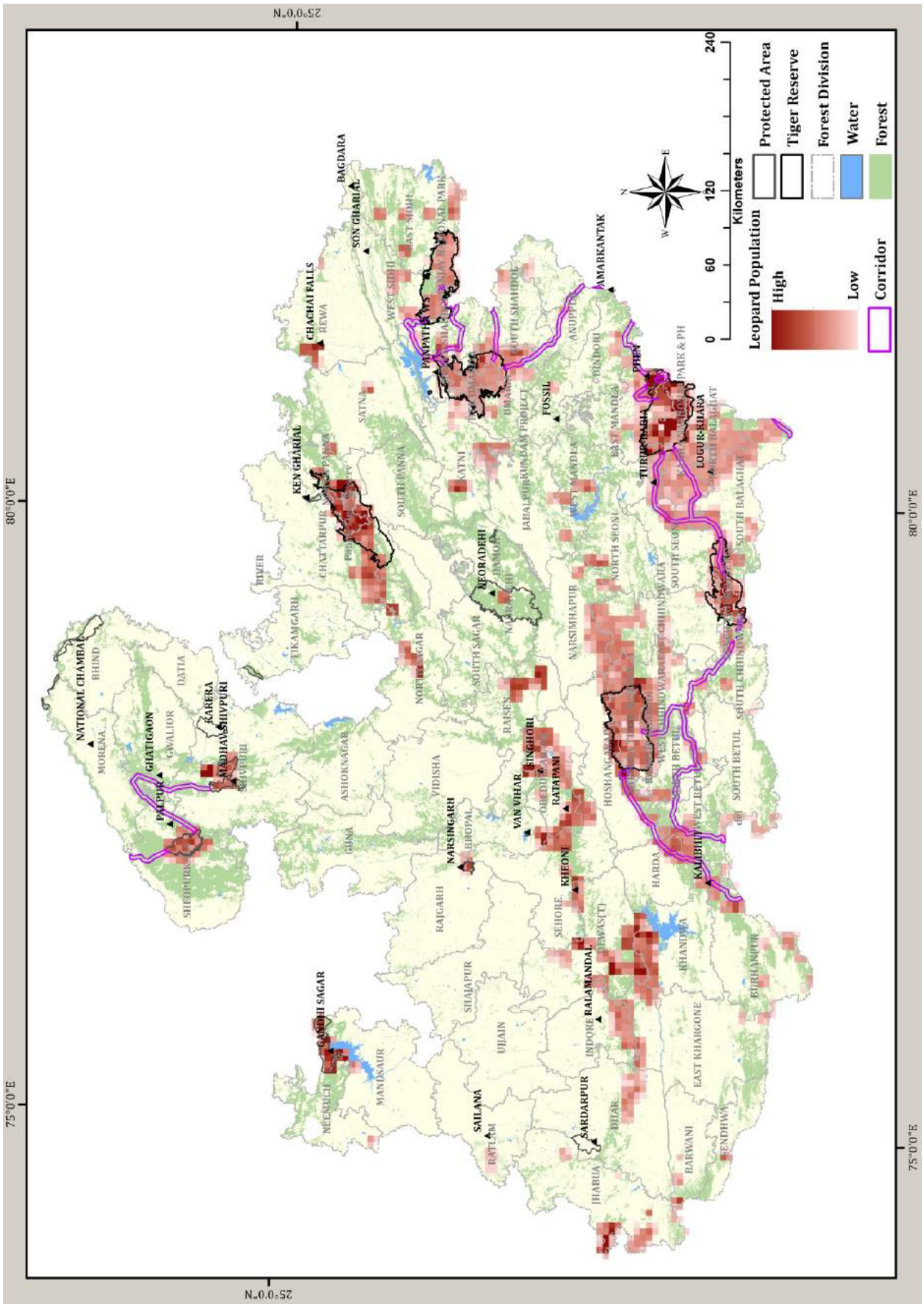

Figure 8: Leopard density overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

4.1.3 Occupancy and relative abundance estimates of dhole in Madhya Pradesh

The Dhole or Asiatic wild dog, *Cuon alpinus* (Pallas 1811) is the only Asian wild canid that primarily inhabits forested areas. Dholes are among the top social predators of large ungulates in tropical forests (Karanth and Sunquist 2000, Grassman *et al.* 2005, Kamler *et al.* 2012). Their numbers have significantly declined and trace populations are now largely restricted to forested areas (Durbin *et al.* 2008). In India, dholes were considered vermin and bounty-hunted to the verge of extinction before they received legal protection in 1972 (Durbin *et al.* 2008, Cohen 1978). They have been extirpated from 60% of their former range in the last century due to human persecution and loss of forest cover, and now occur primarily in protected wildlife reserves embedded within larger multiple-use landscapes (Karanth *et al.* 2009, Karanth *et al.* 2010). Although historically a widespread species, dholes are the least studied social carnivores in the Asian jungles (Acharya *et al.* 2007). Current subjective assessments suggest that <2500 individuals of dholes may survive globally (Durbin *et al.* 2008). The only information on dhole abundance comes from a few protected areas in southern and central India (Johnsingh 1983, Karanth 1993, Venkatraman *et al.* 1995, Acharya *et al.* 2007). These estimates have not been obtained through systematic sample based survey methods, but on estimates of number of packs within the protected areas (derived using known home range areas and knowledge of mean pack sizes) (Durbin *et al.* 2004). Ramesh (2010) estimated population of dhole using vehicle transect method.

Occupancy estimate of dhole

For the occupancy analysis of dhole in Madhya Pradesh by using PRESENCE software, Phase I data was used. Covariates were decided after extracting PC's as many of them are related. Five principal components explained 60% variation of the original variables. The component loading were ecologically explainable as shown in the Table 15. The first component represents different covariates related to the abundance of major prey like chital, sambar. Second component explains covariates related to human disturbance in that area. Third component involves abundance of prey like cattle, hare, langur. Fourth component includes abundance of wild animal like barking deer, wild pig etc and the last component represents the effect of wilderness and protected habitat of the area.

Table 15: Principal component loadings after varimax rotation of covariates From Madhya Pradesh

Variables	PC1	PC2	PC3	PC4	PC5
Pellet Count of Chital	0.8	0	0.14	0.05	0.09
Encounter Rate of Chital	0.78	0.02	0.01	0.11	0.05
Pellet Count of Sambar	0.77	-0.07	0.17	0.07	0.15
Encounter Rate of Sambar	0.72	-0.03	0.05	0.14	0.04
Distance from Protected Areas	-0.51	0.16	-0.03	-0.02	-0.32
People Seen	-0.01	0.86	-0.01	0.04	-0.09
Livestock Seen	0.01	0.85	0.03	0.06	-0.01
Human Tail	-0.01	0.77	0.08	0.13	0.14
Encounter Rate of Cattle	-0.16	0.59	0.3	-0.07	0.08
Pellet Count Hare	0.13	0.08	0.68	0.26	-0.05
Dung Count of Cattle	-0.18	0.35	0.62	-0.12	0.13
Dung Count of Langur	0.24	-0.03	0.61	0.14	0.31
Pellet Count of Wild Pig	0.32	0.03	0.56	0.12	-0.05
Encounter Rate of Barking Deer	0	0.01	-0.08	0.8	0.11
Pellet Count of Barking Deer	0.16	-0.08	0.22	0.59	0.15
Encounter Rate of Wild Pig	0.35	0.15	0.17	0.53	0
Encounter Rate of Hare	-0.03	0.25	0.31	0.44	-0.16
Canopy Cover	0.23	0.23	0.15	0.27	0.63
Core Area	0.22	-0.04	0.05	0.07	0.6
Nightlights Area	0.05	-0.01	0.05	0.08	-0.53
Encounter Rate Langur	0.29	0.11	0.23	0.38	0.5
% Variance Explained	15.223	12.975	9.235	8.883	7.745
Cumulative % Variance	15.223	28.198	37.432	46.315	54.061

PC1 = Abundance of major prey like chital, sambar
PC2 = Human disturbance
PC3= Abundance of prey like cattle, hare, langur
PC4 = Abundance of wild animals like barking deer, wild pig
PC5 = Wilderness and protected habitat of the area

As per best model for dhole occupancy *Psi* (Ψ) considered PC1+PC2+PC3+PC4+PC5 variables and for detection probability *p* considered encounter rate of dhole sign. The naïve occupancy (Ψ) that is generated without correcting for non detection was found to be 0.09, i.e. to say that 9.04% of the sampled landscape was detected to have dholes. Detection corrected of occupancy (Ψ) was estimated to be 0.151 (±0.007). The probability of detecting (*p*) dhole presence, if present by one replicate survey was estimated to be 0.042 (±0.002). From the coefficients of best model it is clear that human disturbance has a negative relation with the presence of dhole, while legal protection, prey availability and forested areas had a positive effect on dhole presence.

Table 16: Competing models tested and model selection using AIC for modelling dhole occupancy in Madhya Pradesh

Model	AIC	ΔAIC	AIC wgt	No. of Parameters	-2*Log (likelihood)
Ψ(PC1+PC2+PC3+PC4+PC5), p(zlnwdg)	5705.67	0	0.9999	8	5689.67
Ψ(PC1+PC2+PC3+PC4), p(zlnwdg)	5725.18	19.51	0.0001	7	5711.18
Ψ(PC1+PC2+PC3+PC5), p(zlnwdg)	5747.37	41.7	0	7	5733.37
Ψ(.),p(zlnwdg)	5755.25	49.58	0	3	5749.25
Ψ(PC3),p(zlnwdg)	5757.25	51.58	0	4	5749.25
Ψ(PC4),p(zlnwdg)	5757.25	51.58	0	4	5749.25
Ψ(PC5),p(zlnwdg)	5757.25	51.58	0	4	5749.25
Ψ(PC1),p(zlnwdg)	5757.25	51.58	0	4	5749.25
Ψ(PC2),p(zlnwdg)	5757.25	51.58	0	4	5749.25
Ψ(PC2+PC3+PC4+PC5), p(zlnwdg)	5761.35	55.68	0	7	5747.35
Ψ(PC1+PC2+PC3+PC4+PC5), p(.)	7480.75	1775.08	0	7	7466.75
Ψ(PC1+PC2+PC3+PC4), p(.)	7567.77	1862.1	0	6	7555.77
Ψ(PC1+PC2+PC3), p(.)	7622.59	1916.92	0	5	7612.59
Ψ(PC1+PC2), p(.)	7628.6	1922.93	0	4	7620.6
Ψ(PC1),p(.)	7628.6	1922.93	0	4	7620.6
Ψ(.),p(.)	7879.98	2174.31	0	2	7875.98

PC1 = Abundance of major prey like chital, sambar
PC2 = Human Disturbance
PC3 = Abundance of prey like cattle, hare, langur
PC4 = Abundance of wild animal like barking deer, wild pig
PC5 = Wilderness and protected habitat of the area
zlnwdg = Encounter rate of wild dog sign


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Table 17: Coefficient of the best model explaining wild dog occupancy in Madhya Pradesh

Variables	Estimate	Standard Error (SE)
A1 Ψ	4.045	1.292
A2 Ψ.PC1	7.088	2.092
A3 Ψ.PC2	-0.481	0.241
A4 Ψ.PC3	1.733	0.768
A5 Ψ.PC4	1.841	0.505
A6 Ψ.PC5	1.597	0.566
B1 P[1]	-3.601	0.06
B2 P[1].ZLNWDPS	1.03	0.027

PC1 = Abundance of major prey like chital, sambar
PC2 = Human Disturbance
PC3 = Abundance of prey like cattle, hare, langur
PC4 = Abundance of wild animals like barking deer, wild pig
PC5 = Wilderness and protected habitat of the area
ZLNWDPS = Encounter rate of dhole sign

The spatial conditional occupancy model of dhole presence in the study area is as shown in Figure 9. In this map, the grid where the dhole sign was detected was assigned a score of 1 (red colour). In grids where the dhole sign was not detected the occupancy is considered as the Ψ value estimated by the occupancy model. This map needs to be interpreted as a habitat suitability map for dholes in Madhya Pradesh showing where dholes are present and the potential areas they can occupy at a high spatial resolution of 25 km^2.

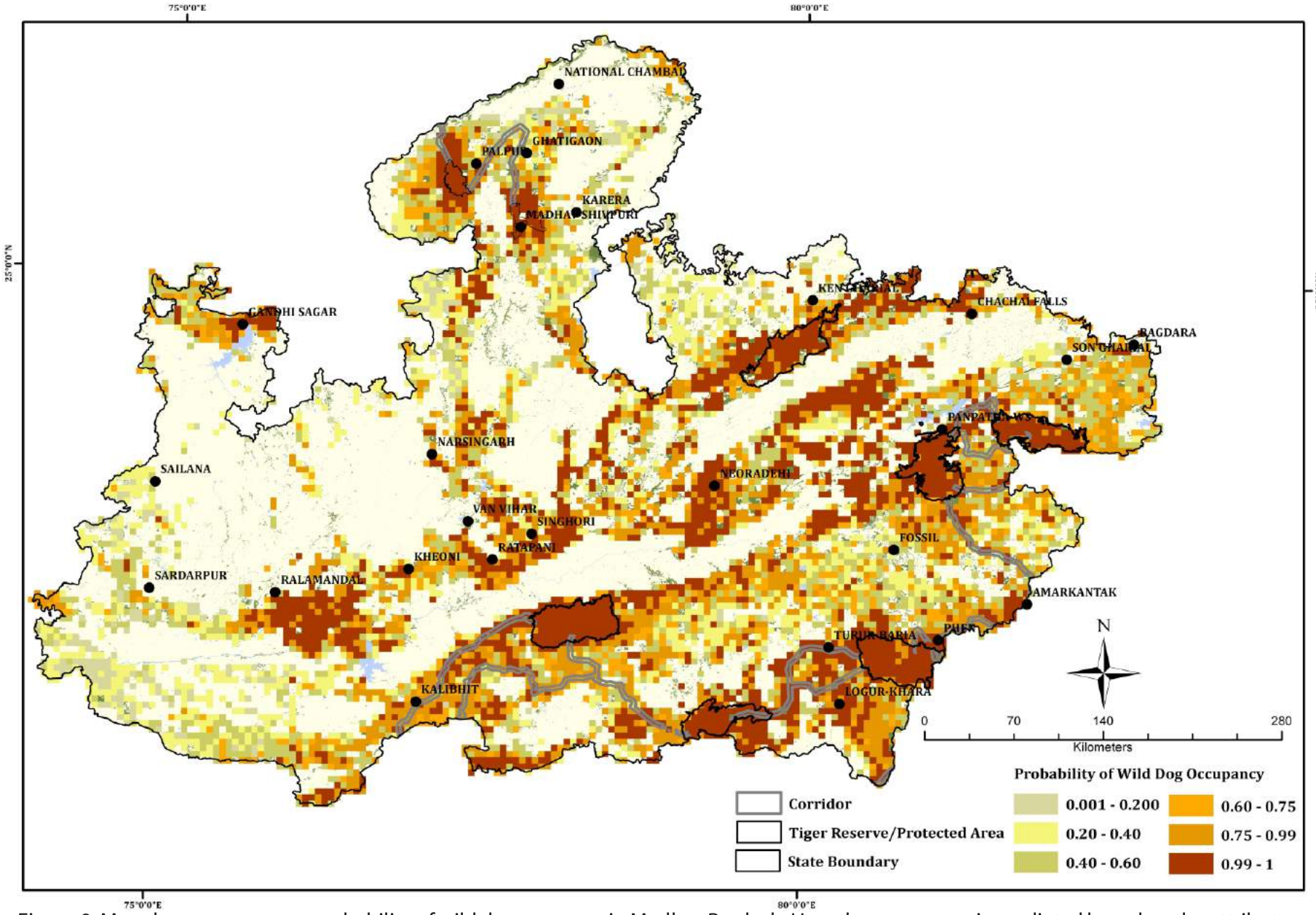
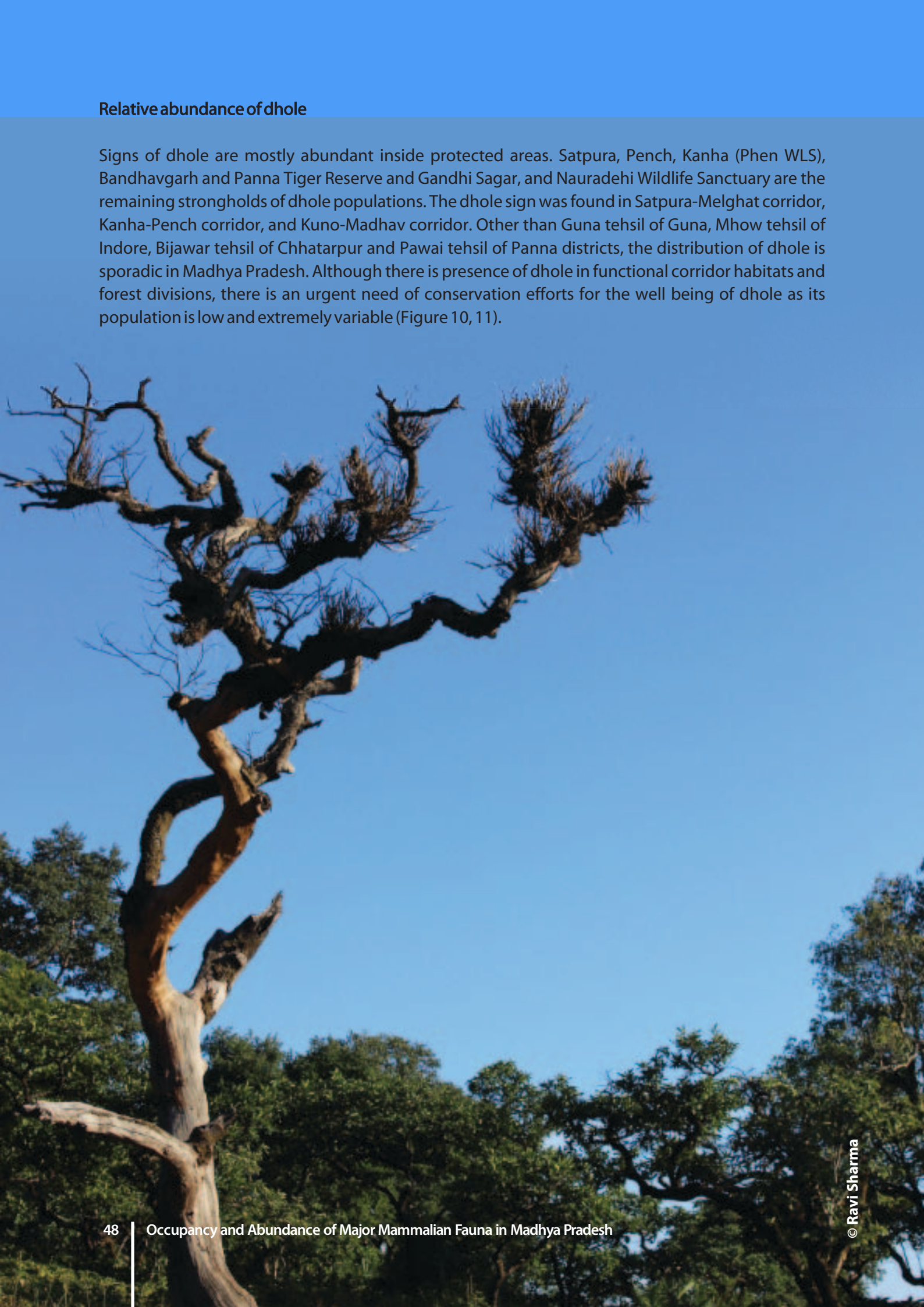


Figure 9: Map shows occupancy probability of wild dog presence in Madhya Pradesh. Here the occupancy is predicted based on the attributes of covariates for each sampled grid after accounting for imperfect detection

Relative abundance of dhole

Signs of dhole are mostly abundant inside protected areas. Satpura, Pench, Kanha (Phen WLS), Bandhavgarh and Panna Tiger Reserve and Gandhi Sagar, and Nauradehi Wildlife Sanctuary are the remaining strongholds of dhole populations. The dhole sign was found in Satpura-Melghat corridor, Kanha-Pench corridor, and Kuno-Madhav corridor. Other than Guna tehsil of Guna, Mhow tehsil of Indore, Bijawar tehsil of Chhatarpur and Pawai tehsil of Panna districts, the distribution of dhole is sporadic in Madhya Pradesh. Although there is presence of dhole in functional corridor habitats and forest divisions, there is an urgent need of conservation efforts for the well being of dhole as its population is low and extremely variable (Figure 10, 11).



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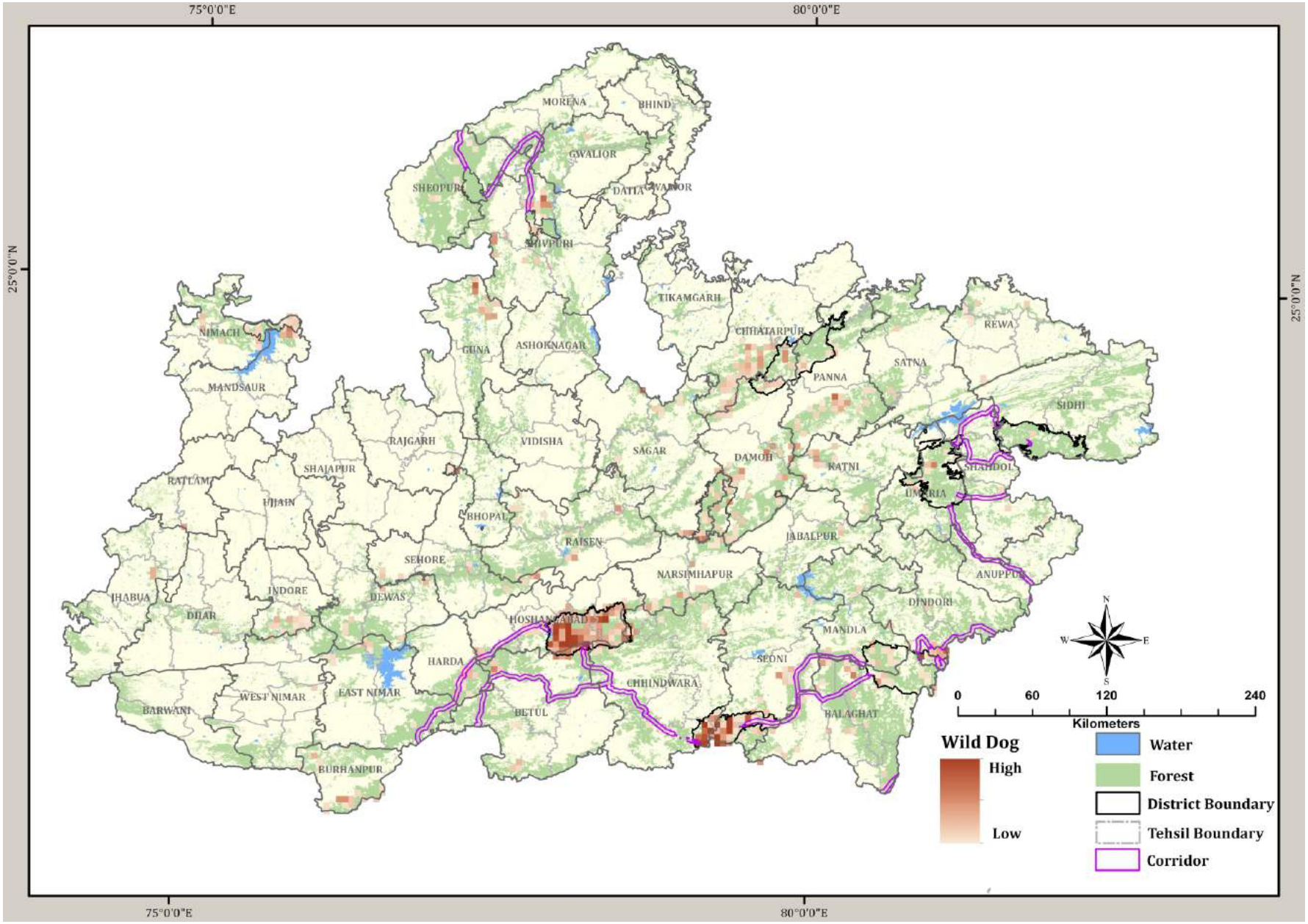

Figure 10: Relative abundance of wild dog overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

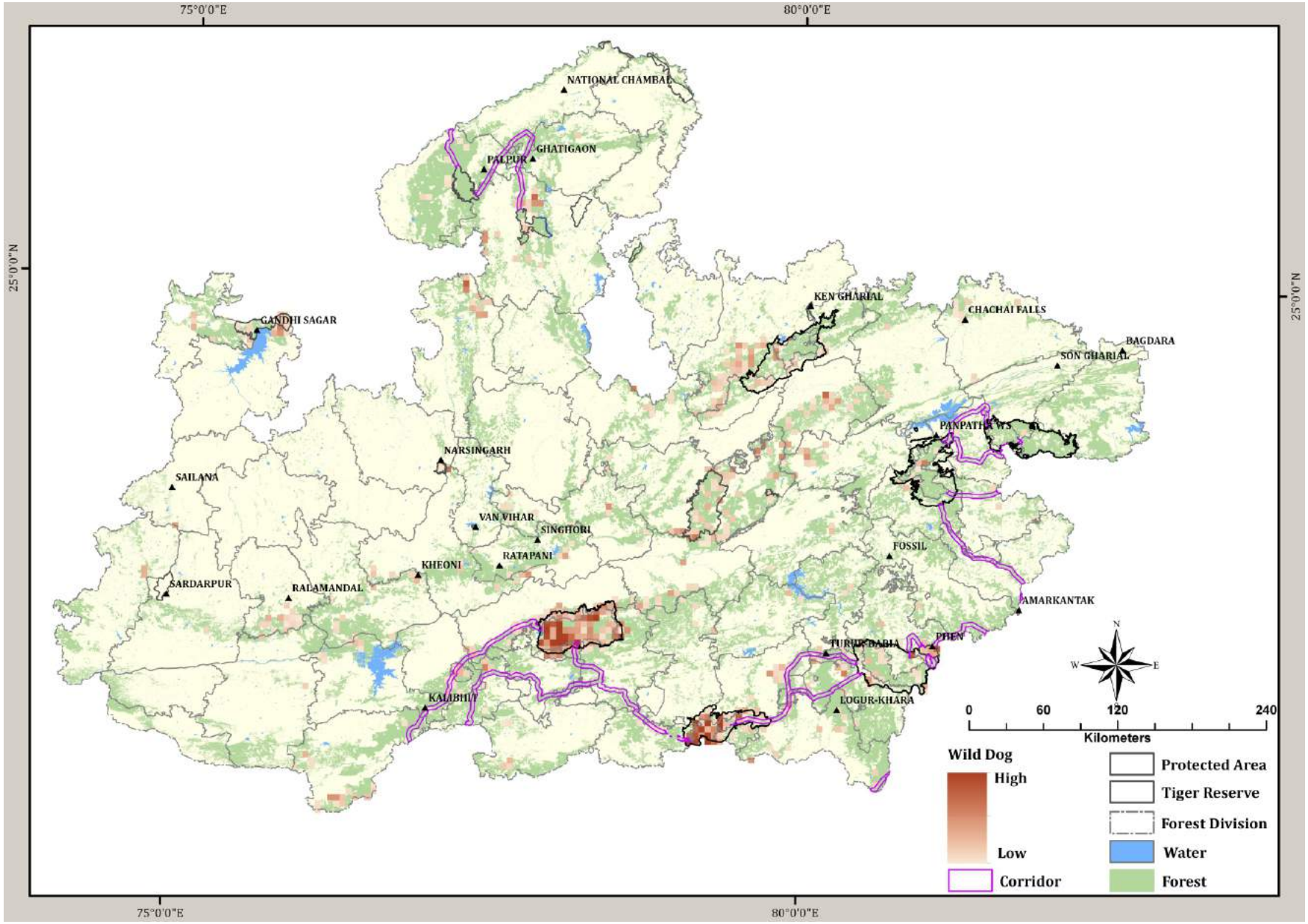

Figure 11: Relative abundance of wild dog overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

4.1.4 Occupancy and relative abundance estimates of sloth bear in Madhya Pradesh

The sloth bear (*Melursus ursinus*) in India are involved in conflicts with humans, including human casualties, because of resource extraction, habitat fragmentation, habitat loss, and high conflict across their range in drier regions in central (Johnsingh 1986, Servheen 1990, Chauhan *et al.* 1999, Rajpurohit and Krausman 2000, Bargali *et al.* 2004), western, and southeastern (Krishnaraju *et al.* 1987) India. The sloth bear is endemic to the Indian subcontinent (Erdbrink 1953, Sathyakumar *et al.* 2012), with a historical distribution from the foothills of the Himalayas in northern India to the dry slopes of the Western Ghats in the south (Bargali *et al.* 2004). However, sloth bear populations are currently limited to 5 regions in India: northern, northeastern, central, southeastern, and southwestern populations (Garshelis *et al.* 1999b, Johnsingh 2003, Yoganand *et al.* 2006, Sathyakumar *et al.* 2012). This drastic range contraction along with illegal demand for bear bile and trafficking of sloth bear gall bladder has rendered the species Vulnerable to Extinction (IUCN 2013) and led to its inclusion in Schedule I of the Indian Wildlife (Protection) Act as amended in 2003 (GOI 1972, 2003). Currently, only about 10% of the species' current distribution in India contains high-quality habitat (Yoganand *et al.* 2006).

Occupancy estimate of sloth bear

To evaluate the present status of sloth bear in Madhya Pradesh occupancy analysis was done from the Phase I data. Since there were many covariates which were correlated, principal components were extracted and the PC's were subsequently used as covariates in the model. From covariates we got four principal component values. The component loading were ecologically explainable as shown in the Table 18. The first component represents ruggedness and vegetation of the area. Second component involves abundance of tiger, leopard in that area. Third component explains covariates related to human disturbance in that area. Forth component represents the night light and canopy cover of the area. These four principal components explained 64% variation in original covariate data (Table 18).

Table 18: Principal component loadings after varimax rotation of covariates From Madhya Pradesh

Variables	PC1	PC2	PC3	PC4
Ruggedness	0.91	0.02	-0.01	0.14
Elevation	0.91	0.03	-0.08	-0.07
Mean NDVI pre monsoon	0.63	0.16	-0.01	0.59
Mean NDVI post monsoon	0.57	0.3	-0.04	0.5
Leopard presence	0.14	0.82	-0.07	0.07
Tiger presence	0.12	0.78	-0.06	0.02
Distance to protected area	0.04	-0.68	0.1	-0.32
Wild dog presence	0	0.67	0.04	-0.02
People seen	-0.02	-0.05	0.88	-0.11
Livestock seen	-0.08	-0.03	0.86	-0.01
Human trail	-0.01	-0.08	0.82	0.14
Core area	0.02	0.2	-0.05	0.74

Table 18: Contd.

Canopy cover	0.27	0.17	0.33	0.58
Night light	-0.01	0.06	0.02	-0.39
% Variance Explained	17.724	17.032	16.515	12.79
Cumulative % Variance	17.724	34.756	51.27	64.06

PC1= Ruggedness and vegetation
PC2= Presence of leopard
PC3= Human disturbance
PC4= Nightlight and distance to PA

As per best model for bear occupancy *Psi* (Ψ) considered PC1+PC2+PC3+PC4 variables and for detection probability *p* considered encounter rate of bear sign in that area. The naïve occupancy (Ψ) that is generated without using the occupancy models was found to be 0.256, i.e. to say that 25.6% of the sampled landscape was detected to have bears. Final parameter of occupancy (Ψ) was estimated to be 0.318 (±0.007). The probability of detecting (*p*) bear presence, if present at a replicate was estimated to be 0.474 (±0.006).

Table 19: Competing models tested and model selection using AIC for modelling bear occupancy in Madhya Pradesh

Model	AIC	ΔAIC	AIC wgt	No. of Parameters	-2*Log (likelihood)
Ψ(PC1+PC2+PC3+PC4), p(ZLNBearPS)	13929.01	0	1	7	13915.01
Ψ(.), p(ZLNBearPS)	14210.16	281.15	0	3	14204.16
Ψ(PC1+PC2+PC3+PC4), p(.)	18362.4	4433.39	0	6	18350.4
Ψ(PC1+PC2+PC4), p(.)	18363.76	4434.75	0	5	18353.76
Ψ(PC1+PC2+PC3), p(.)	18583.83	4654.82	0	5	18573.83
Ψ(PC1+PC3+PC4),p(.)	18631.36	4702.35	0	5	18621.36
Ψ(PC1+PC2), p(.)	18676.45	4747.44	0	4	18668.45
Ψ(PC1+PC4), p(.)	18738.03	4809.02	0	4	18730.03
Ψ(PC1+PC3), p(.)	19088.21	5159.2	0	4	19080.21

PC1 = Rugedness, vegetation
PC2 = Abundance of tiger leopard
PC3 = Human disturbance
PC4 = Night light, canopy cover etc
ZLNBearPS = Encounter rate of bear

Table 20: Coefficient of the best model explaining bear occupancy in Madhya Pradesh

Variables	Estimate	Standard Error (SE)
A1 Ψ	4.228587	0.486582
A2 Ψ.PC1	-0.49517	0.156808
A3 Ψ.PC2	0.60885	0.217558
A4 Ψ.PC3	-0.57315	0.206677
A5 Ψ.PC4	-0.58647	0.226215
B1 P[1]	-2.22937	0.027612
B2 P[1].ZLNBearPS	2.155263	0.032406

PC1 = Rugedness, vegetation
PC2 = Abundance of tiger leopard
PC3 = Human disturbance
PC4 = Night light, canopy cover
ZLNBearPS = Encounter rate of bear

The spatial conditional occupancy model of bear presence in the study area is as shown in Figure12. In this map, the grid where the bear sign was detected was assigned a score of 1 (red colour). In grids where bear sign was not detected the occupancy is considered as the Ψ value estimated by the occupancy model is shown. This map needs to be interpreted as a habitat suitability map for sloth bear in Madhya Pradesh showing where sloth bears are present and the potential areas they can occupy.

Relative abundance of sloth bear

Sloth bears are widely distributed in tropical dry and moist deciduous forests, scrubland, and grasslands and prefer rugged rocky terrain which provides den sites. Satpura-Melghat corridor which passes through Itarsi, Seonimalwa, Harda and Harsud tehsils of Hoshangabad, Harda, and East Nimar districts has a high abundance of sloth bear. A relatively high abundance of sloth bear was recorded from Budhni tehsil of Sehore, Goharganj and Bareli tehsils of Raisen, Baihar and Balaghat tehsils of Balaghat, Bijawar tehsils of Chhatarpur, Gadarwara and Narsimhapur tehsils of Narsimhapur, Pawai tehsil of Panna, Sheopur and Bijaipur tehsil of Sheopur district. The relative abundance of sloth bear in different corridors suggests potential connectivity of protected areas (Figure 13, 14).

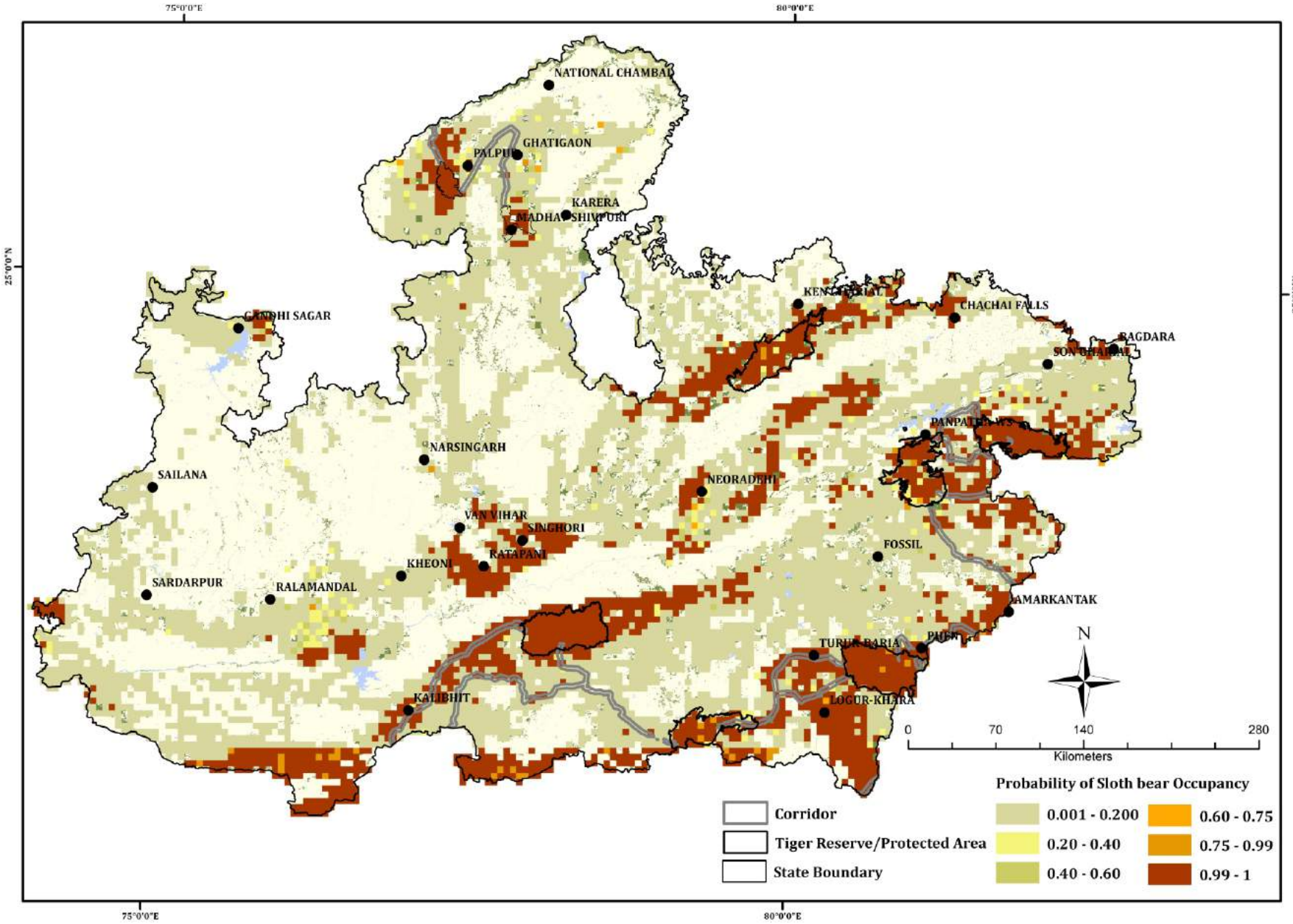

Figure 12: Map shows predicted occupancy model of sloth bear presence in Madhya Pradesh. Here the occupancy is predicted based on the attributes of covariates for each sampled grid after accounting for imperfect detection.

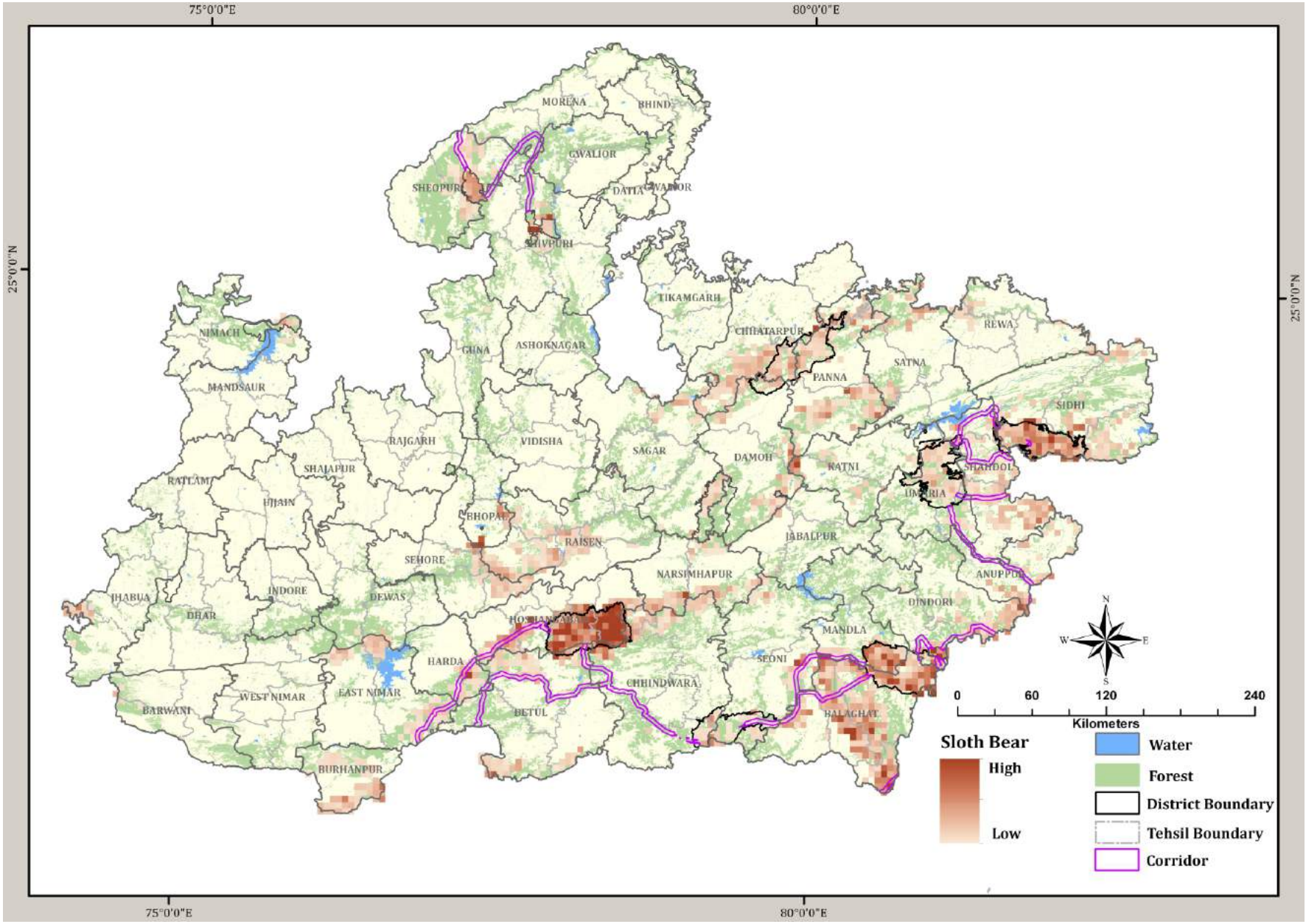

Figure 13: Relative abundance of sloth bear overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

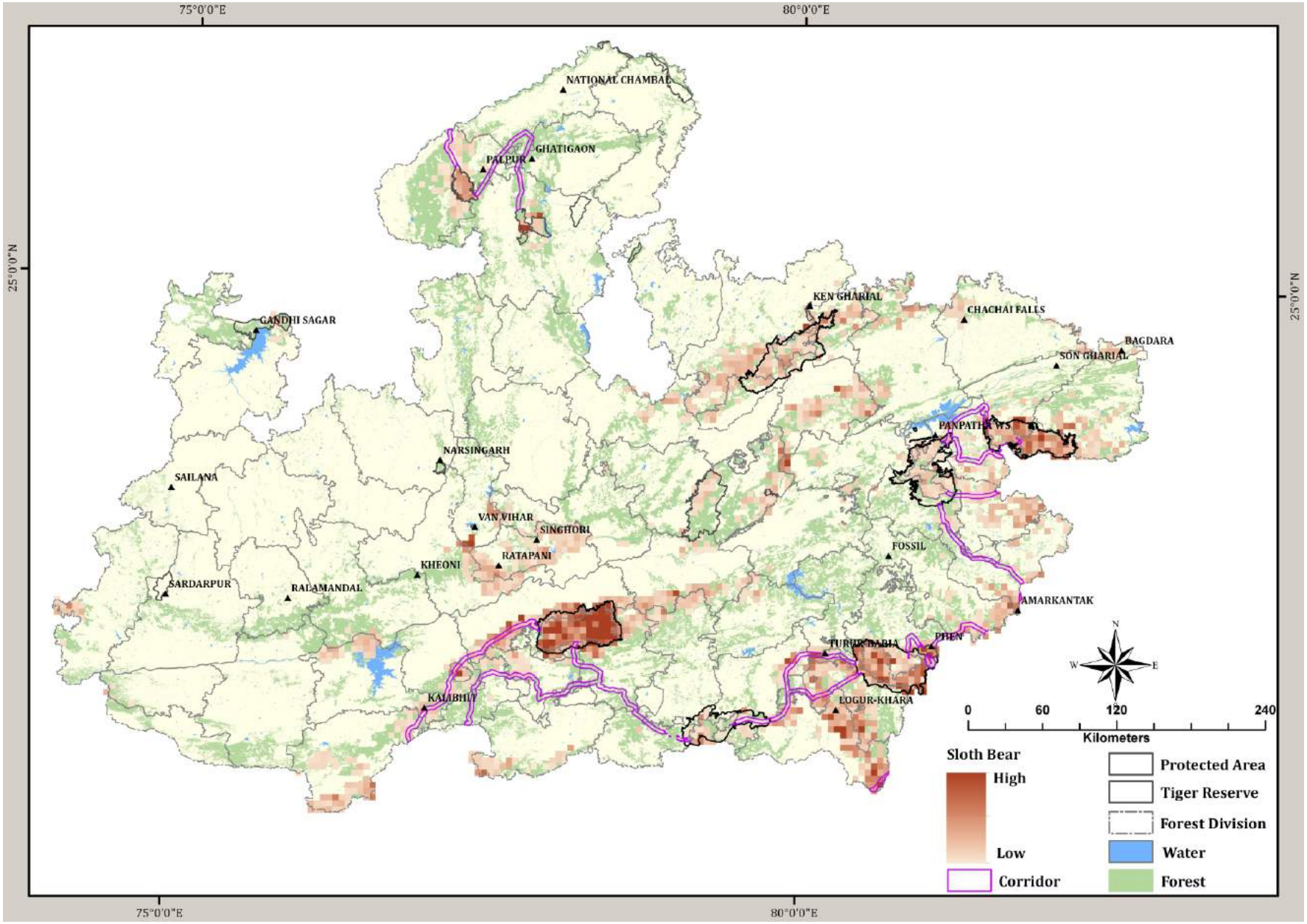

Figure 14: Relative abundance of sloth bear overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

4.1.5 Occupancy and density estimates of jackal in Madhya Pradesh

The golden jackals, *Canis aureus*, means 'Golden dog' (also known as Common Indian or Asiatic jackal) as a group amongst canids are true members of the dog family. Jackals are slated to be schedule III species in India under Wildlife Protection Act (1972) and are placed under appendix II of CITES. In India they are declared as species with least concern (Jhala and Moehlman 2008). Being a generalist species, jackal occupies variety of habitats by adapting local abundance of food (Jhala and Moehlman 2013). High number of jackal is observed around human settlements with abundant food and shelter (Prater 2005). Due to their tolerance of dry habitats and their omnivorous feeding ecology, the golden jackal can inhibit a wide variety of habitats. They are opportunistic foragers and can cause damage to poultry, and variety of crops. They were observed to visit the vicinity of human habitation during night (Aiyadurai and Jhala 2006). In India Jackal population found to be high in pastoral and semi arid areas such as Kutch, Maharastra, Rajasthan and Haryana (Chourasia 2015). Based on known density estimates for parts of India and considering that about 19% (i.e. about 637,000 km^2) of the geographical area of India as forest cover, jackal populations (and that jackals are also found outside forested habitats) has a minimum population estimates of over 80000, does not seems unreasonable for the Indian subcontinent (Jhala and Moehlman 2008). Road kills on rural roads and roads which traverse forested area account for a large number of jackal mortality. Prevalence of rabies amongst jackal is common and there are several reports of rabid jackal attacks on humans.

Occupancy estimate of jackal

To evaluate the present status of jackal in Madhya Pradesh occupancy analysis was done from the Phase I data. The occupancy of jackal was modeled using variable defining prey and habitat quality. Factors affecting jackal presence was determined and used those covariates for estimating jackal occupancy. Factors that taken on account for jackal analysis were presence of tiger sign, presence of leopard sign, presence of livestock sign and distance to protected area. The best model that explain occupancy of jackal in Madhya Pradesh contains covariates of presence of tiger sign, presence of leopard sign and presence of livestock sign. As per best model for jackal occupancy *Psi* (Ψ) considered tigps+leops+live variables and for detection probability *p* was constant. The naïve occupancy (Ψ) that is generated without using the capture-recapture framework was found to be 0.665, i.e. to say that 66.5% of the sampled landscape was detected to have jackal in Madhya Pradesh. Final parameter of occupancy (Ψ) was estimated to be 0.750809 (±0.009734). The probability of detecting (*p*) jackal presence, if present at a replicate was estimated to be 0.5718 (±0.0039). All the covariates have positive effect on jackal presence.

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Table 21: Competing models tested and model selection using AIC for modelling Jackal occupancy in Madhya Pradesh

Model	AIC	ΔAIC	AIC wgt	No. of Parameters	-2*Log (likelihood)
Ψ(tigps+leops+live),p(.)	31736.5	0	0.473	5	31726.51
Ψ(tigps+leops+live+distpa), p(.)	31737.2	0.66	0.34	6	31725.17
Ψ(leops+live),p(.)	31739.6	3.04	0.1034	4	31731.55
Ψ(leops+live+distpa),p(.)	31740	3.51	0.0818	5	31730.02
Ψ(tigps+live),p(.)	31750	13.52	0.0005	4	31742.03
Ψ(tigps+leops),p(.)	31750.9	14.34	0.0004	4	31742.85
Ψ(tigps+live+distpa),p(.)	31751.1	14.6	0.0003	5	31741.11
Ψ(live),p(.)	31752	15.45	0.0002	3	31745.96
Ψ(tigps+leops+distpa),p(.)	31752.4	15.89	0.0002	5	31742.4
Ψ(live+distpa),p(.)	31752.9	16.38	0.0001	4	31744.89
Ψ(leops),p(.)	31754.8	18.28	0.0001	3	31748.79
Ψ(leops+distpa),p(.)	31756.2	19.72	0	4	31748.23
Ψ(tigps),p(.)	31766	29.44	0	3	31759.95
Ψ(tigps+distpa),p(.)	31767.8	31.26	0	4	31759.77

tigps = Presence of tiger
leops = Presence of leopard
live = Livestock seen
distpa = Distance to protected area

Table 22: Coefficient of the best model explaining jackal occupancy in Madhya Pradesh

Variables	Estimate	Standard Error (SE)
A1 Ψ	1.060378	0.036986
A2 Ψ.ZLNTigPS	0.112557	0.051355
A3 Ψ.ZLNLeopPS	0.135638	0.039271
A4 Ψ.ZLNLiveseen	0.141178	0.037218
B1 P[1]	0.289118	0.015813

ZLNTigPS = Presence of tiger
ZLNLeopPS = Presence of leopard
ZLNLiveseen = Livestock seen

The spatial conditional occupancy model of jackal presence in the study area is as shown in Figure 15. In this map, the grid where the jackal sign was detected was assigned a score of 1 (red colour). In grids where the jackal sign was not detected the occupancy is considered as the Ψ value estimated by the occupancy model. This map needs to be interpreted as a habitat suitability map for jackals in Madhya Pradesh showing where jackals are present and the potential areas they can occupy.

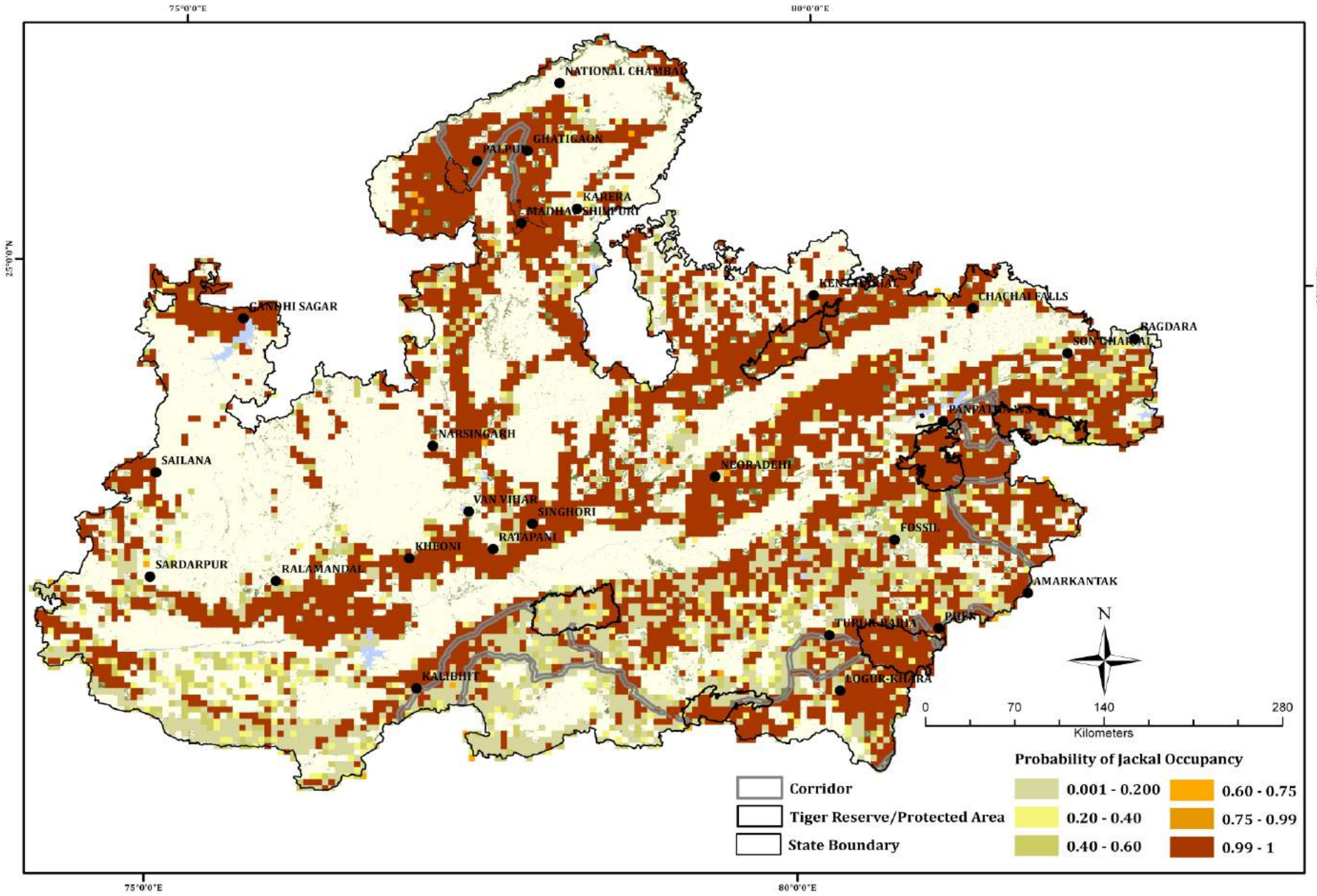

Figure 15: Map shows predicted occupancy model of jackal presence in Madhya Pradesh. Here the occupancy is predicted based on the attributes of covariates for each sampled grid. Based on the covariate values of each grid and capture histories, the model predicts occupancy estimates as shown.

Relative abundance of jackal

Golden jackal is the most abundant of carnivores found in Madhya Pradesh and its relative abundance was found to be high in majority of the surveyed forest area. Kuno-Ghatigaon-Madhav-Panna corridor has a contiguous distribution of this species. However Satpura Tiger Reserve has less abundance of jackals inside the protected area because of its extremely rugged terrain. Jackals are found to be more abundant in the Northern and eastern part of the state when compared to the western part (Figure 16, 17).

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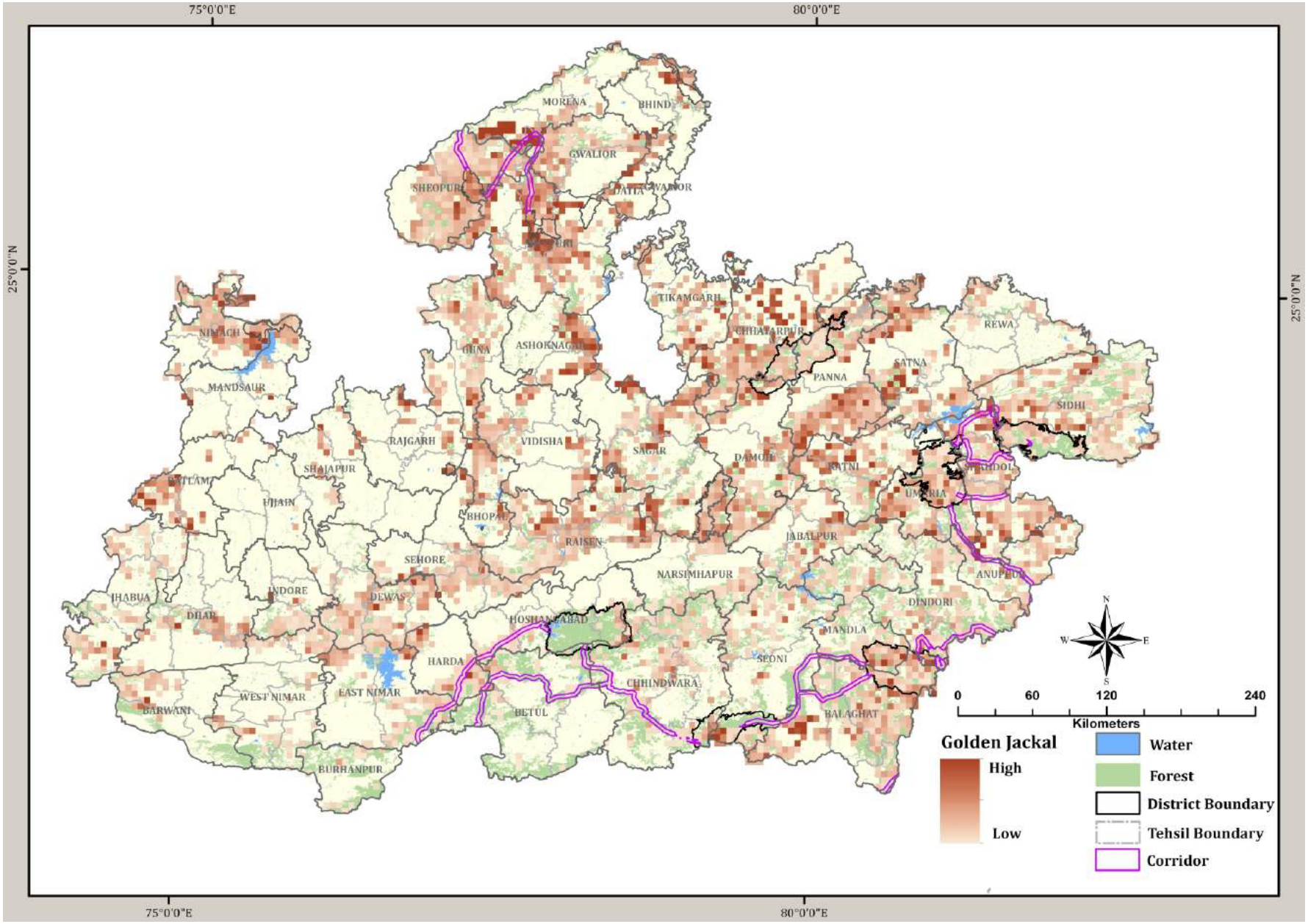

Figure 16: Relative abundance of golden jackal overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

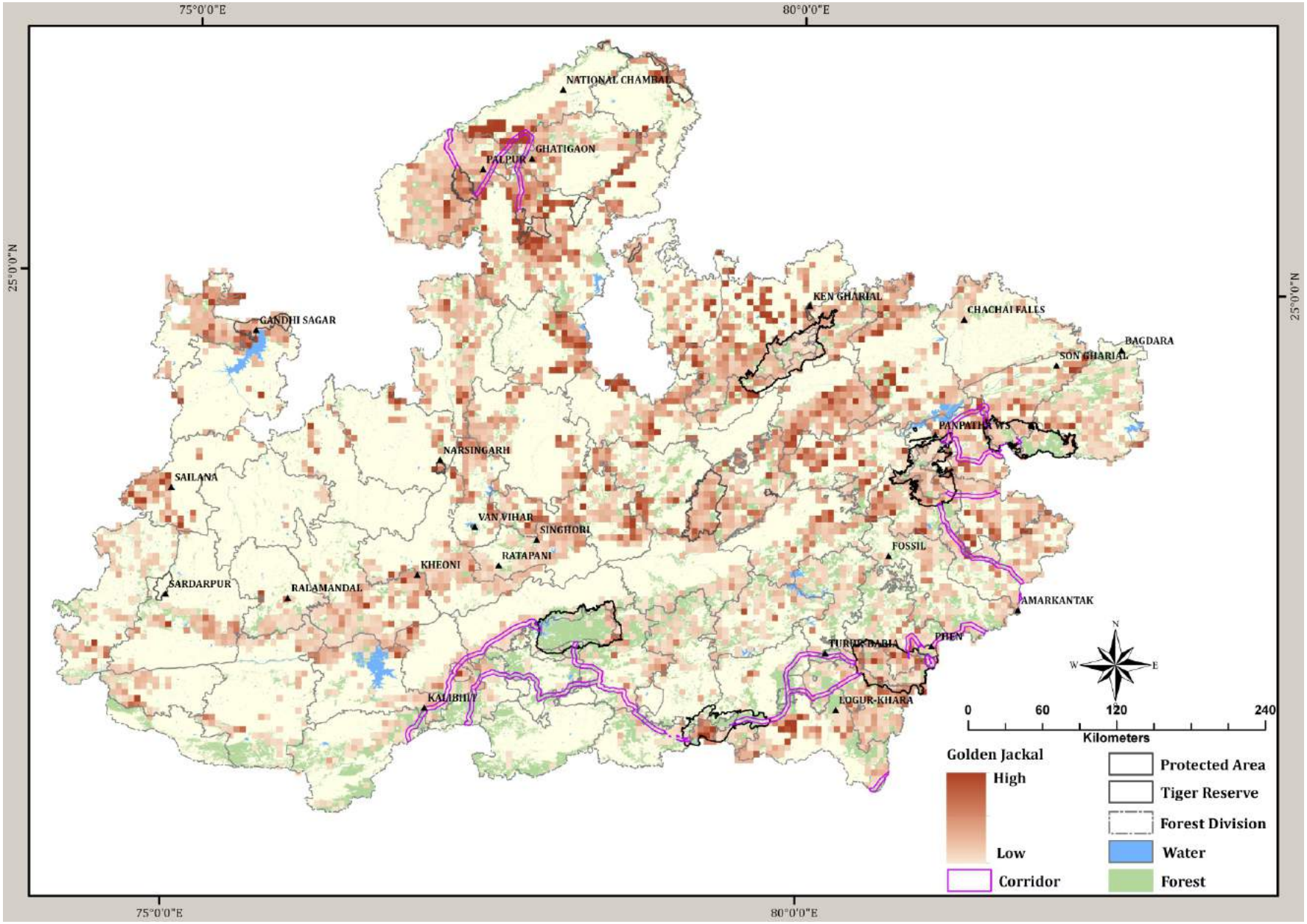

Figure 17: Relative abundance of golden jackal overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh

4.1.6 Relative abundance of Striped Hyena

Madhya Pradesh has a wide distribution of hyenas. As striped hyena prefers open habitat in an arid or semi-arid environment, they are relatively more abundant in areas which are classified as Gujrat-Rajputana (4B) biogeographic province. The Protected areas of Panna and Sanjay-Dubri Tiger Reserve, eastern part of Satpura Tiger Reserve, Kuno Wildlife Sanctuary and Gandhi Sagar Wildlife Sanctuary harbour abundant hyena populations. Apart from the aforementioned protected areas, Kuno-Madhav corridor, Satpura-Melghat corridor and Kanha-Pench corridor also host abundant hyena populations. Large tracts of Obedullaganj, Sheopurkala, South Panna, Indore, Dewas and Nimuch forest divisions have high hyena abundance (Figure 18, 19).

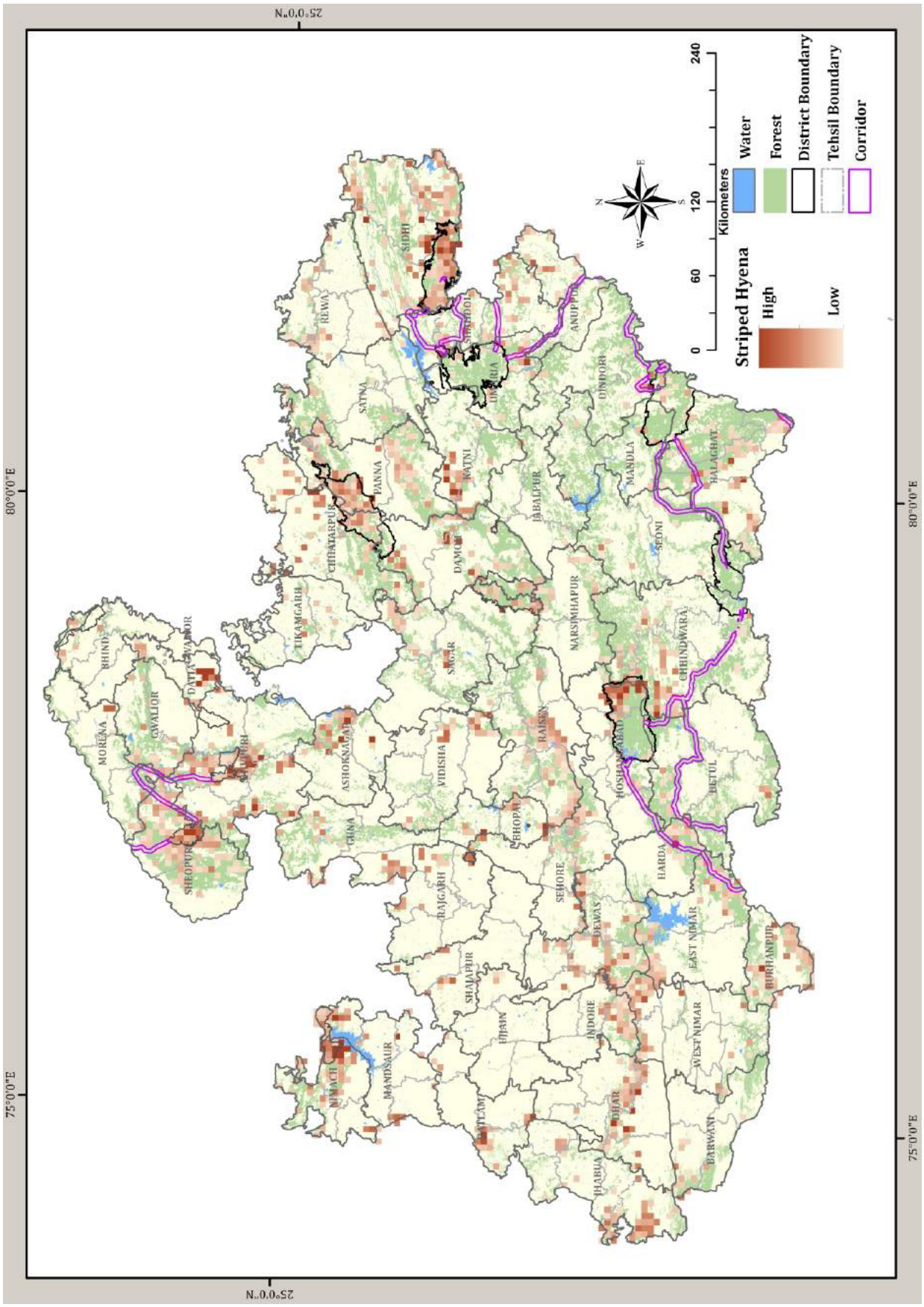

Figure 18: Relative abundance of striped hyena overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

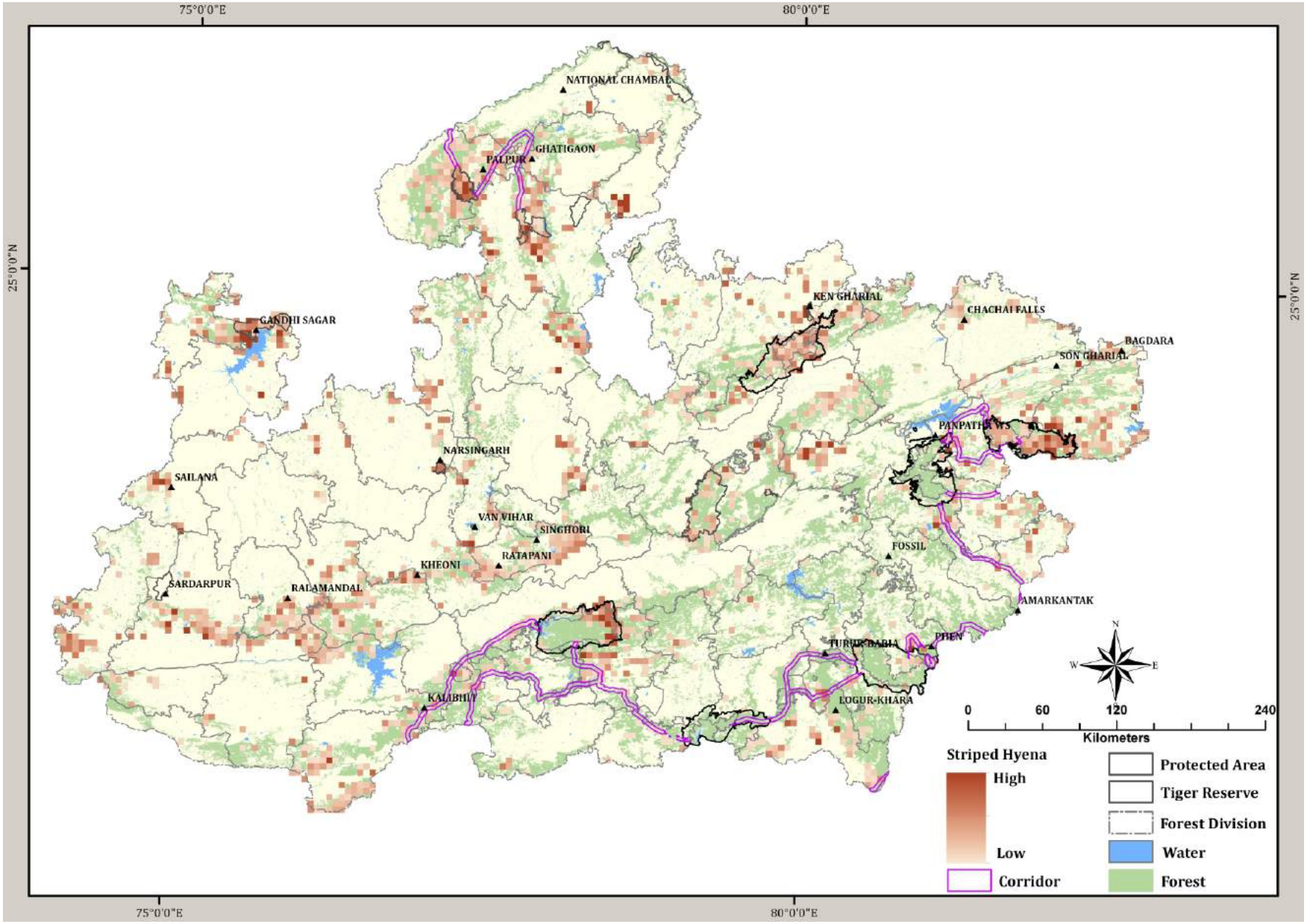

Figure 19: Relative abundance of striped hyena overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

4.1.7 Relative abundance of Grey Wolf:

Wolves are mainly adapted to open scrubland, grassland and semi-arid agro-pastoral habitats. Other than Sanjay-Dubri Tiger Reserve and Nauradehi and Gandhi Sagar Wildlife Sanctuary, wolf signs are mostly abundant outside protected areas. Devsar tehsil of Sidhi, Shivpuri and Kolaras tehsils of Shivpuri, Sheopur tehsil of Sheopur, Ratlam tehsil of Ratlam, Parasia tehsil of Chhindwara, Pawai tehsil of Panna, Murwara tehsil of Katni district have relatively abundant wolf populations. The relative abundance of wolf was found to be scattered in other sampled forest areas of the state (Figure 20, 21).

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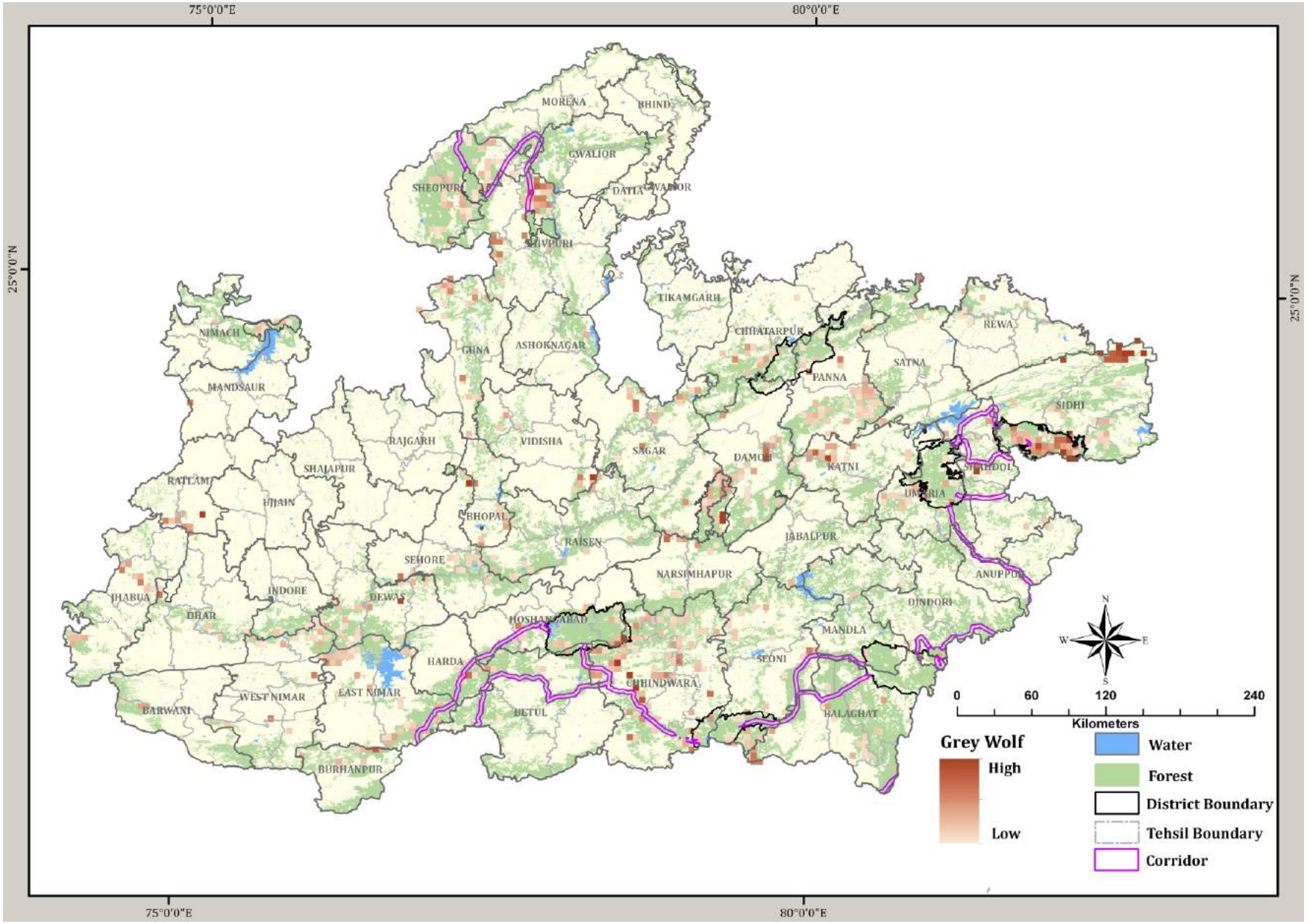

Figure 20: Relative abundance of grey wolf overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

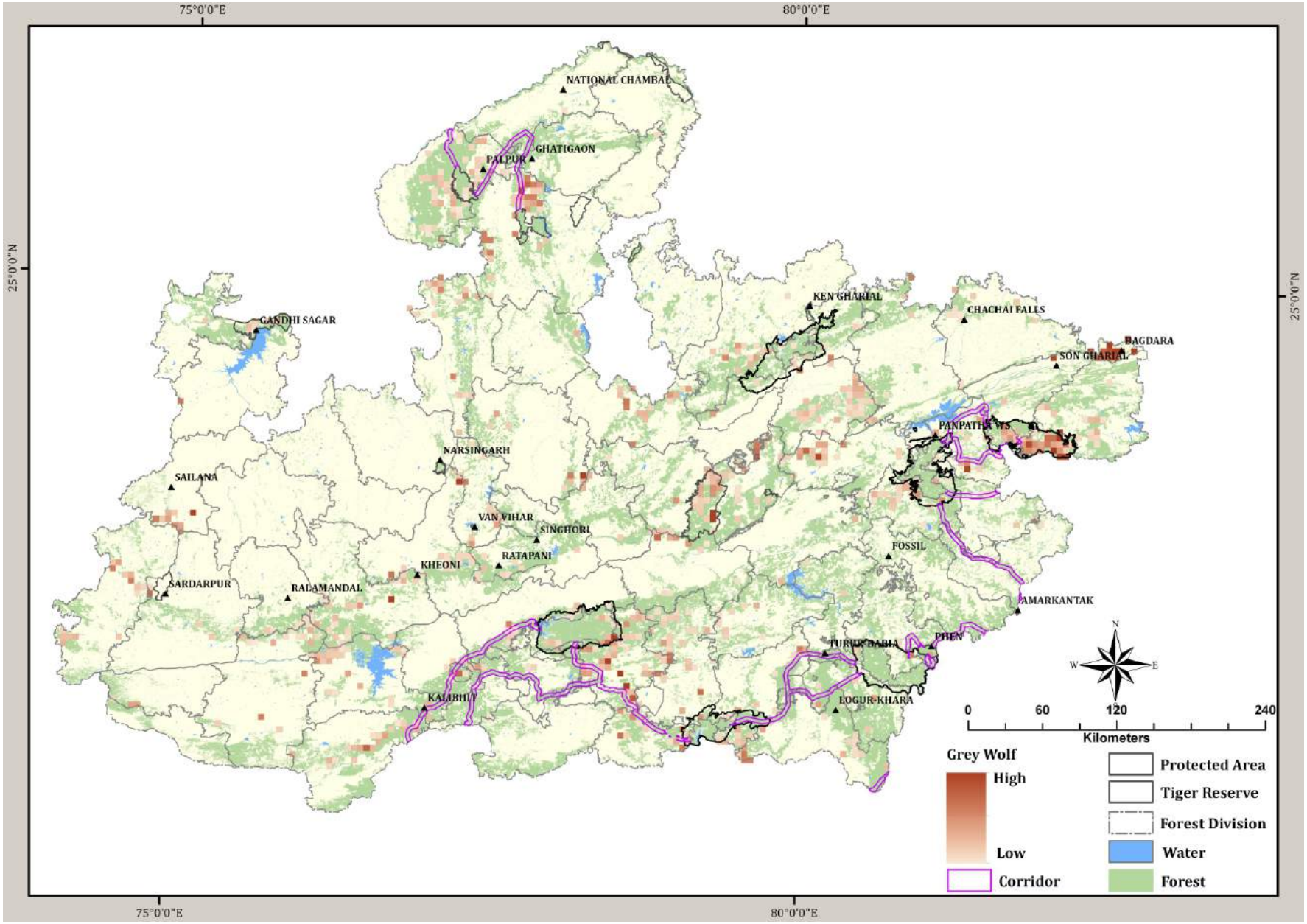

Figure 21: Relative abundance of grey wolf overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

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4.2 Abundance of Ungulates in Madhya Pradesh

4.2.1 Chital (*Axis axis*)

Chital, an endemic cervid of South Asia, are a common and widespread ungulate in the protected areas of Madhya Pradesh. The maximum densities of chital are reported from dry and moist deciduous forests; especially with adjoining grasslands or dry thorn scrub. In Madhya Pradesh chital were found to be occupying 28,925 km^2 of forested area.

Individual density of chital was found highest for teak and teak mixed habitat (9.98±0.77 per km^2) followed by sal and sal mixed habitat (7.71±0.78 per km^2) in forest areas which had been surveyed during Phase I sampling (Table 25). Density of chital found to be relatively low in miscellaneous habitats (3.18±0.08 per km^2) (Table 25). After relocation of villages and better protection, Kuno has shown a great increase in chital abundance since 2006, from 4.36±1.03 to 39.84±6.54 per km^2 (Benerjee 2005, Jhala *et al.* 2015).

Kanha-Pench corridor which traverses through Seoni and North Balaghat forest divisions has a high relative abundance of chital. Most part of the Pawai tehsil of Panna, Bijawar tehsil of Chhatarpur, Kannod tehsil of Dewas, Jabalpur tehsil of Jabalpur and Waraseoni tehsil of Balaghat district have high relative abundance of chital (Figure 22, 23).

Chital faces threat from poaching, free-ranging dogs, and from intensive livestock grazing. Protection from these threats via managerial efforts can reduce livestock depredation by large carnivores, and therefore can mitigate the human-wildlife conflict to a great level. Chital are relatively poor dispersers and require contiguous habitat corridors for dispersal that are relatively disturbance free and are therefore good indicators of conservation efforts.

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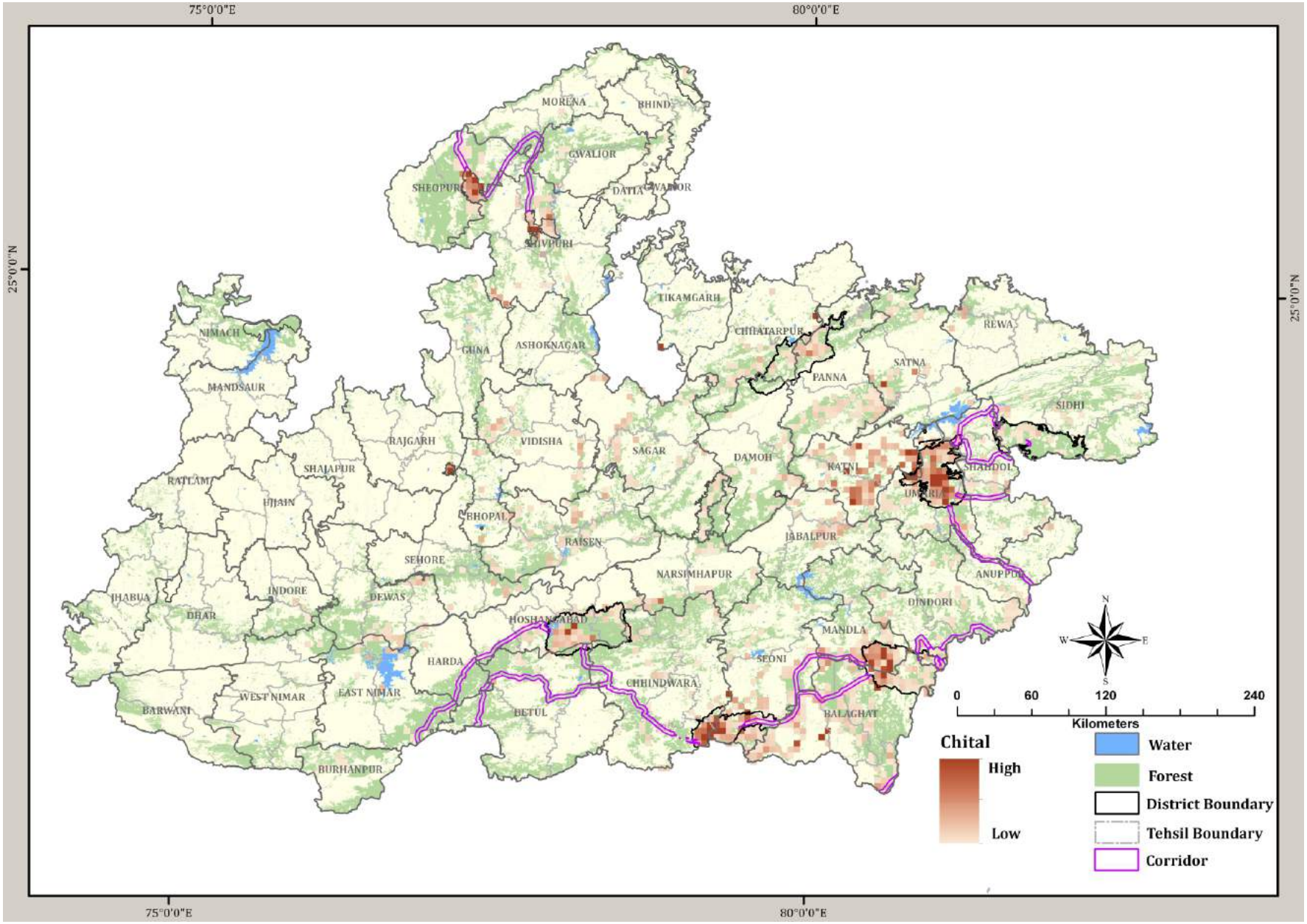

Figure 22: Relative abundance of chital overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

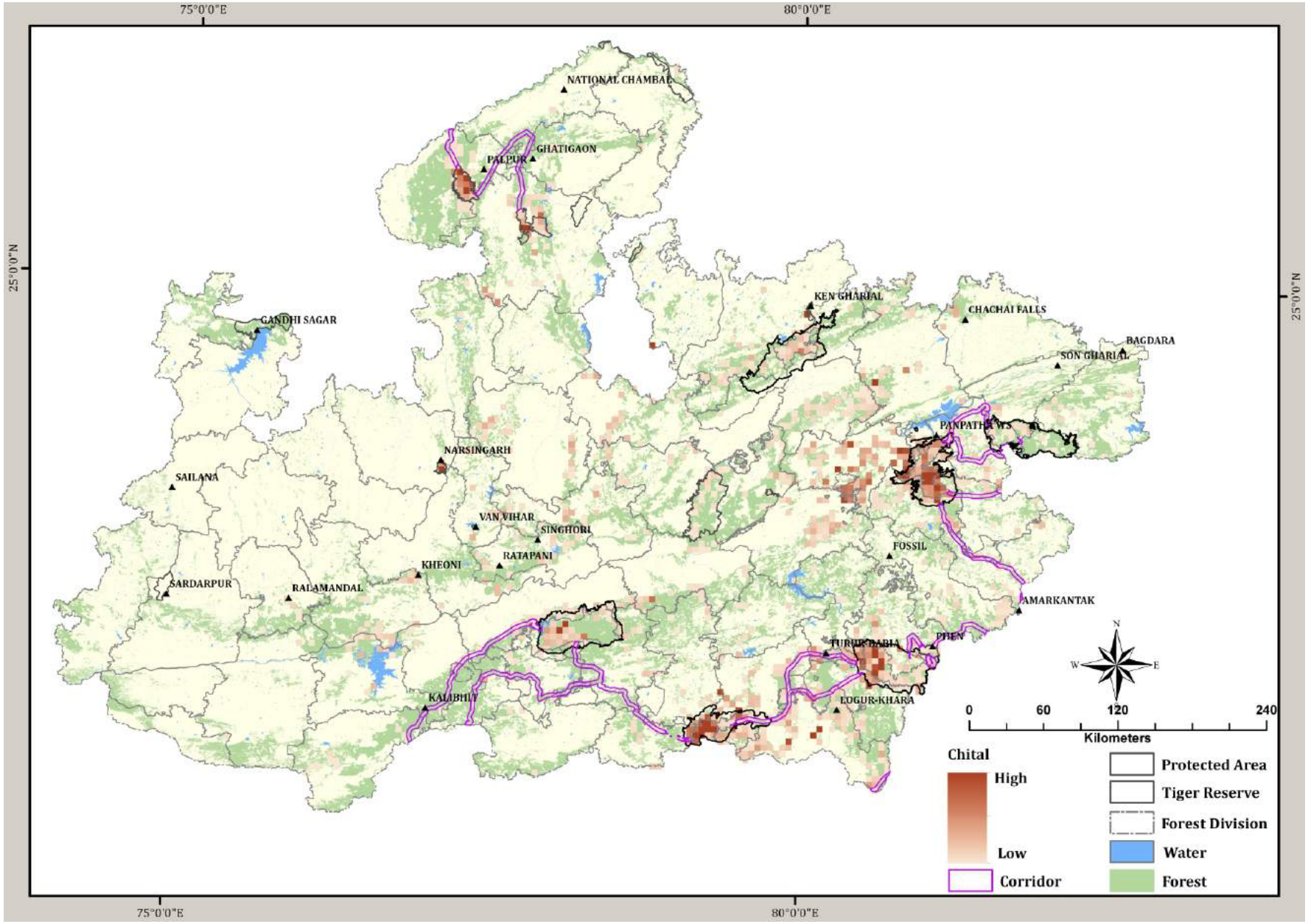

Figure 23: Relative abundance of chital overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh

4.2.2 Sambar (*Rusa unicolor*)

Sambar is the largest deer among the seven deer species found in South Asia and is adapted to survive in a wide variety of habitats. Sambar prefers forests with dense canopy cover, and is highly dependent on protection. Forest patches of eastern and southern Madhya Pradesh have an almost contiguous distribution of sambar.

Individual density of sambar in Phase I sampled area found to be almost same in miscellaneous (3.93±0.15 per km^2), and sal and sal mixed habitats (3.71±0.71 per km^2). Whereas in teak and teak mixed habitat sambar density is 2.68±0.26 per km^2 (Table 25). Sambar occupies 18,850 km^2 in surveyed forested area of Madhya Pradesh.

Besides major protected areas, Bijawar tehsil of Chhatarpur, Pawai tehsil of Panna, Murwara tehsil of Katni district acts as a refuge for sambar populations. Sambar abundance is extremely low in south-western Madhya Pradesh, except for a few areas of Harsud tehsil of East Nimar district. On account of being one of the principle prey species of large carnivores, presence of sambar in various forested patches plays a key role in the functional movement of carnivores (Figure 24, 25) through corridors and is an important element for their meta population existence.

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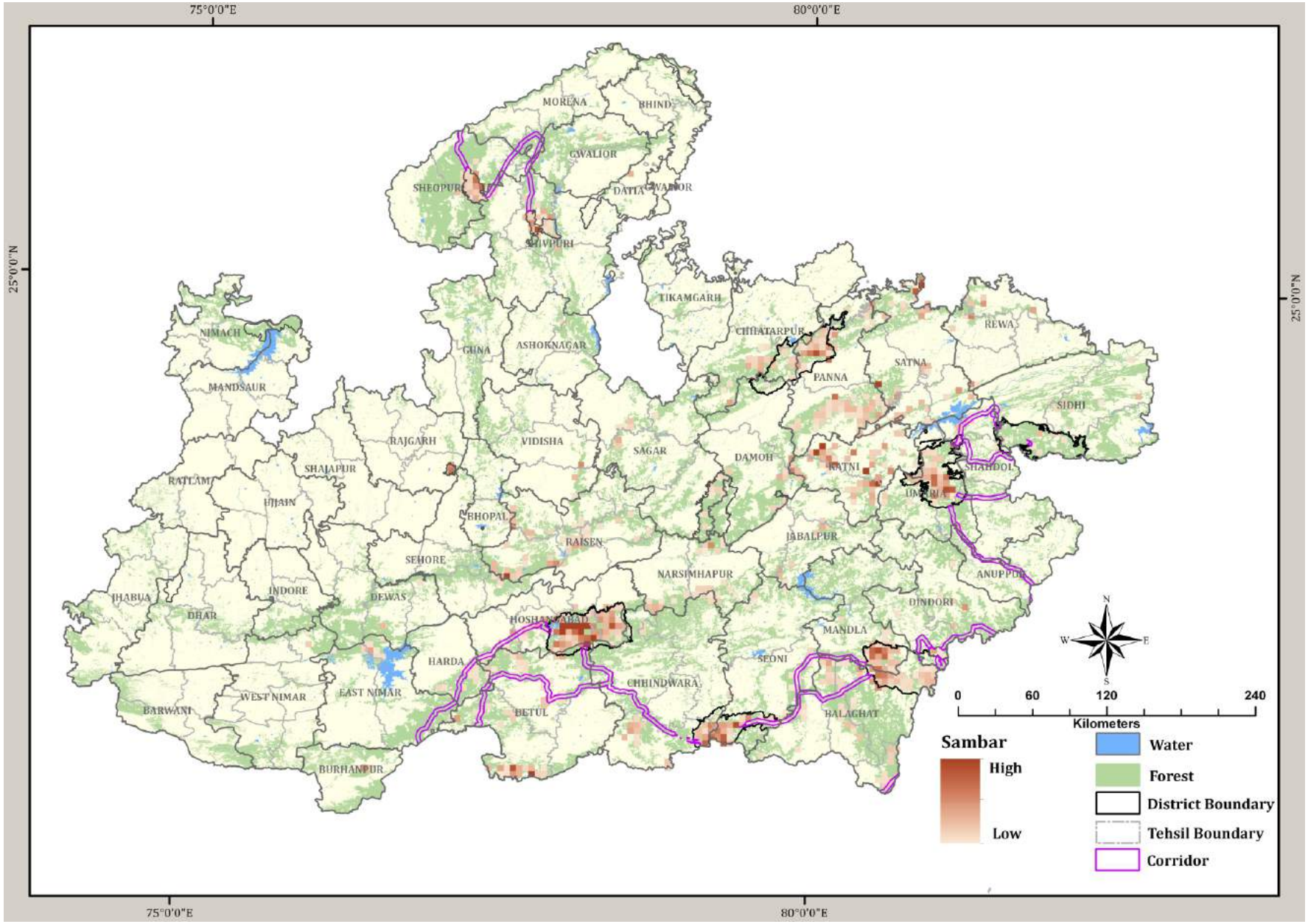

Figure 24: Relative abundance of sambar overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

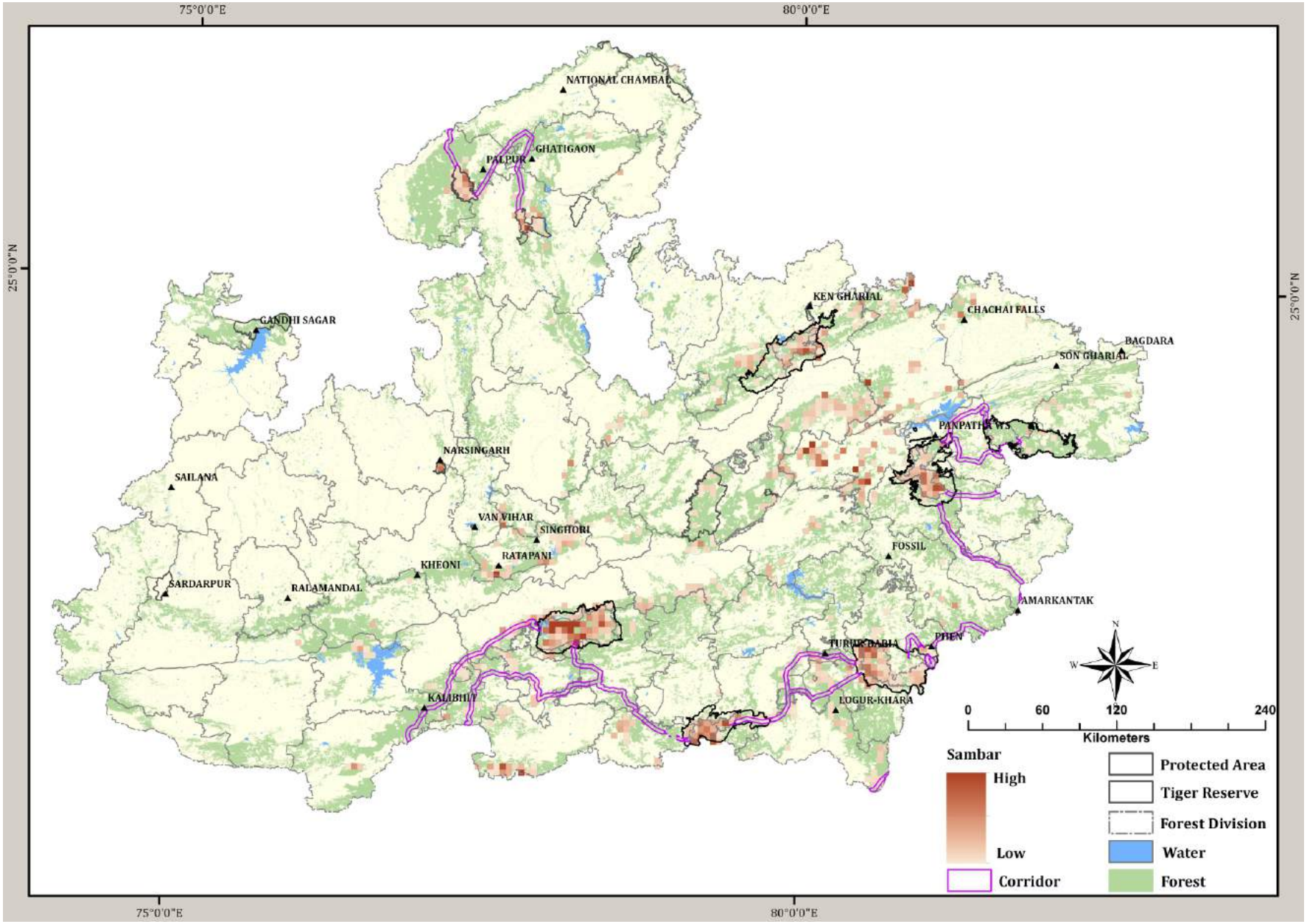

Figure 25: Relative abundance of sambar overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

4.2.3 Gaur (*Bos gaurus*)

Gaur, the largest living bovine and bulk feeder, is an indicator of good habitat. Gaur populations were primarily restricted to Protected Areas with scattered records within connecting corridor habitats and surrounding forests of Protected Areas. Gaur is known for its local migration patterns, usually movements between foraging sites (Schaller 1967). Degradation of connectivity of Bandhavgarh National Park was one of the important factors responsible for the species becoming locally extinct and finally having to be reintroduced. Importantly Kanha-Pench-Achanakmar and Satpura-Melghat landscape hold promise for meta-population existence of Gaur in the Central Indian landscape (Jhala *et al.* 2011). Forested area occupied by gaur in Madhya Pradesh is only 3450 km^2 and mostly in the south of Narmada river. Gaur density is estimated only for miscellaneous habitat, as observation of gaur in other habitats were too few for analyses. Gaur density for the miscellaneous habitat is found to be 2.27±0.31 per km^2, which has been estimated for the Phase I surveyed area subjective to gaur presence (Table 25).

Gaur abundance is medium to low through Kanha-Pench corridor. Baihar and Waraseoeni tehsil of Balghat, Niwas tehsil of Mandla, and Dindori tehsil of Dindori district have low gaur abundance. Proper measures should be taken to ensure the persistence of connectivity between protected areas as these are important for the movement of large ungulates like gaur (Figure 26, 27). Major threats to gaur population are fragmentation of forests, disease and illegal hunting.

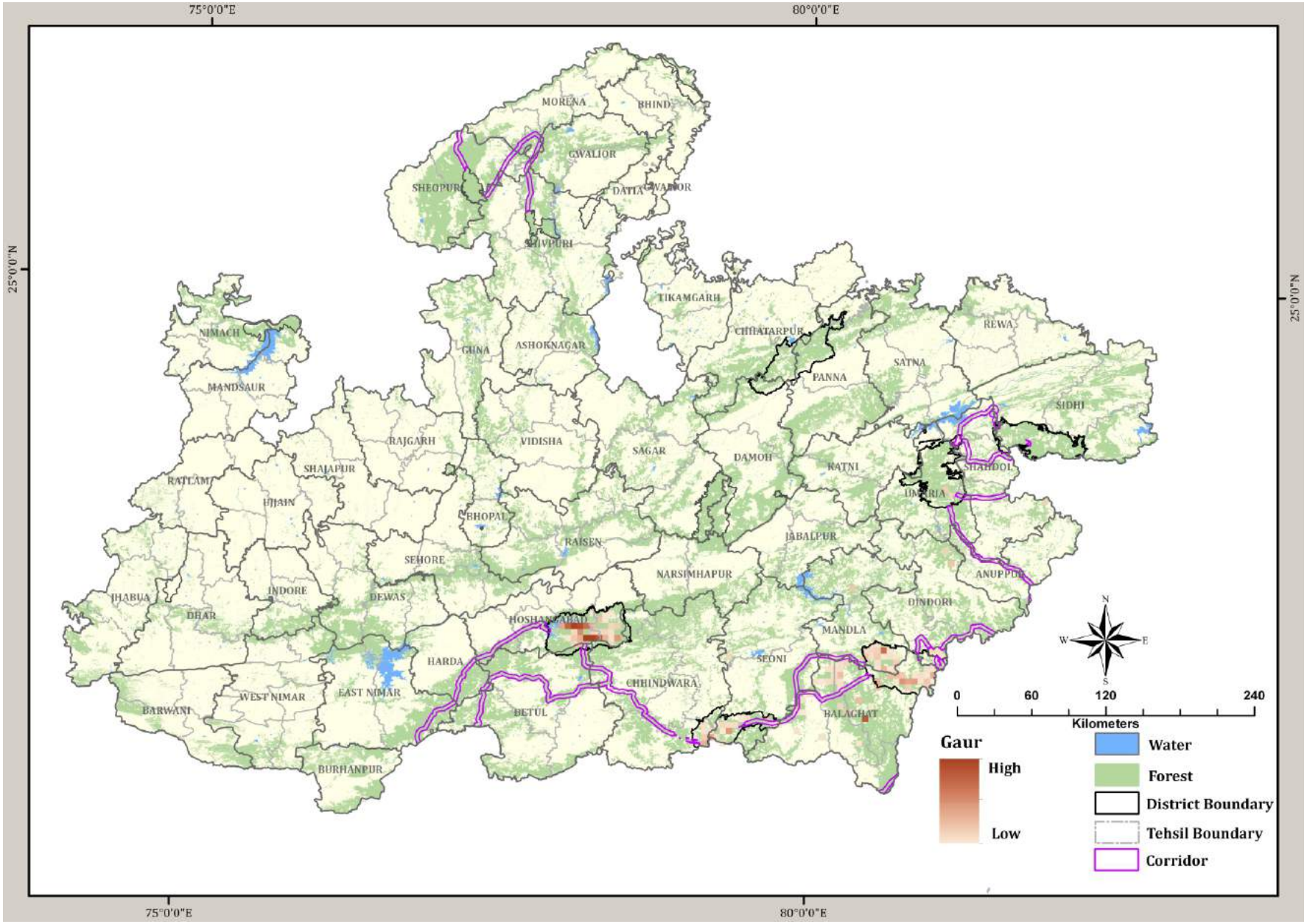

Figure 26: Relative abundance of gaur overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

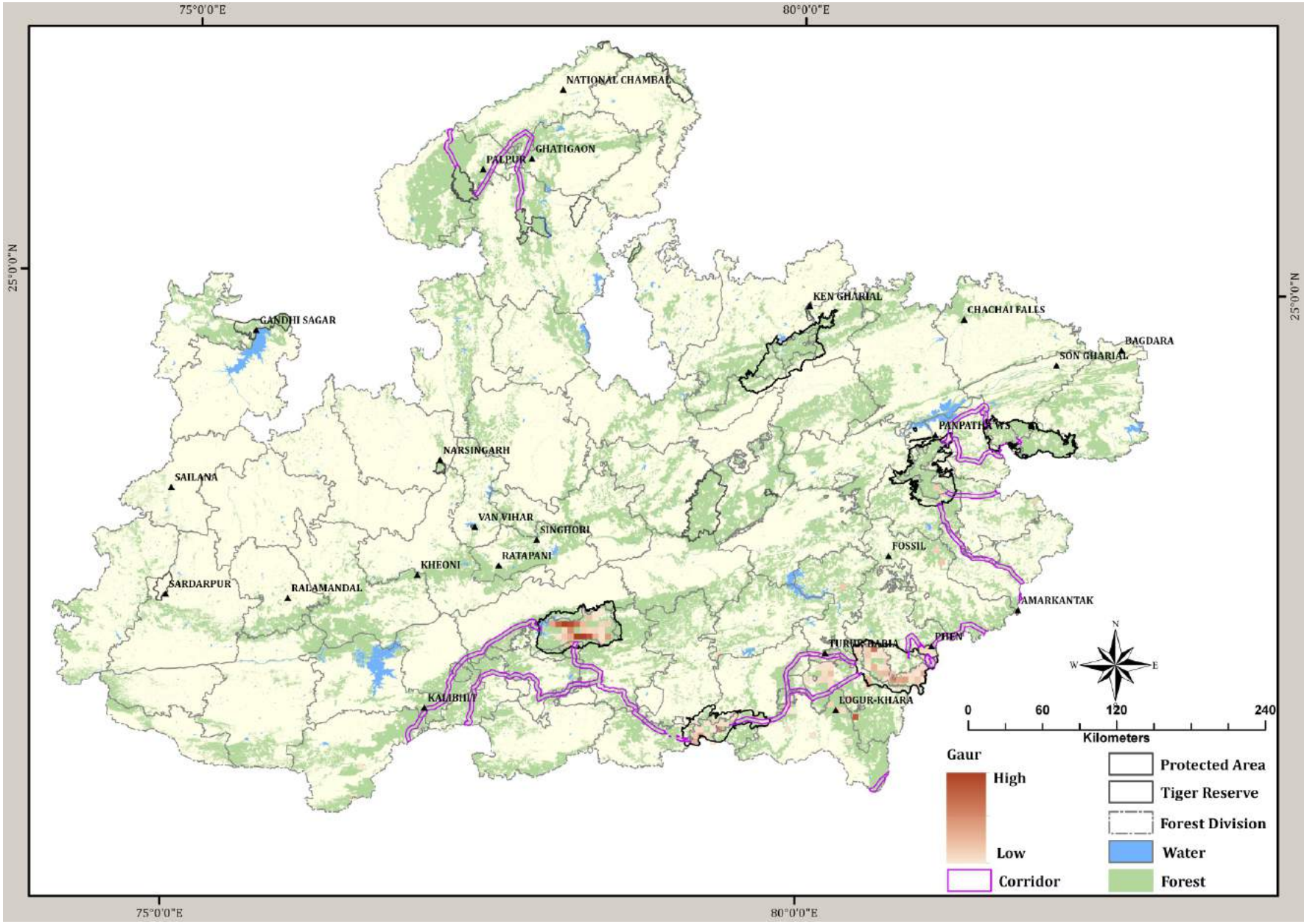

Figure 27: Relative abundance of gaur overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

4.2.4 Barking Deer (*Muntiacus muntjac*)

Barking deer is a small and solitary deer which are found over most of the oriental biogeographic region of the world (Prater 2005) often recorded as pairs that show site fidelity and territoriality. Barking deer is difficult to survey due to difficulty in its detection in the undergrowth with any acceptable level of precision. Barking deer is abundant in the dense peninsular sal and teak forest of Madhya Pradesh. Barking deer was recorded to occupy 32,300 km^2 of forested area in Madhya Pradesh. Various corridor habitats like Satpura-Melghat corridor and Kanha-Pench corridor have continuous distribution of barking deer which serves as prey for movement of carnivores across these corridors.

Mhow tehsil of Indore, Bagli and Kannod tehsils of Dewas and Goharganj tehsil of Raisen district on northern banks of Narmada river have more or less contiguous distribution of barking deer than other districts (Figure 28, 29). Forested habitat is important for barking deer. For that reason, barking deer are likely to suffer from habitat degradation resulting from livestock grazing, wood cutting or fodder collection.

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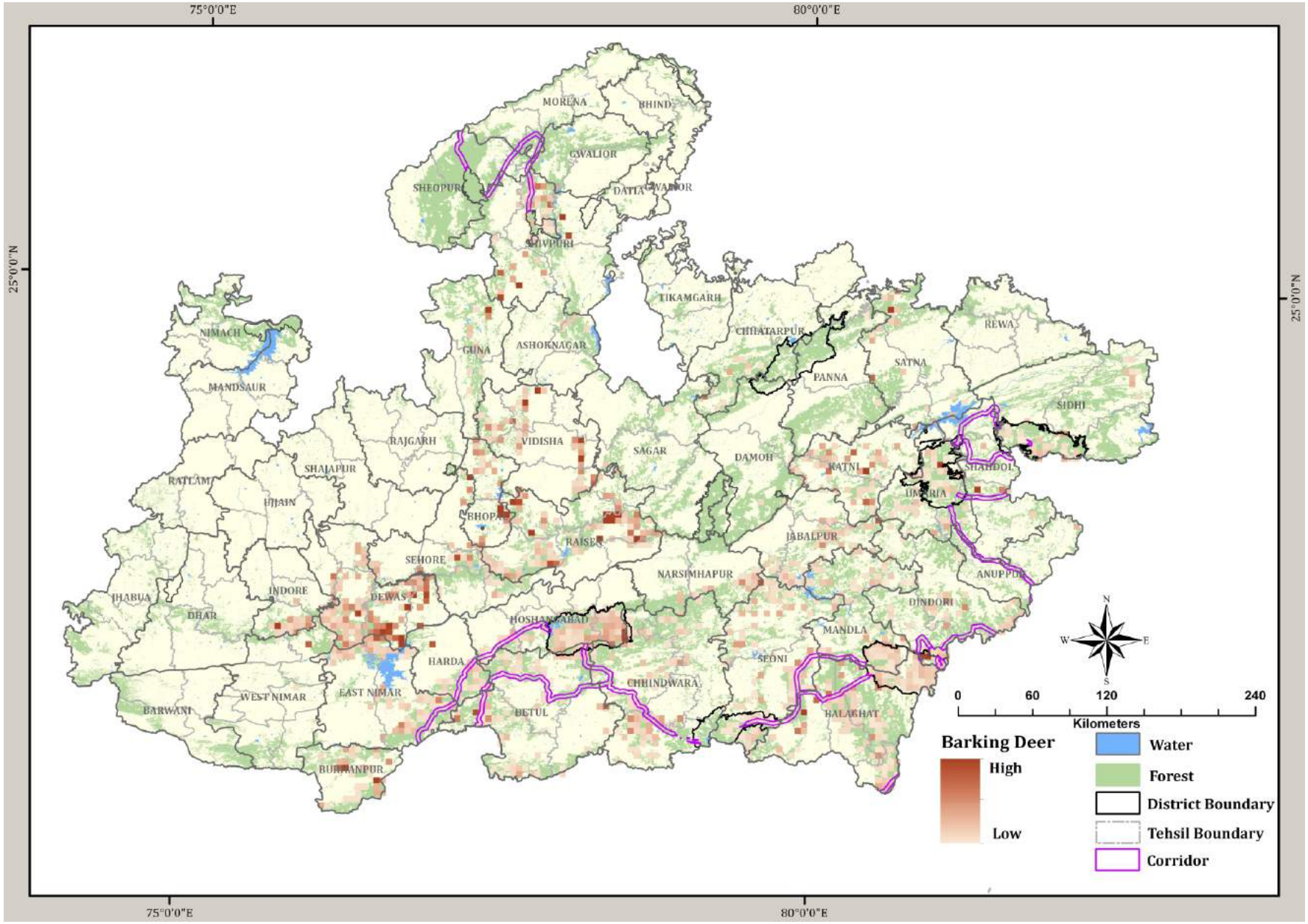

Figure 28: Relative abundance of barking deer overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

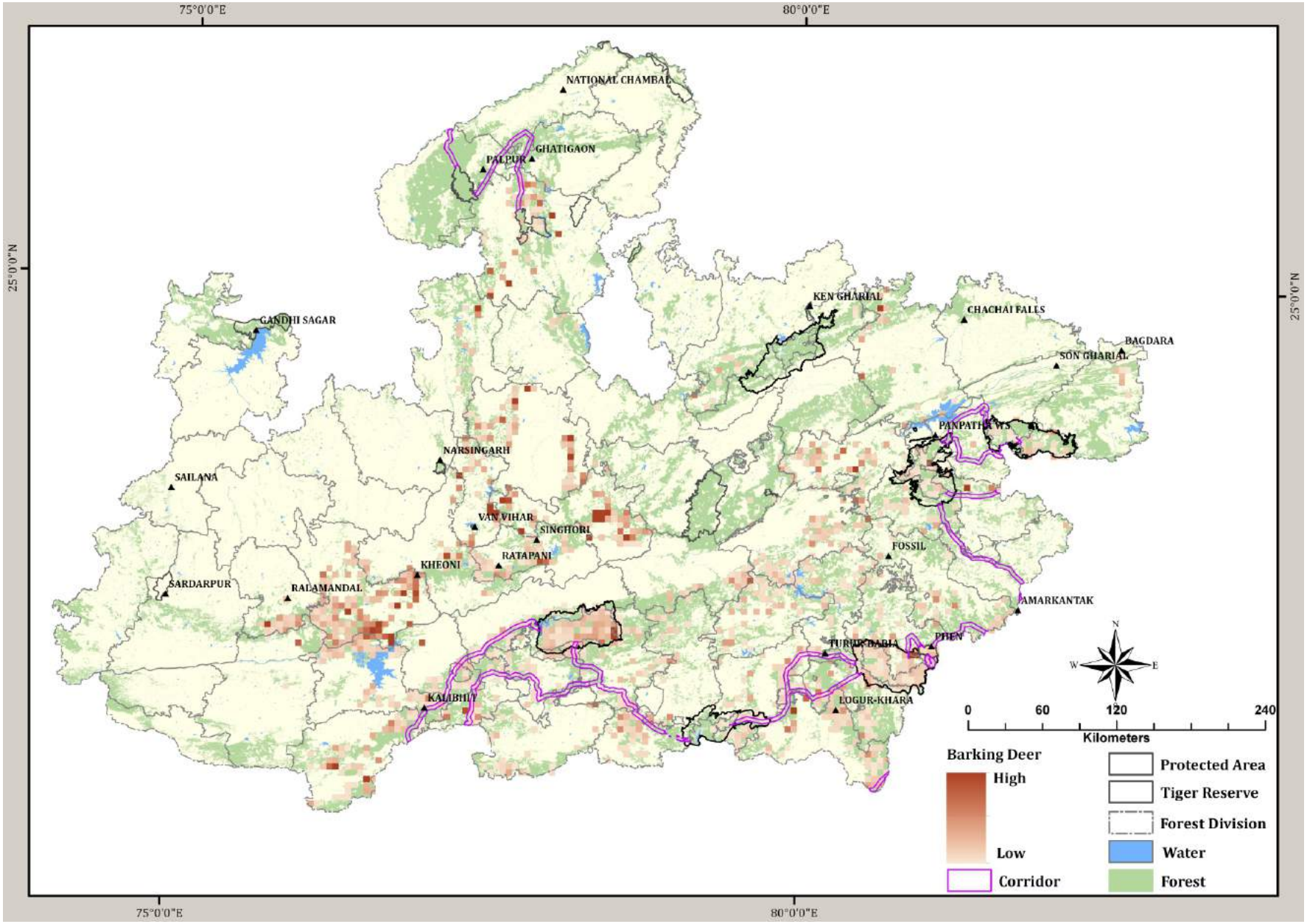

Figure 29: Relative abundance of barking deer overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh

4.2.5 Nilgai (*Boselaphus tragocamelus*)

Nilgai, the largest antelope species in Asia, are endemic to India. Nilgai occupy variety of habitats, but avoids dense forests and steep hills (Blanford 1888, Prater 2005). Except for a few forest divisions of south eastern Madhya Pradesh, Nilgai is abundant in most sampled forest area. Out of the total sampled area Nilgai were found to occupy 59,325 km^2 area of Madhya Pradesh, which is highest among all ungulate.

Districts with a high relative abundance of nilgai are Rewa, Satna, Panna, Chhatarpur and Tikamgarh in North-eastern part, Shivpuri, Datia, Gwalior and Bhind in Northern part, Nimach, Shajapur and Dewas in Western part, and Katni, Damoh, Sagar, Vidisha and Bhopal in Central part. The Central highlands biogeographic province have a high abundance of nilgai in forested areas as well as agricultural pastures (Figure 30, 31).

Gradual degradation of dense forests to open scrub with bordering agricultural pastures and change in cropping pattern has favored the increase of nilgai population which in turn has made nilgai serious pests as crop raiders and a major concern of human-wildlife conflict.

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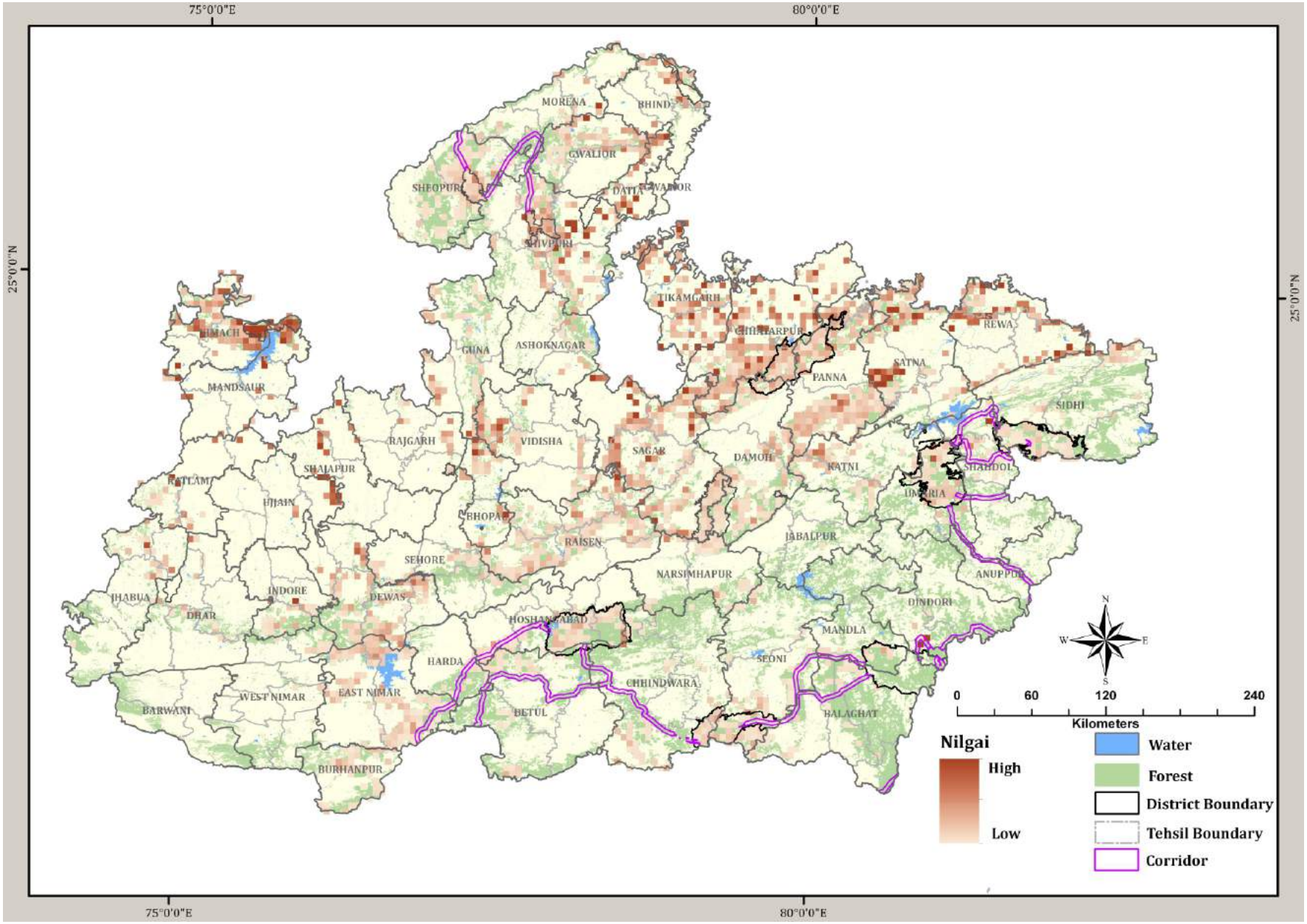

Figure 30: Relative abundance of nilgai overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

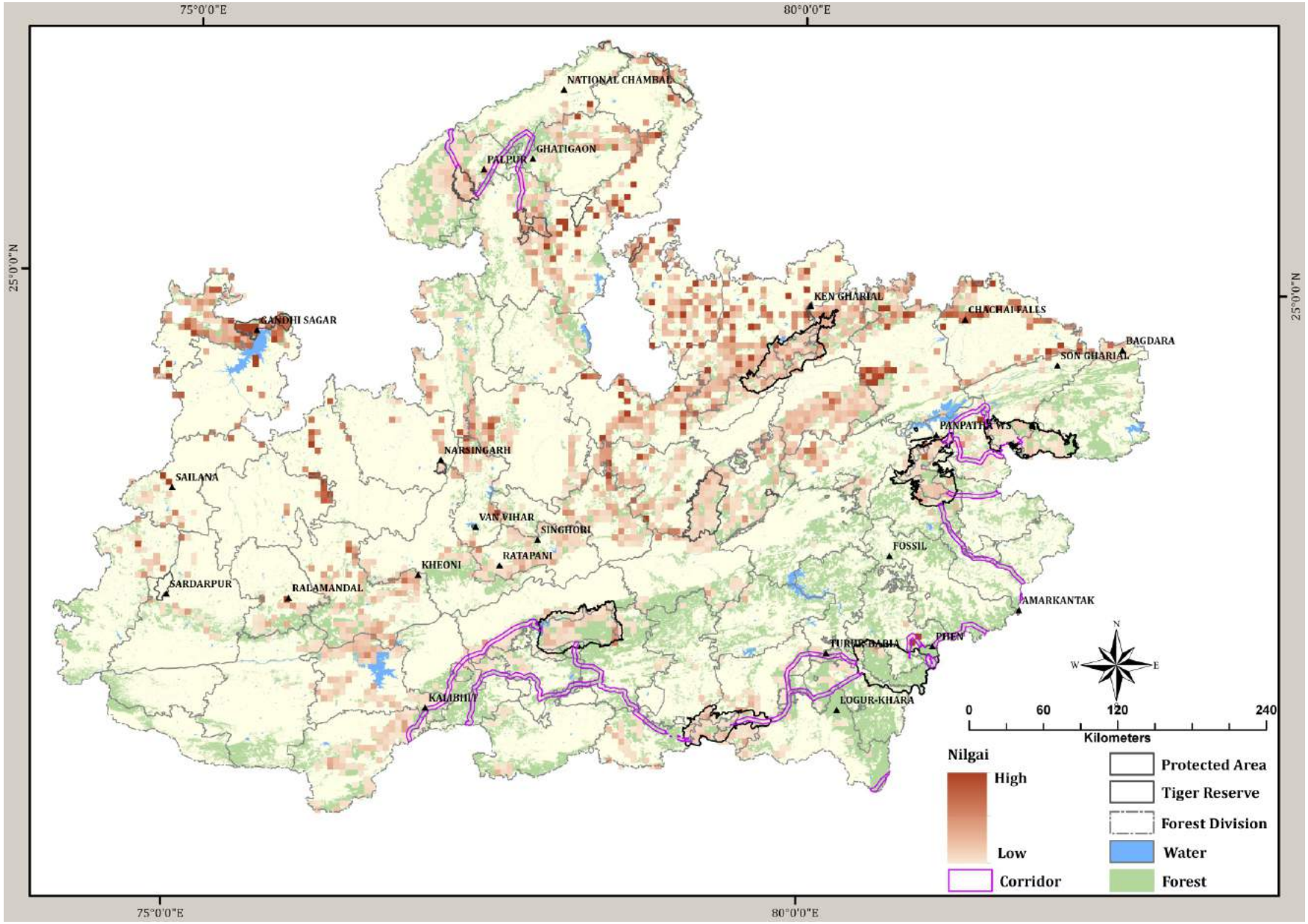

Figure 31: Relative abundance of nilgai overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

4.2.6 Wild Pig (*Sus scrofa*)

The wild pig is one of the most widely spread herbivore in Madhya Pradesh. Wild pig is distributed in wide variety of habitats, from semi-arid to dry deciduous and moist deciduous. The forested area occupied by wild pig in Madhya Pradesh is 58,600 km^2. Both northern and southern part of Narmada river has a continuous distribution of this species.

Habitat destruction and hunting pressure are main threats to wild pigs. As wild pigs utilize agro-ecosystem for food and shelter, they cause a high level of crop damage, and are a major concern for human-wildlife conflict. Abundance of wild pigs in different corridors is important for movement of large carnivores (Figure 32, 33).

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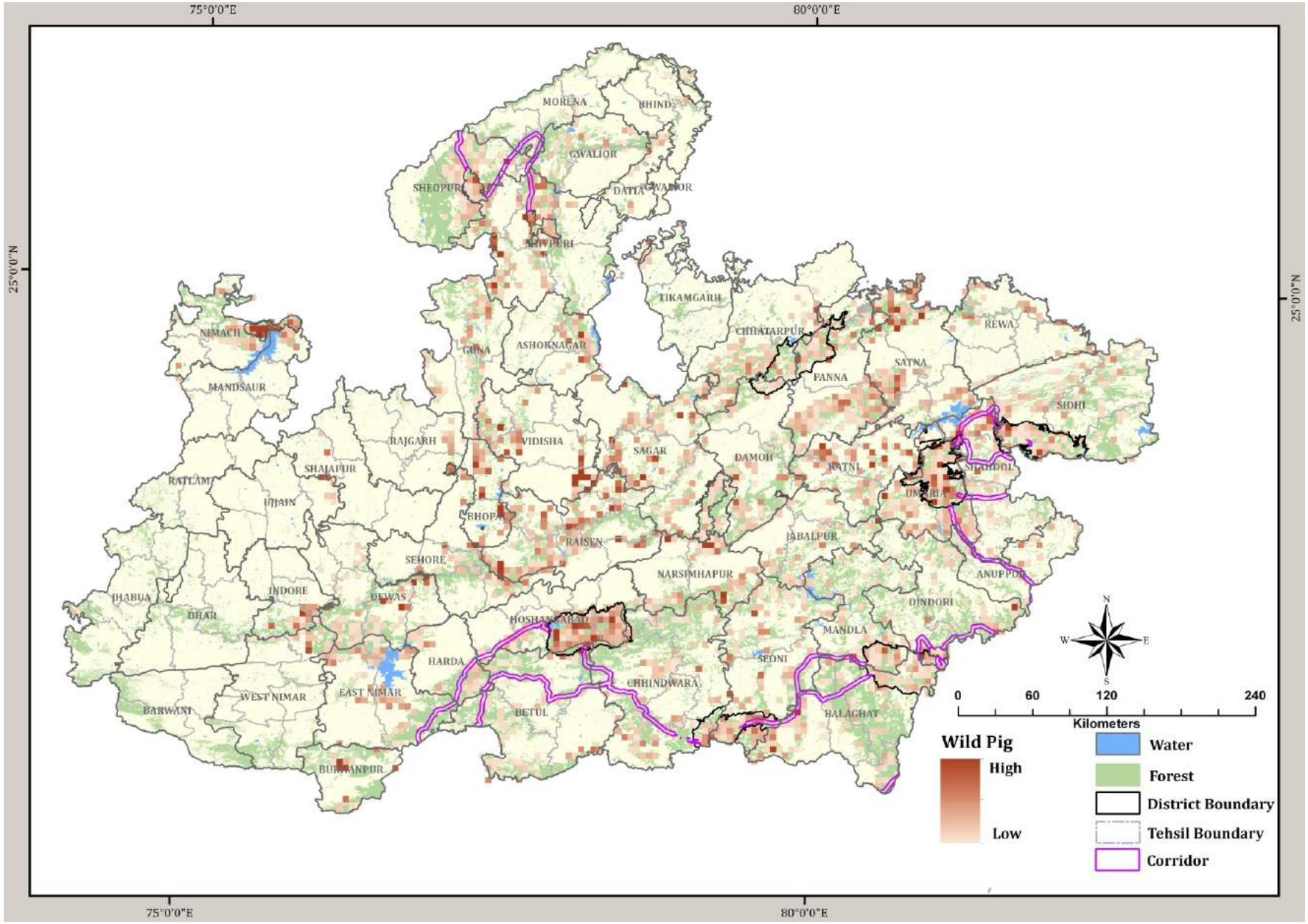

Figure 32: Relative abundance of wild pig overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh

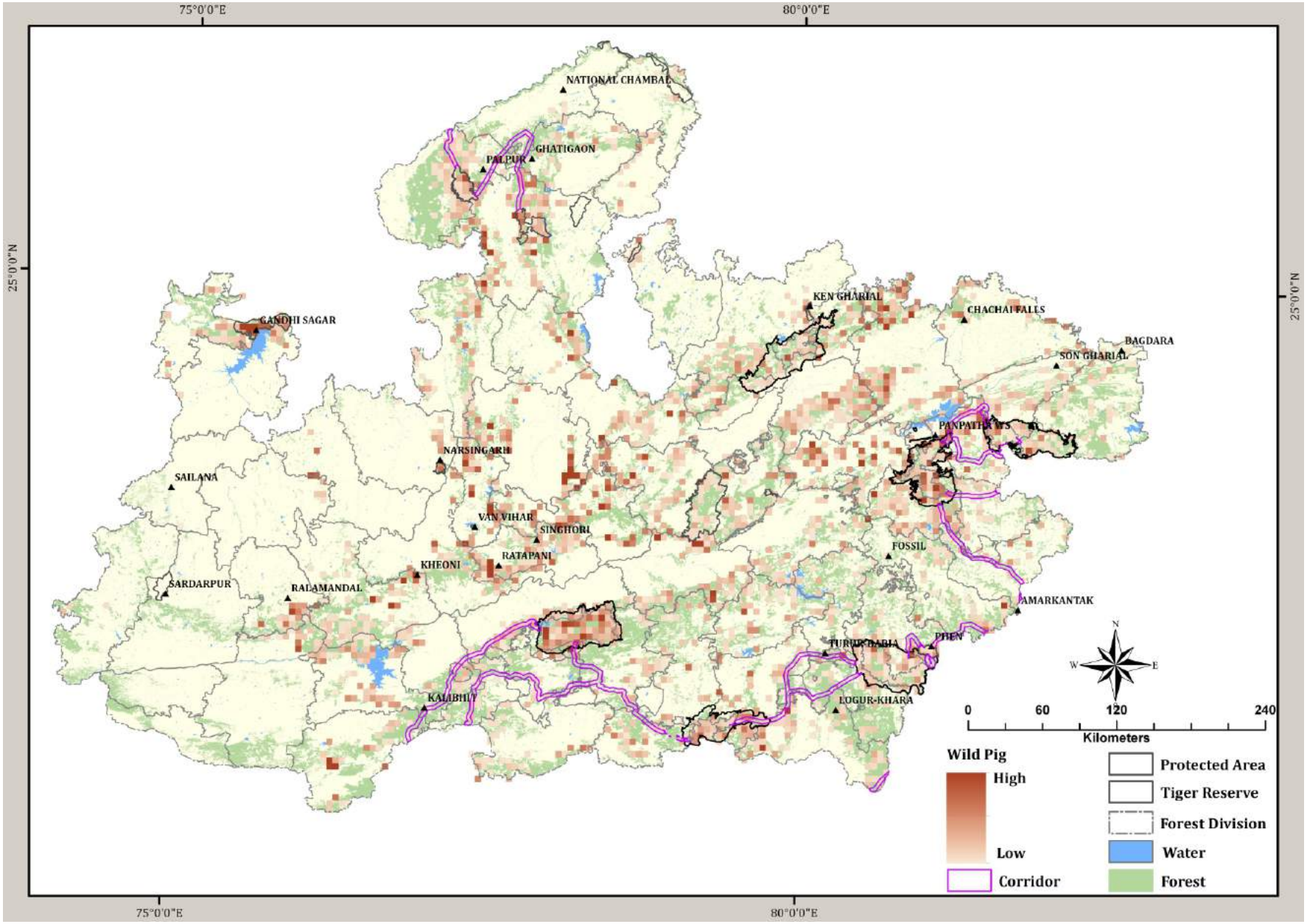

Figure 33: Relative abundance of wild pig overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

4.2.7 Barasingha (*Rucervus duvauceli branderi*)

The Central Indian barasingha is a highly endangered and endemic species. Historically, hard ground barasingha was spread across scattered pockets in Madhya Pradesh and Chattisgarh (Forsyth 1889). It has responded well to various scientific managerial and conservation efforts and recovered from the brink of extinction. This cervid inhabits marshy or swampy areas, open meadows and grasslands bordering sal forests. The Central Indian barasingha is a food specialist and exclusively graminivore and needs specific conservation efforts for long term survival. In the terai region, the extensive terai savannas and marshy tall grasslands favour these animals. But, in central India, the Branderi subspecies has adapted itself to the hard ground conditions. In this region, the deer favours grassy areas in moist pockets; the animals never move far away from water. Now they are distributed only in small pockets of Kanha National Park and as a recently translocated population in Satpura National Park. As the state animal of Madhya Pradesh, special managerial efforts are being made for the conservation of the species (Figure 34, 35).

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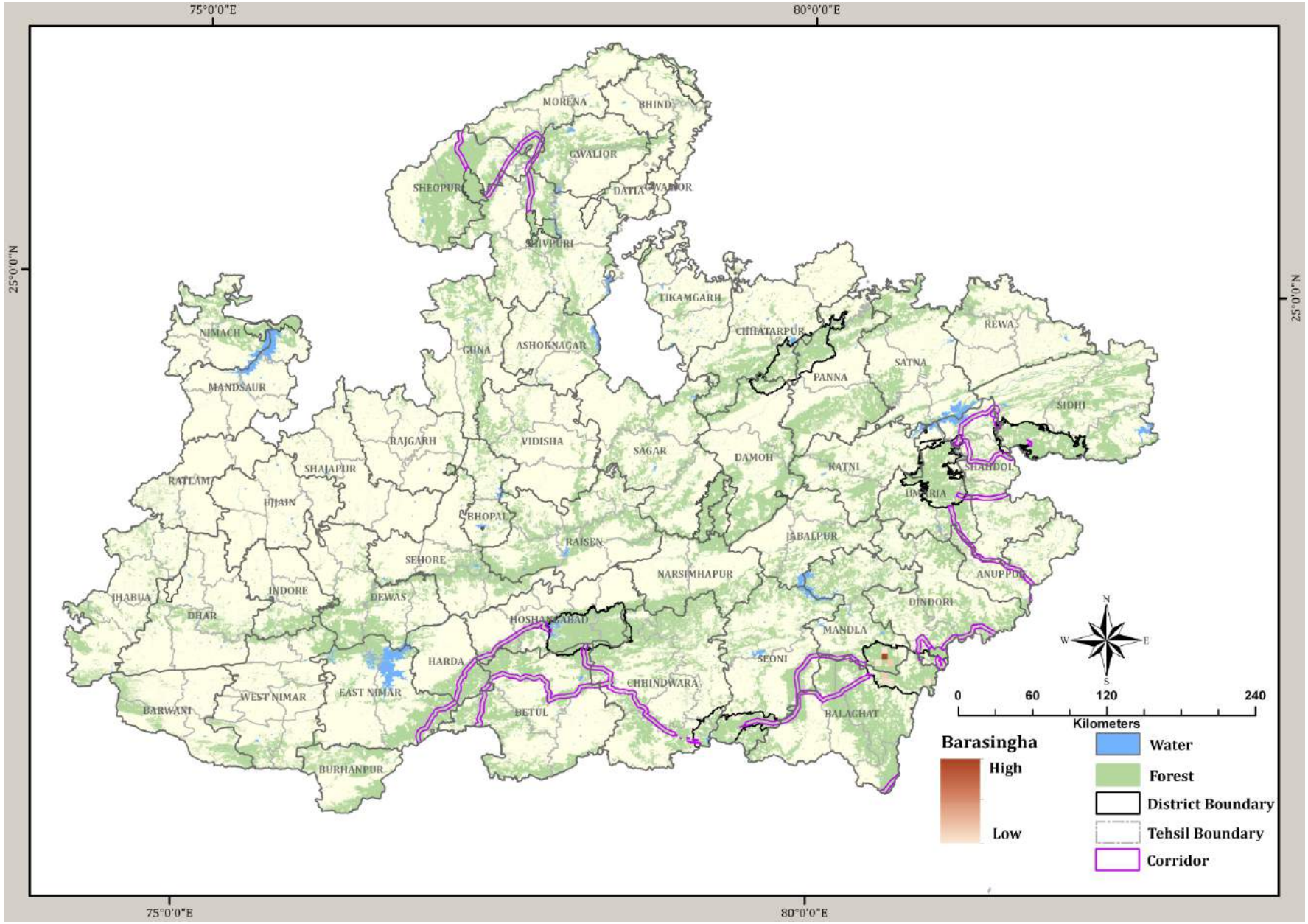

Figure 34: Relative abundance of barasingha overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

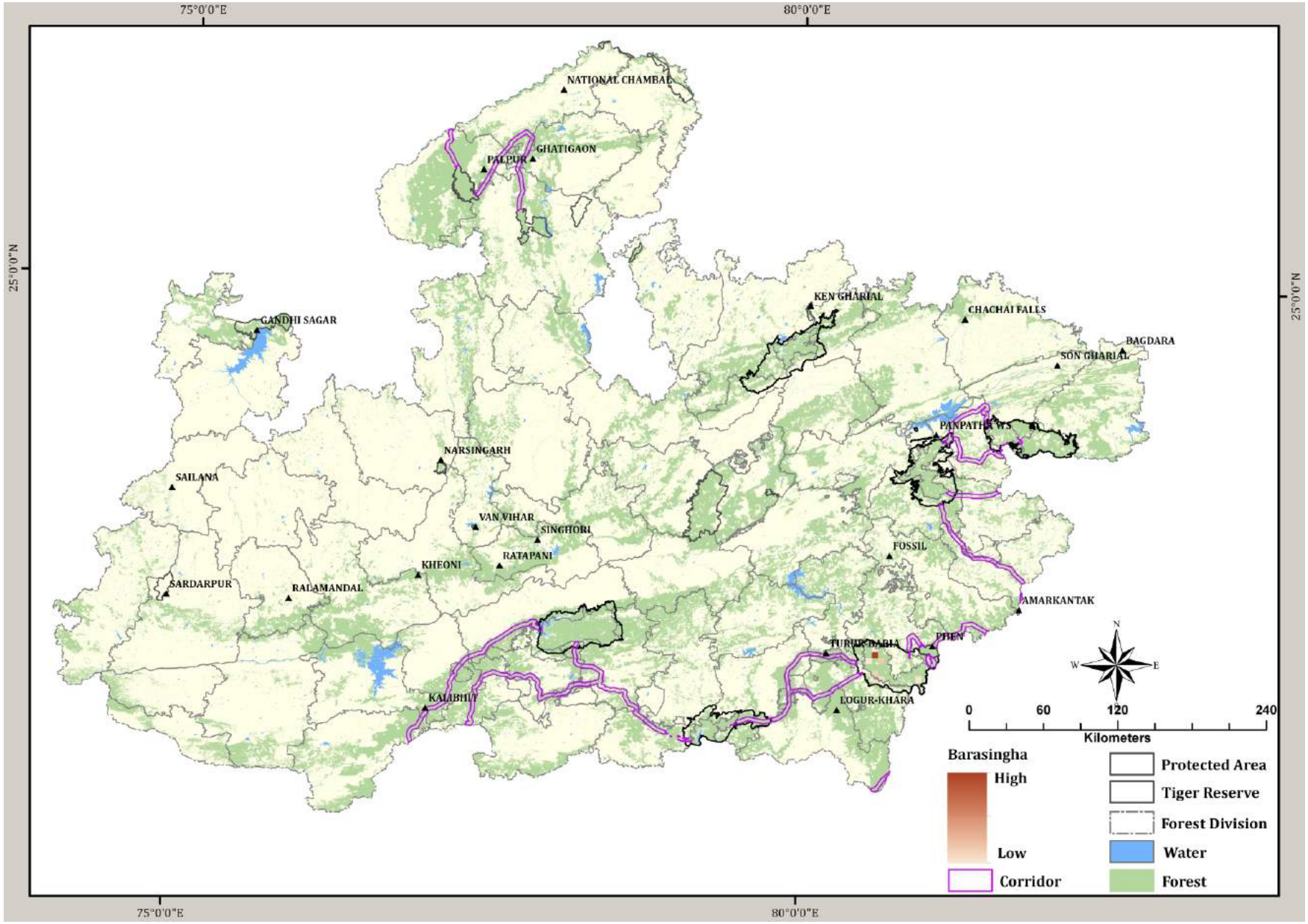

Figure 35: Relative abundance of barasingha overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh

4.2.8 Four-Horned Antelope or Chowsingha (*Tetracerus quadricornis*)

The chowsingha, listed as Schedule I species of WPA 1972, is a monotypic species of its genus and is endemic to India. It is sparsely distributed across Madhya Pradesh and nowhere found in high abundance. Only 2500 km^2 of surveyed forested area in the state is occupied by chowsingha. This skittish antelope inhabits dry deciduous forests and prefers forested areas to open grasslands. Kuno has a high relative abundance of chowsingha when compared to other protected areas of Madhya Pradesh. Few forested pockets of Shivpuri, Guna, Ashoknagar, Raisen, Bhopal, Chhindwara, and Jabalpur district have low to medium relative abundance of chowsingha population (Figure 36, 37). Chowsingha faces threats from habitat destruction and habitat alteration. As an unique and endemic species, chowsingha needs more scientific research and conservation efforts.

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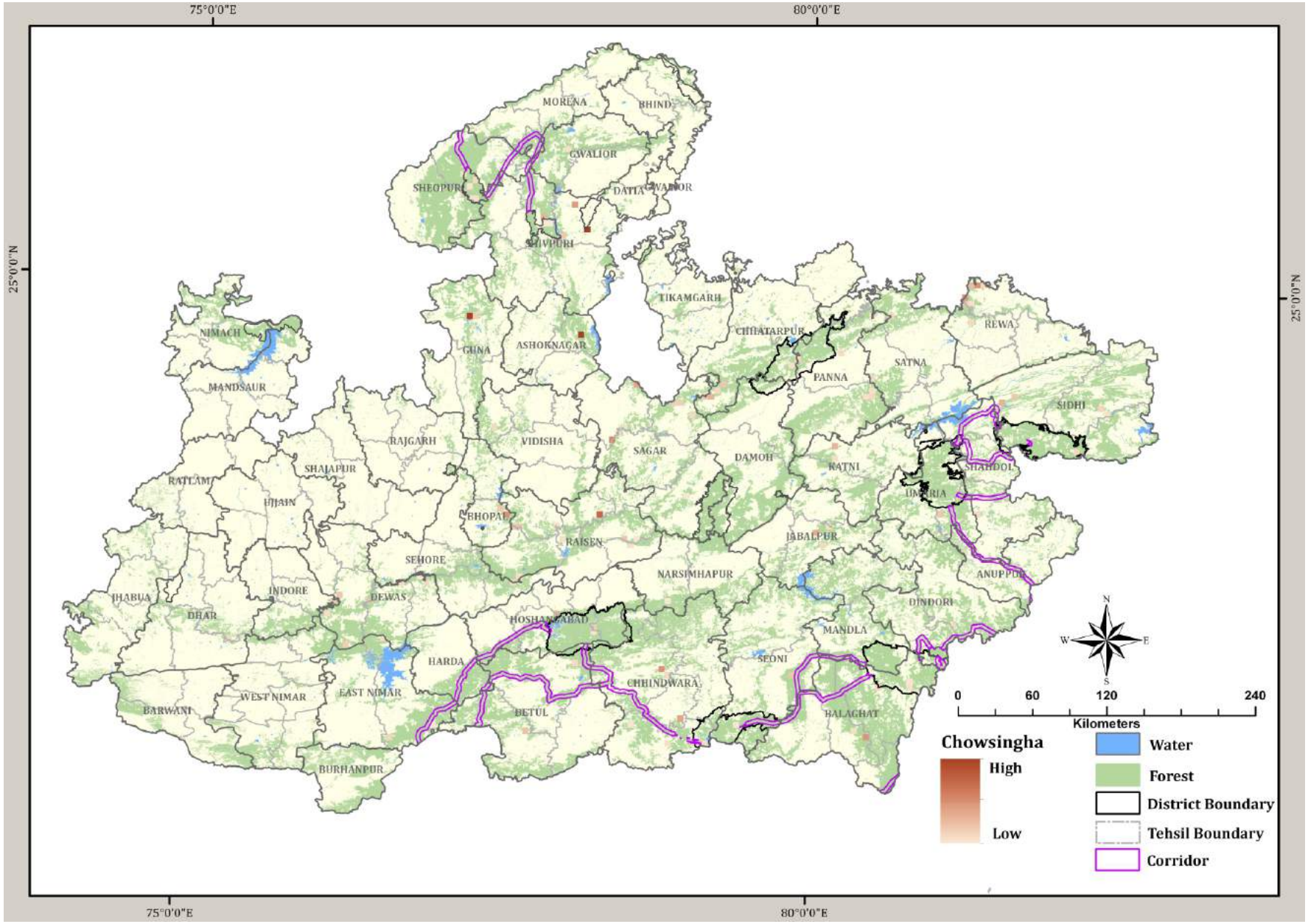


Figure 36: Relative abundance of chowsingha overlaid on forest cover, corridors, tehsil and district boundaries of Madhya Pradesh.

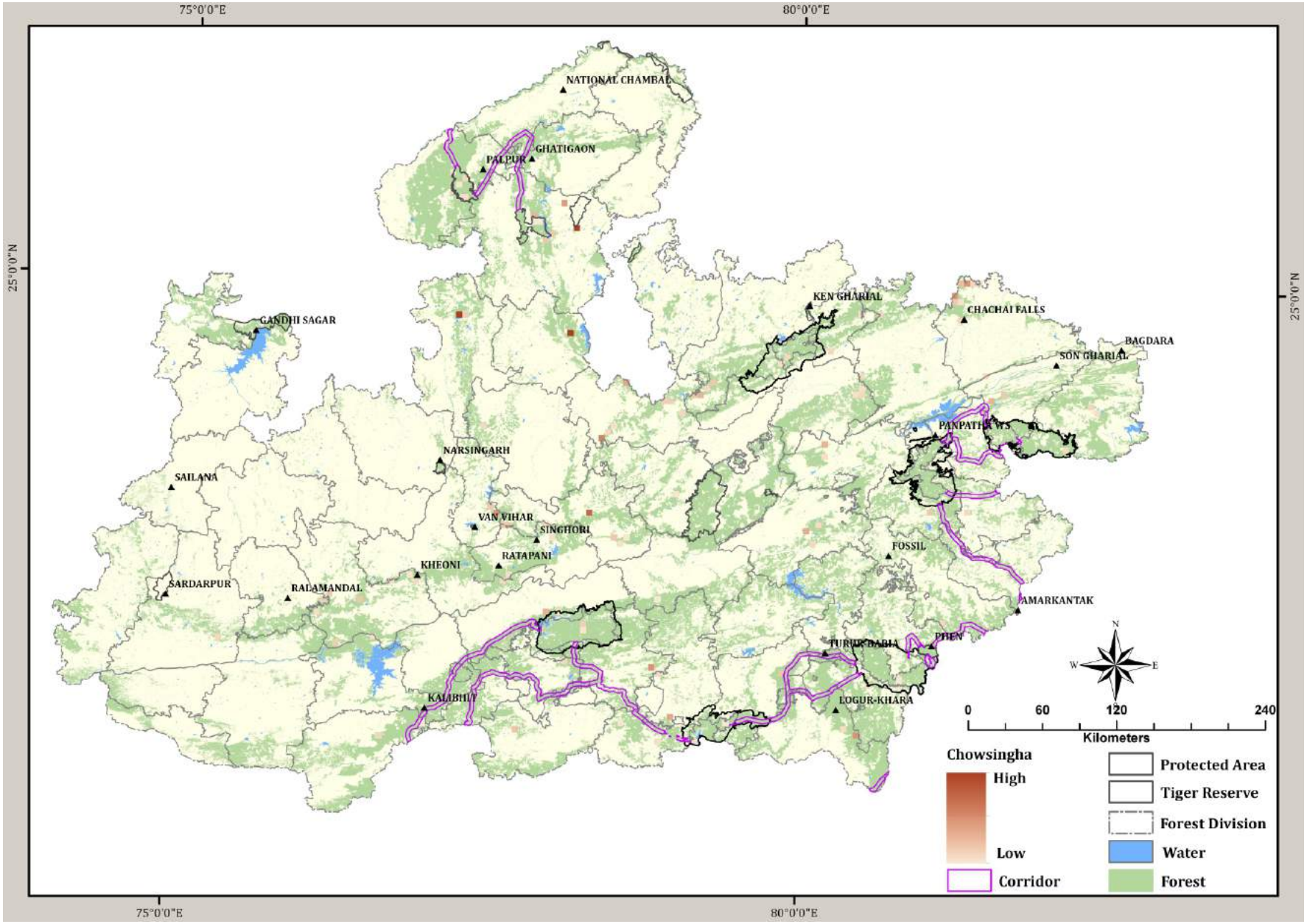


Figure 37: Relative abundance of chowsingha overlaid on forest cover, corridors and forest division boundaries of Madhya Pradesh.

The site specific density estimates were obtained by Distance sampling in areas sampled by Phase III where distance was recorded by laser range finder and bearing was recorded by see-through compass is given in Table 24. These are robust density estimates for protected areas of Madhya Pradesh. However these density estimates cannot be extrapolated across the larger landscape outside of the sampled areas mentioned in the methods section.

Table 23: Site specific density estimates of prey species from Distance sampling in some protected areas of Madhya Pradesh.

Site	No. Transect	Total Effort (Km)	Species	Group Density (SE)	Individual Density (SE)
Kanha TR (Core)	150	900	Barking deer	1.81 (0.21)	2.3 (0.27)
			Chital	3.03 (0.44)	31.12 (4.85)
			Gaur	1.12 (0.21)	5.65 (1.29)
			Sambar	3.02 (0.35)	8.55 (1.05)
			Wild pig	1.32 (0.19)	6.79 (1.21)
Kanha TR (Buffer)	61	366	Barking deer	2.47 (0.45)	3.14 (0.59)
			Chital	2.52 (0.42)	13.43 (2.59)
			Gaur	0.23 (0.12)	0.86 (0.46)
			Sambar	1.22 (0.41)	3.3 (1.17)
			Wild pig	1.88 (0.41)	8.32 (2.23)
Phen WLS (KTR)	19	114	Barking deer	4.52 (0.97)	5.45 (1.2)
			Chital	0.71 (0.26)	3.25 (1.4)
			Sambar	1.89 (0.53)	3.71 (1.15)
			Wild pig	3.18 (0.81)	18.2 (5.78)
Kuno WLS	77	298.65	Chital	5.45 (0.74)	39.84 (6.54)
			Nilgai	1.04 (0.18)	3.31 (0.69)
			Sambar	2.13 (0.39)	5.58 (1.17)
			Wild pig	1.37 (0.28)	3.77 (0.89)
Panna TR	39	225.6	Chital	1.04 (0.36)	9.17 (3.7)
			Nilgai	3.43 (0.5)	11.34 (1.96)
			Sambar	2.33 (0.41)	5.03 (1.01)
			Wild pig	0.62 (0.17)	2.88 (0.94)
Pench TR (MP)	61	343	Chital	10.18 (1.44)	64.29 (9.61)
			Nilgai	0.59 (0.18)	1.01 (0.33)
			Sambar	2.87 (0.45)	7.59 (1.3)
			Wild pig	2.42 (1)	12.56 (5.59)
Satpura TR	37	226	Chital	0.72 (0.38)	4.5 (2.58)
			Gaur	0.29 (0.15)	1.57 (0.93)
			Sambar	4.40 (0.99)	8.96 (2.10)

From Table 23 habitat wise transects were used to determine Effective Strip Width (ESW) and detection probability of different species (Table 24).

Table 24: Model statistics and parameter estimates of line transect based distance sampling for prey species in Phase III surveyed area of Madhya Pradesh. The effective strip width (ESW) was subsequently used to estimate density from encounter rates (ER) of Phase I data.

Species	Forest Type	Effort (km)	Observations	Best Model	ESW (±SE)	Detection Probability (±SE)
Barasingha	Grassland	368	34	Uniform-cosine	114.75 (17.99)	0.706 (0.111)
Barking Deer	Miscellaneous	7325	178	Half-normal- Cosine	38.58 (2.43)	0.261 (0.016)
	Sal	1217	57	Uniform-cosine	32.07 (3.43)	0.559 (0.06)
Chital	Grassland	368	96	Hazard Rate- Cosine	85.81 (5.27)	0.43 (0.026)
	Miscellaneous	7325	816	Half-normal- Cosine	61.91 (1.83)	0.168 (0.005)
	Sal	1217	48	Hazard Rate- Cosine	31.32 (4.77)	0.228 (0.035)
	Scrubland	48	26	Hazard Rate- Cosine	33.91 (16.6)	0.31 (0.061)
	Teak	609	22	Hazard Rate- Cosine	39.33 (12.88)	0.414 (0.136)
Gaur	Grassland	368	11	Hazard Rate- Cosine	83.54 (16.52)	0.634 (0.125)
	Miscellaneous	7325	146	Hazard Rate- Cosine	53.64 (5.42)	0.262 (0.026)
Nilgai	Miscellaneous	7325	93	Hazard Rate- Cosine	63.98 (7.34)	0.369 (0.042)
	Teak	609	52	Hazard Rate- Cosine	38.77 (3.74)	0.451 (0.044)
Sambar	Grassland	368	13	Half-normal- Cosine	51.42 (10.31)	0.699 (0.14)
	Miscellaneous	7325	465	Hazard Rate- Cosine	42.43 (2.04)	0.256 (0.012)
	Sal	1217	57	Hazard Rate- Cosine	37.31 (5.07)	0.378 (0.051)
	Teak	609	42	Uniform-cosine	44.53 (3.78)	0.377 (0.032)
Wild Boar	Miscellaneous	7325	202	Half-normal- Cosine	37.17 (2.97)	0.205 (0.016)
	Sal	1217	40	Half-normal- Cosine	28.85 (4.35)	0.694 (0.105)

The estimates provide in Table 25 are crude estimates of density in areas where line transects walked but distance and bearing were not recorded, only encounter rate of ungulates were recorded. Density was obtained by converting encounter rates (ER) to density by using habitat specific effective strip width (ESW) obtained in Table 24.

Total number of each ungulate species in Madhya Pradesh was obtained by adding robust estimates of Distance sampling from some protected areas with habitat specific estimates of the landscape (Table 26). These population estimates are crude estimate and provide some indication of population size of major prey species in the state of Madhya Pradesh.

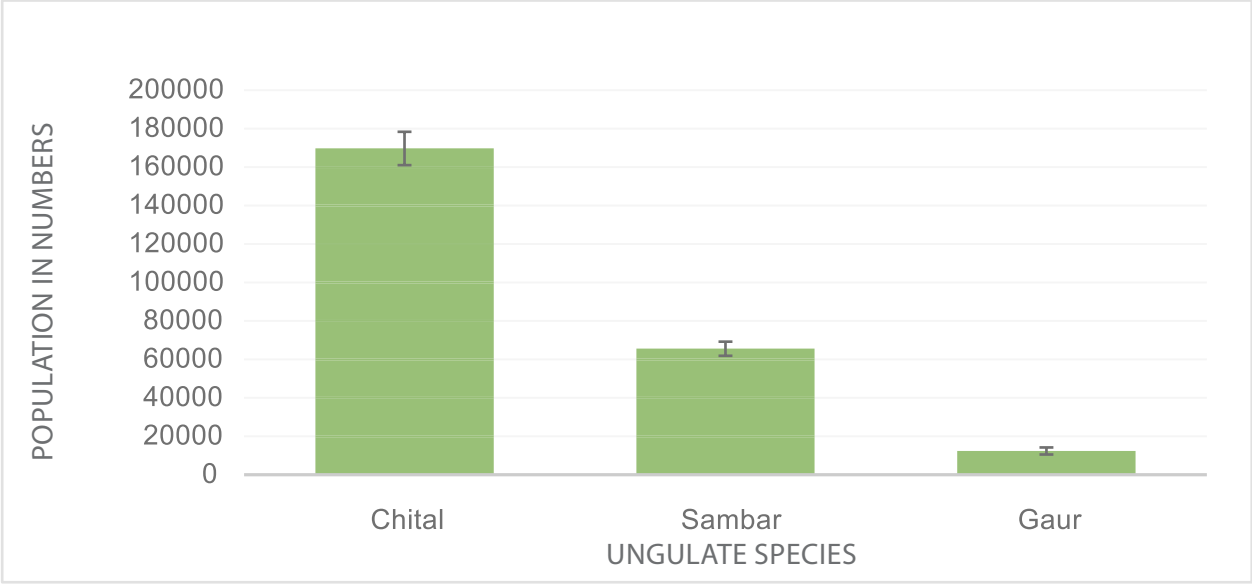
Table 25: Habitat wise abundance estimates of major prey species obtained from Phase I surveyed areas of Madhya Pradesh derived from the species-specific encounter rate and habitat wise effective strip width from Distance sampling of some protected areas. These density estimates do not include the sampled protected areas.

Species	Habitat	Encounter Rate/km^2	Effort (km)	Density (±SE)/km^2
Chital	Sal & Sal Mixed	0.73	1119	7.71 (0.78)
	Teak & Teak Mixed	0.78	2215	9.98 (0.77)
	Miscellaneous	0.39	9443	3.18 (0.08)
Sambar	Sal & Sal Mixed	0.28	287	3.71 (0.71)
	Teak & Teak Mixed	0.24	1485	2.68 (0.26)
	Miscellaneous	0.33	6410	3.93 (0.15)
Gaur	Miscellaneous	0.24	659	2.27 (0.31)

Table 26: Population estimates of major prey in Madhya Pradesh derived from habitat specific species densities and areas occupied by these species. The estimates include all data from Phase I and Phase III.

Species	Occupied Area (km^2)	Population (±SE)
Chital	28925	169726 (8678)
Sambar	18850	65590 (3663)
Gaur	3450	12411 (1836)

Figure 38: A bar-chart representing population estimates of major prey in Madhya Pradesh



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