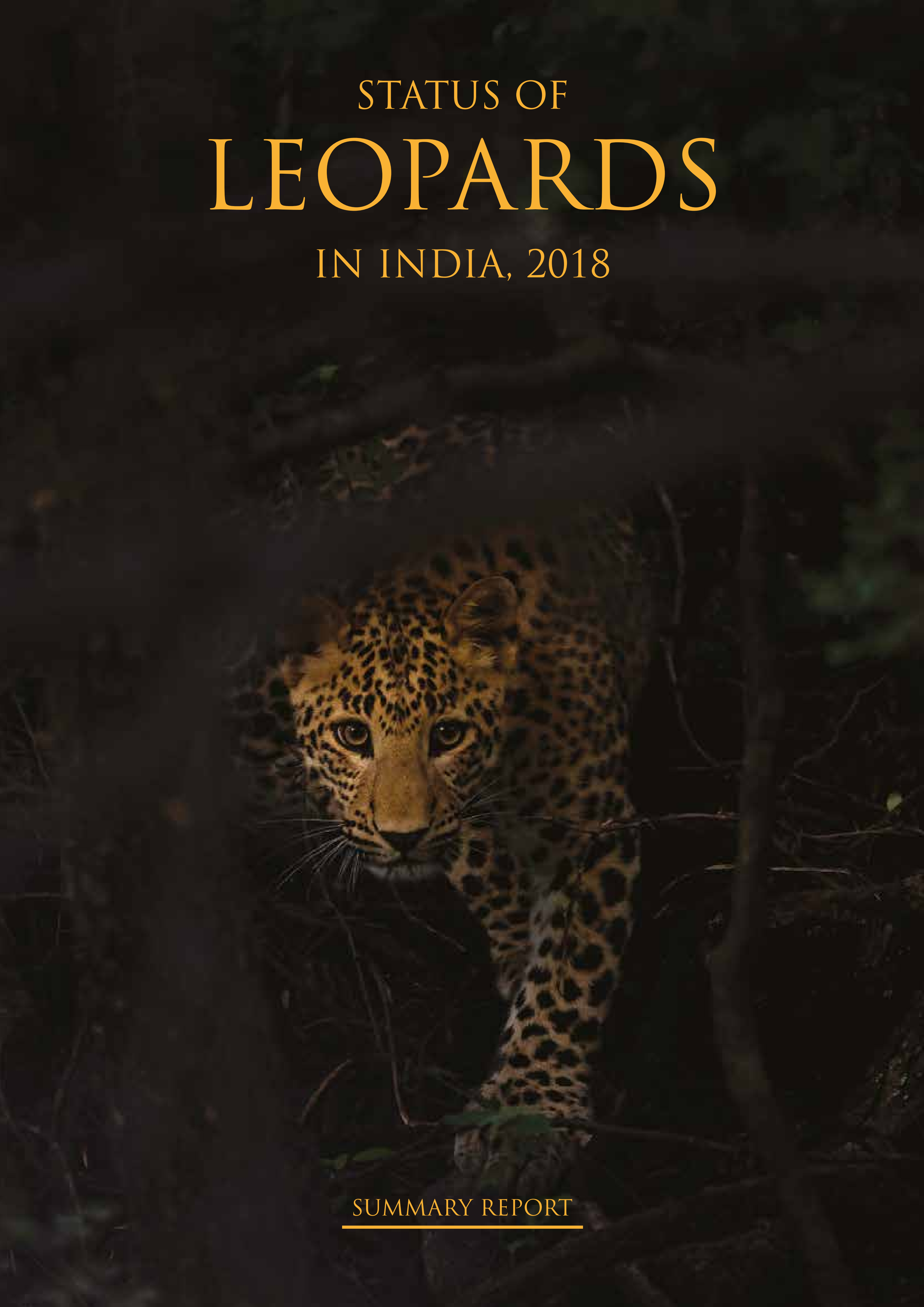
STATUS OF LEOPARDS IN INDIA, 2018



SUMMARY REPORT

STATUS OF LEOPARDS IN INDIA, 2018

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INTRODUCTION

Leopard *(Panthera pardus)* is the most widely distributed and adaptable member of the family *Felidae*. Leopard's historic range spanned across nearly 35,000,000 km^2 covering all of the sub Saharan and North Africa, the Middle East and Asia Minor, South and Southeast Asia, and extended to the Amur Valley in the Russian Far East. Island ranges included Sri Lanka, Java, Zanzibar and Kangean (Seidensticker and Lumpkin 1991, Uphykrina et al. 2001, Jacobson et al. 2016). It occurs in almost every kind of habitat, from the rainforests of the tropics to desert and temperate regions (Kitchener 1991). 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, Daniel 1996). In the Himalayas they are sympatric with snow leopards *(Panthera uncia)* upto 5,200 m (Uphyrkina et al. 2001).

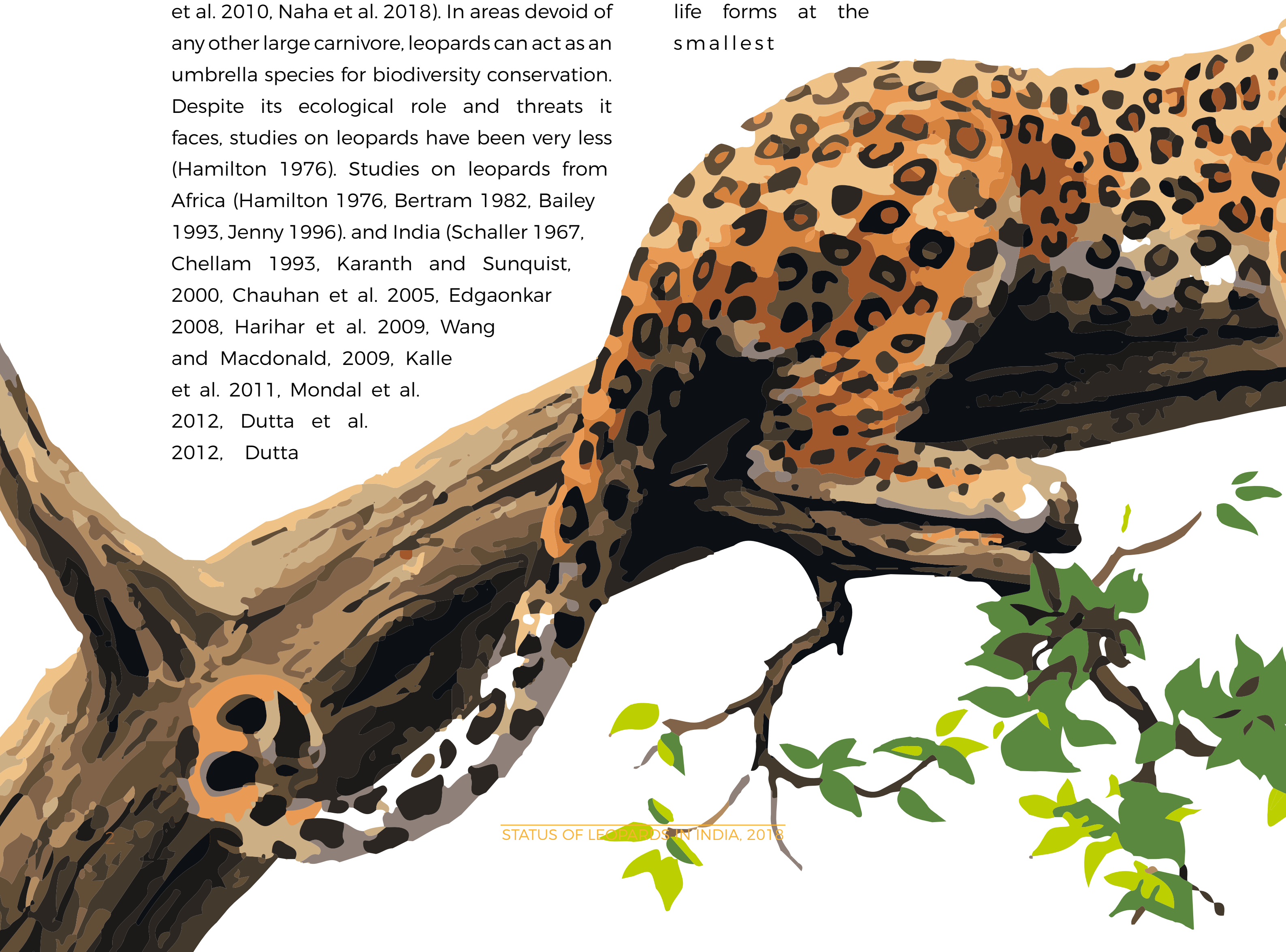
Leopards are quite adaptable with respect to habitat and food requirements, being found in intensively cultivated and inhabited areas as well as near urban developments (Nowell and Jackson 1996). They are prolific breeders and are known to grow at an annual rate of over 10% from central India (Kumar et al. 2019).

However, their current distribution and numbers have significantly decreased across the range due to habitat loss, prey depletion, conflict and poaching over the last century. Recent meta-analyses of leopard status and distribution suggest 48–67% range loss for the species in Africa and 83–87% in Asia (Jacobson et al. 2016). This is in consonance with what a recent genetic study in India has where leopards have experienced a possibly human induced 75-90% population decline in the last ~120-200 years (Bhatt et al. 2020). All these have resulted in changing the species status from 'Near Threatened' to 'Vulnerable' by IUCN (Stein et al. 2016). It is also listed in Appendix I of the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) and in Schedule I of the Wildlife (Protection) Act 1972 in India providing it with the highest level of protection. Despite decreasing numbers and range, their ubiquitous presence across human habitations leads to misconceptions regarding their current abundance.

Among all the subspecies, Indian leopard retains the largest population size and range outside Africa (Jacobson et al. 2016). In Indian subcontinent poaching, habitat loss, depletion of natural prey and conflict are major threats to leopard populations (Athreya et al. 2010, Raza et al. 2012). Leopards also frequently occur outside protected areas in human dominated landscapes, increasing their vulnerability to conflict with humans (Rahalkar 2008, Athreya et al. 2010, Naha et al. 2018). In areas devoid of any other large carnivore, leopards can act as an umbrella species for biodiversity conservation. Despite its ecological role and threats it faces, studies on leopards have been very less (Hamilton 1976). Studies on leopards from Africa (Hamilton 1976, Bertram 1982, Bailey 1993, Jenny 1996). and India (Schaller 1967, Chellam 1993, Karanth and Sunquist, 2000, Chauhan et al. 2005, Edgaonkar 2008, Harihar et al. 2009, Wang and Macdonald, 2009, Kalle et al. 2011, Mondal et al. 2012, Dutta et al. 2012, Dutta et al. 2013, Thapa et al. 2014, Borah et al. 2014, Selvan et al. 2014, Pawar et al. 2019, Chaudhary et al. 2020) have contributed to our knowledge on demography, status and ecology of leopard.

In India, tiger is not only a conservation icon but also acts as an umbrella species for majority of eco-regions in the Indian subcontinent. Project Tiger, was initiated in 1973 aimed to harness the functional role of tiger and its charisma to garner resources and public support for conserving representative ecosystems and biodiversity therein. Under the stewardship of Project Tiger, the initial number of nine tiger reserves (~18,278 km^2) has now expanded to 50 tiger reserves (~72,749 km^2) covering about 2.21% of India's geographical area conserving many endangered flora and fauna.

Securing tigers thus safeguards micro niches in the forest ecosystem which conserve the life forms at the smallest



levels ensuring water and climate security.

For designing, implementing, and evaluating success of any conservation program for an endangered species, it is vital to monitor its status, distribution, and trends. Scientific objectives aim to understand the dynamics of the monitored system, while management objectives seek to use such information for making informed decisions. Hence, monitoring is a process, not a result, a means to an end rather than an end in itself. To gauge the success of tiger conservation, the National Tiger Conservation Authority (NTCA) in collaboration with the State Forest Departments, Conservation NGO's and coordinated by the Wildlife Institute of India (WII), conducts a National tiger assessment every four years since 2006.

This exercise not only comes up with tiger numbers for the country but also evaluates the status of co-predators, prey, habitat and human disturbance parameters for all tiger occupied forested landscapes of the country thereby reiterating the 'umbrella' role of Project Tiger for biodiversity conservation in India. Third cycle of this exercise yielded the first country wide minimal population estimation of leopards at 7,910 (SE 6,566-9,181) in forested habitats of 18 tiger bearing states of the country (Jhala et al. 2015).

The fourth cycle of the tiger assessment was undertaken in 2018 using the best available science, technology and analytical tools (Jhala et al. 2020) which, like previous cycle, also estimated leopard abundance for each tiger conservation landscape in India. Due to their broad geographic distribution, leopard populations are perceived to be stable and locally abundant. However, as mentioned earlier, their global range is dwindling and population is declining and the species probably demands similar conservation attention as that of tigers in India.

In absence of robust abundance information, conservation management decisions are often based on crude estimates, expert opinions or educated guesses, which may result in erroneous decisions that can be counterproductive for conservation (Blake and Hedges 2004). Unbiased estimates of animal population abundance is essential for monitoring conservation programs, prioritization of resource allocation and often political decision making (Karanth 2003). Landscape wise leopard abundance in conjunction with tiger assessment estimates serves as a benchmark for future monitoring and would further enrich our understanding of its ecological roles, resource partitioning and population dynamics.

METHOD

During all India tiger estimation 2018, leopard population was also estimated within the forested habitats in tiger occupied states. Other leopard occupied areas such as non-forested habitats (coffee and tea plantations and other land uses from where leopards are known to occur), higher elevations in the Himalayas, arid landscapes and majority of North East landscape were not sampled and, therefore, the population estimation should be considered as minimum number of leopards in each of the landscapes.

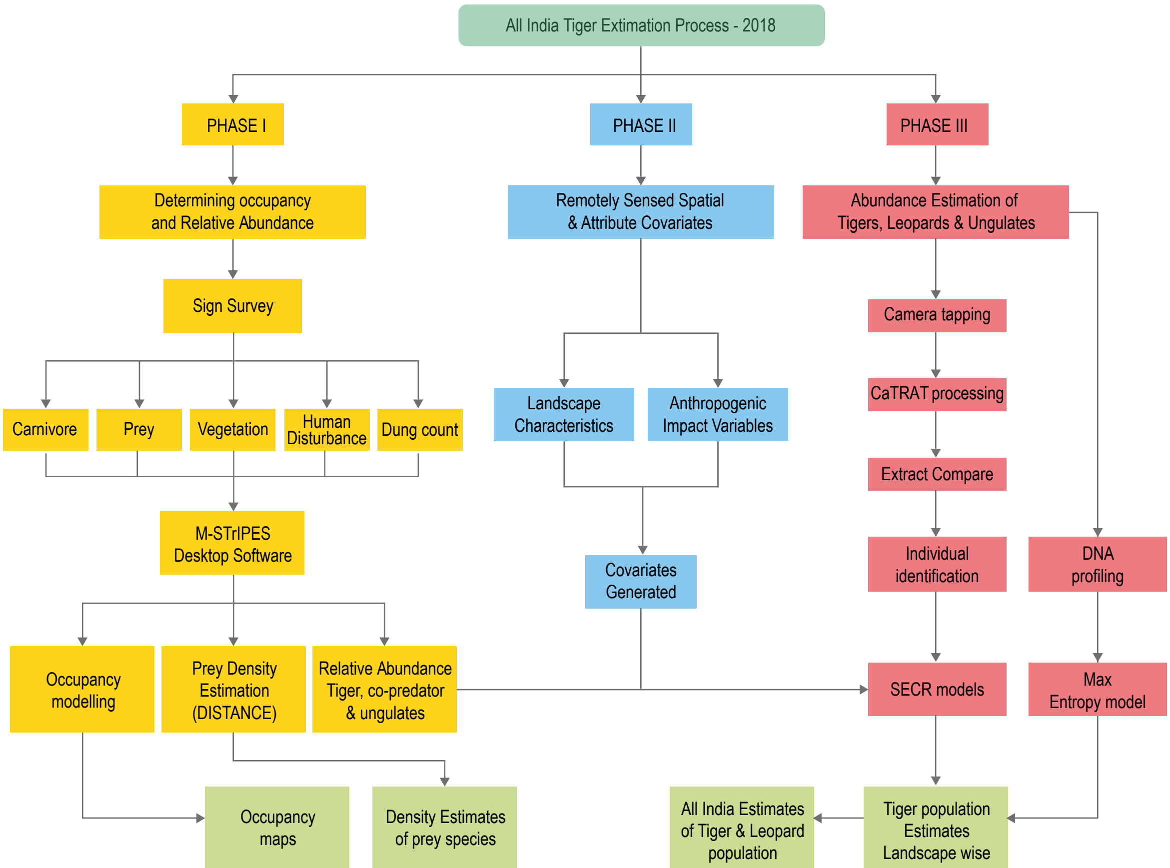
Leopard abundance was estimated at the scale of four major tiger conservation landscapes 1) Shivalik Hills and Gangetic plains, 2) Central India and Eastern Ghats, 3) Western Ghats and, 4) North Eastern Hills and Brahmaputra Flood Plains. Details of these landscapes are available in Jhala et al. 2020.

Spatial data on individual leopard photo-captures was used in combination with spatial data on prey, habitat, and anthropogenic factors as covariates in a likelihood based spatially explicit capture mark-recapture (SECR) covariate framework (Efford 2015) to arrive at leopard population estimates for each tiger landscape. This method entails estimating spatial covariates of relative abundance of tigers, co-predators (leopards), ungulates, human impact indices, and habitat characteristics across all potential tiger habitats in India, at a fine spatial resolution of a forest beat which is on average about 15 km^2 (Phase I and II). Subsequently an adequate area within each landscape was sampled using camera traps at a high spatial density of one double camera location in 2 km^2 (Phase III). The concept is similar to that of double sampling wherein indices or raw counts of abundance obtained from the entire sample space are calibrated against absolute density obtained from limited samples **(Figure 1)**. The difference between double sampling and SECR approach is that double sampling uses ratio or regression to calibrate indices while leopard population estimation uses spatial information on capture-mark-recapture (that accounts for detection correction) in a joint likelihood with spatial covariates of leopard sign intensity, prey abundance, human disturbance and habitat characteristics. This approach estimates leopards directly within camera trapped areas and extrapolates it to forested areas with leopards but not camera trapped based on joint distribution of covariates.

Phase I – Determining occupancy and relative abundance:

The forest administration system across most of India is based on division of States into Forest Divisions, Divisions into Ranges and Ranges into Beats in a spatially hierarchical manner. The boundaries of Beats are based on natural features that are easily identifiable in the field. Besides, each forest beat is allocated to a beat guard who usually has intimate knowledge of his beat. The average size of a forest beat in India is about 15-16 km^2. We used this spatial administrative system to systematically distribute sampling units at a very fine spatial scale across all forested areas within each landscape.

Figure 1. Outline of double sampling framework for all India leopard estimation



State forest departments were trained by NTCA-WII Tiger Cell to sample all current and potential tiger habitats (in Tiger Reserves, Protected Areas, Reserve Forests, Protected Forests, Revenue Forests in all Wildlife and Territorial divisions) using Phase I protocols across 18 tiger bearing states apart from Nagaland and Goa **(Figure 2)** with each beat as a sampling unit. Data were either recorded manually on forms or digitally using M-STrIPES (Monitoring System for Tigers: Intensive Protection and Ecological Status) ecological android mobile application. The protocol for Phase I (Jhala et al. 2017) consisted of five forms with simple procedures for :

a) Carnivore sign encounters (Form 1: multiple occupancy surveys in a beat)

b) Ungulates abundance (Form 2: Distance sampling on line transect(s) in a beat)

c) Vegetation (Form 3A and 3C: Canopy cover, tree, shrub and herb composition, weed infestation on plots on a transect in a beat)

d) Human disturbance (Form 3B: Multiple plots of 15m radius on line transects in a beat) and

e) Dung counts (Form 4: count of all dung identified to species in multiple 40m^2 plots on transects)

With two persons (a Forest Guard and his assistant) sampling a beat, the entire exercise of laying transects and data collection for the above mentioned five aspects (Phase I data) were collected within a period of eight to ten days for each beat.

Phase I Data Processing & Analysis:

Shape files of all administrative boundaries of Divisions, Ranges and Beats were customized for major part of the country so that the data could be collected using M-STrIPES mobile android app and could directly be imported and analyzed in M-STrIPES desktop software. Phase I data was received from 491 Forest Divisions of India and these were processed using M-STrIPES desktop software. Data for each spatial and temporal replicate was recorded at the beat scale (occupancy surveys, line transects, and plots) were transferred to the standard 100 km^2 grids for analysis and subsequent inference. Tiger and leopard sign encounter rates, ungulate encounter (direct sighting) rates, ungulate dung density, human disturbance indices (signs of livestock, human trails, wood cutting, lopping, grass removal) were computed as average encounter rates for 10x10 km grids based on effort (km of survey) invested in each 100 km^2 grid.

Phase II- Remotely sensed spatial and attribute covariates:

Distribution and abundance of leopards (wildlife) are likely to be determined by habitat characteristics and anthropogenic impacts. These covariates were obtained from remotely sensed data and used to model leopard occupancy and abundance. Habitat characteristics were surrogated by forest area, vegetation cover [Normalized Difference Vegetation Index, (NDVI)], forest patch size, forest core areas, elevation, distance from protected areas and drainage density. Human impacts were surrogated by human footprint, distance to night lights, night light intensity, distance to roads and density of road network.

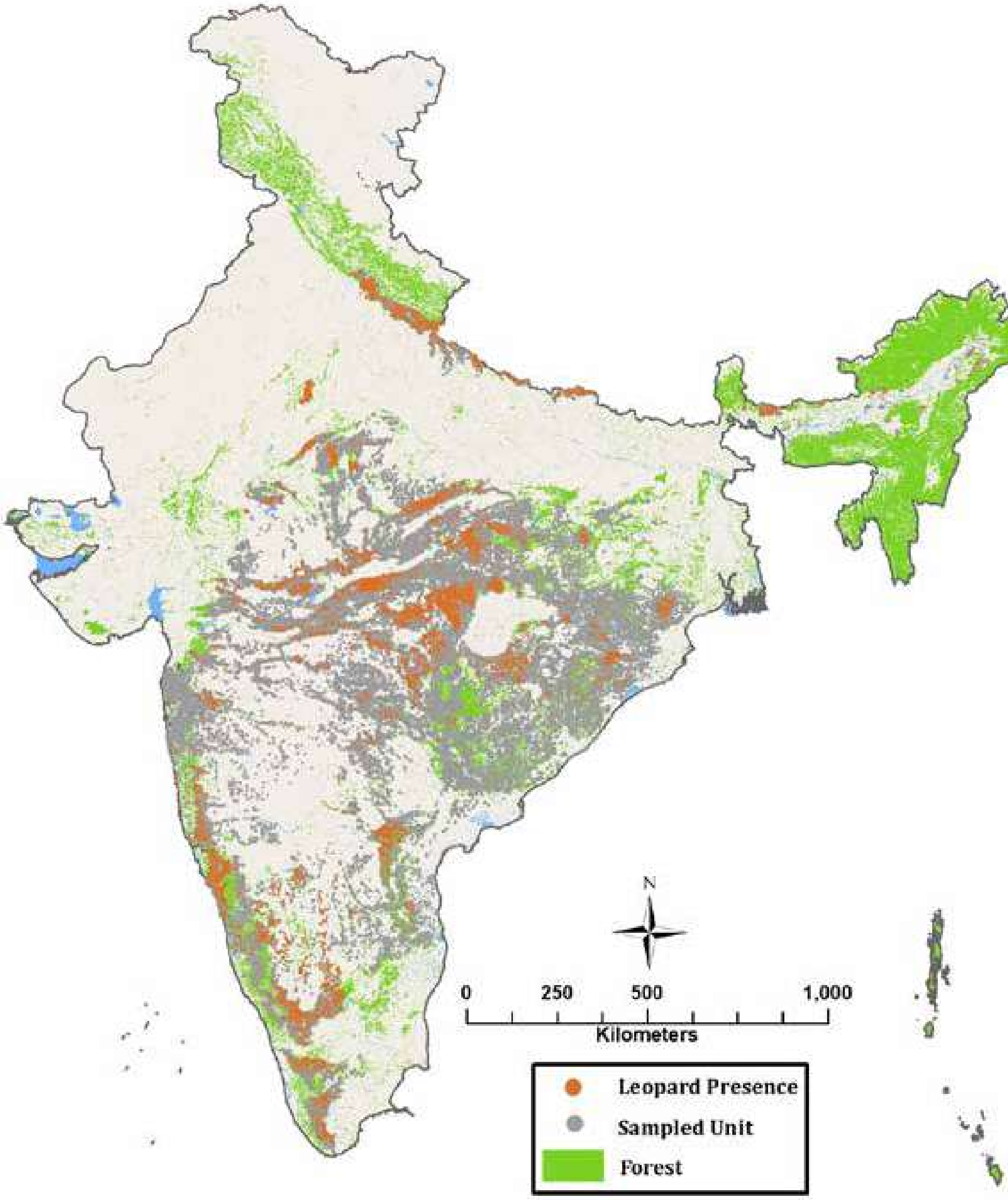


Figure 2. Spatial coverage of sampled forests for carnivore signs, ungulate abundance, habitat characteristics and anthropogenic impacts. Sites where leopard evidence was recorded is shown in red and provides a range map of leopard distribution within tiger bearing forests in India for 2018

Phase III: Camera trap based Capture-Mark-Recapture:

With availability and affordability of digital camera traps, these have become a mainstream tool for monitoring elusive wildlife (Sunarto et al. 2013). Tigers and leopards with their unique individualistic stripes and rosettes permit individual identification and subsequent estimation of their abundance using capture-mark-recapture framework. Spatially explicit capture-recapture models (SECR) consider the spatial context of capture and recapture of individuals alongside their temporal capture history to estimate density. SECR ties the detection process to the actual space usage of an animal hence giving robust population parameter estimates (Borchers and Efford 2008).

Camera traps were placed at 26,838 locations spread across 141 sites for mark recapture analysis **(Figure 3)**. Camera traps were systematically distributed within the sampling area by superimposing 2 km^2 grid and deploying at least one pair of cameras (Cuddeback, or Reconyx) within each grid. The cameras are placed in the best possible location to maximize photo-captures of tigers and leopards, identified through extensive search during sign surveys. Each grid was uniquely coded and was set within the 100 km^2 country wide grid that has been fixed since first cycle of National Tiger Status Estimation in 2006 so that subsequent inferences can be compared on the same spatial scale and extent. Sampling was carried out simultaneously in a minimum block of 200 km^2. If more number of camera traps were available to cover > 200 km^2, then sampling was done in larger size blocks. Minimum camera trap location spacing was maintained at around 1 km. Cameras were usually operated between 25 to 35 days at each site, with an average effort of over 1,200 trap-nights per ~100 km^2.

Processing of Phase III data:

An artificial intelligence (AI) based image processing tool, to automatically geotag and segregate the camera trap images into species **(Figure 4)**, was developed in collaboration with Indraprastha Institute of Information Technology, New Delhi. This image processing software known as CaTRAT (Camera Trap Data Repository and Analysis Tool) (Cheema et al. 2018) was used for geotagging, coding and segregating the images to individual species folders. The geo-tagged images were scrutinized for potential software misclassification. Segregated photos of tigers and leopards were further processed for identification of individual tigers and leopards.

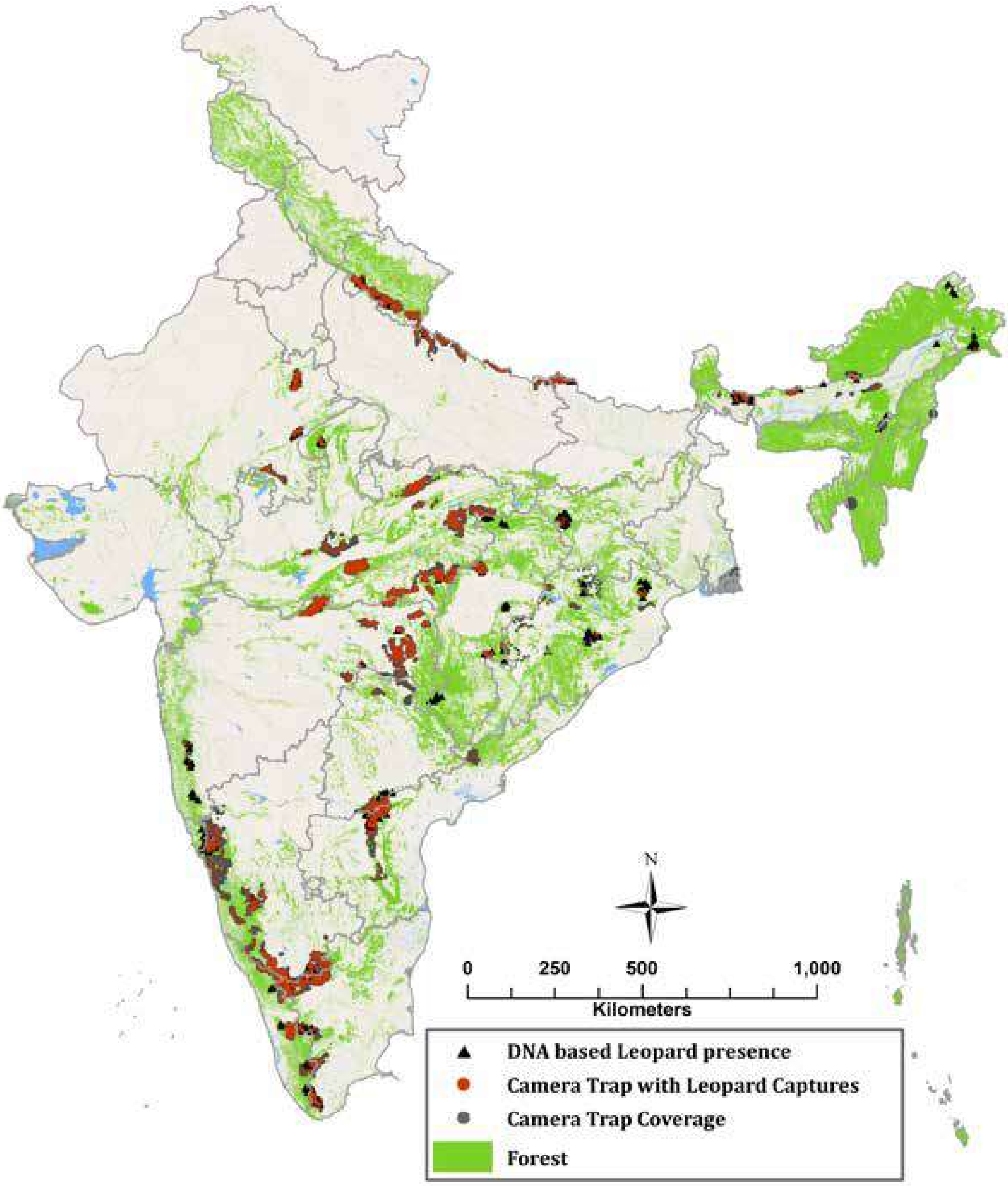
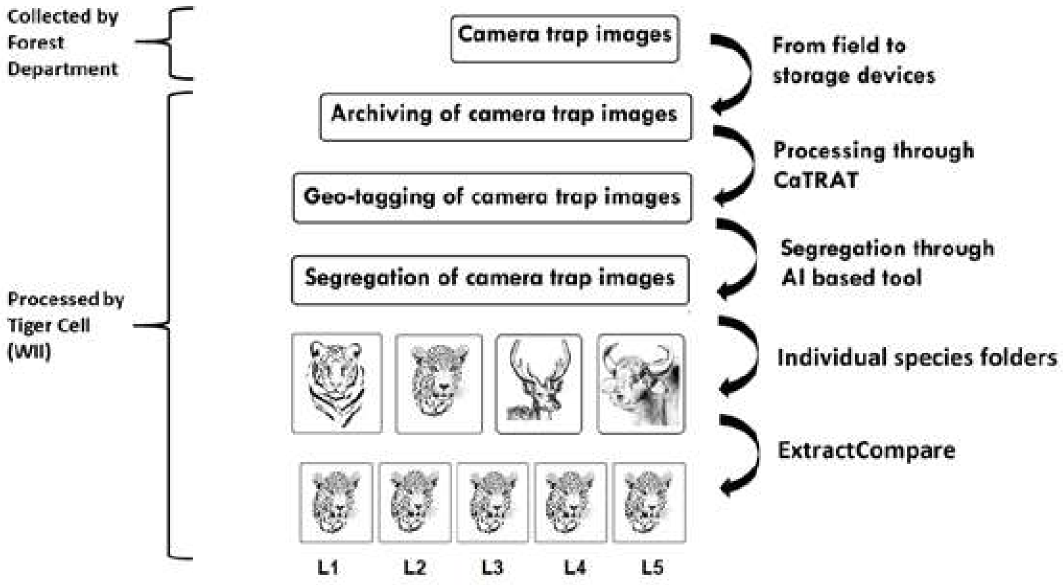


Figure 3. Camera trap locations, cameras with leopard captures and leopard positive scat locations across tiger bearing forests of India in 2018

Figure 4. Workflow of species identification from camera trap images using artificial intelligence based tool, CaTRAT

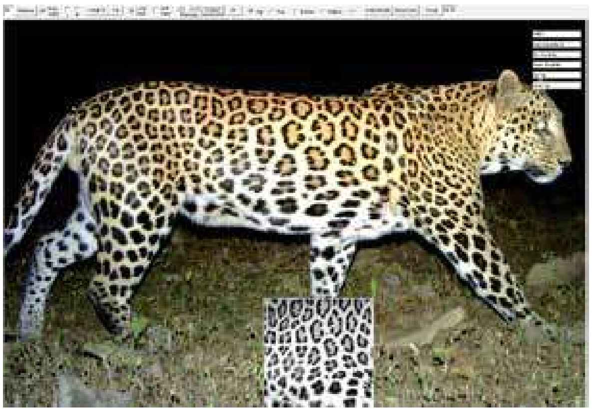


Individual identification of leopards:

We grouped leopard images using Hotspotter (Crall et al. 2013) and used ExtractCompare (Hiby et al. 2009) for final leopard identification. A total of 51,337 leopard photographs were obtained from camera traps. In ExtractCompare, a three-dimensional surface model of a leopard is superimposed on a leopard photo to account for pitch and roll related to body posture before extracting the spot pattern **(Figure 5)**. Using an automated process, pattern recognition software searches through the database of images, to calculate similarity scores between digitized leopard coat patterns to recognize common and unique individuals. Leopard(s) photocaptured in each camera trap site were identified first using this method. Subsequently, leopard photographs of adjoining sites and within each landscape were compared using the National database, so as to remove duplicate leopards, if any, and understand leopard dispersal events. Once individual leopards were identified, a matrix of spatial capture history for each leopard was developed for each site with camera trap IDs, their coordinates and, deployment and operation history of each camera.

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

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



c) Pattern extracted

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

Figure 5. Process of individual identification of leopards using Program ExtractCompare

Abundance estimation through Spatially Explicit Capture Recapture (SECR):

We used likelihood based SECR (Borchers et al. 2008, Efford 2011) to estimate leopard abundance from camera trap data. The two basic detection parameters in SECR are detection probability (g_0) at the home range centre of the animal and a parameter for spatial movement (σ). We provided a habitat mask with a sufficiently realistic buffer around the camera trap array that excluded non-habitat. In our analysis, density was modelled as a function of covariates. Tiger and leopard sign encounter rates, prey encounter or dung densities and human footprint variables obtained from the ground surveys and remotely sensed data were used within SECR as covariates in a joint likelihood framework to model leopard density through package secr (Efford 2015) in program R (R Development Core Team 2010). Covariate based abundance models were developed for each landscape to estimate leopard abundance within tiger occupied forests. The best covariate model was then selected on the basis of Akaike Criteria Information (Akaike 2011) for that landscape. In areas where leopards were detected but the area was not camera trapped, their numbers were then estimated by predicting leopard density from covariates (prey, habitat and human disturbances) using the best model or model averaged parameters.

Genetic sampling:

To understand the genetic structure of leopards across tiger habitats in the country, putative carnivore scats were collected during the All India tiger monitoring exercise throughout tiger reserves and landscapes across the country. DNA from these scats was extracted and assigned to species based on molecular identification through species specific primer amplification (Maroju et al. 2018). Leopard positive samples from the aforementioned step were then identified to individuals based on a panel of eleven microsatellites, as described in Kolipakam et al. (2019).

Results

A total of 5,240 adult individual leopards were photo-captured. The overall leopard population in tiger range landscape of India was estimated at 12,852 (SE range 12,172 - 13,535) **(Table 1).** Out of a total 10,602 surveyed grids in India, leopard presence was recorded for 3,475 grids.

Table 1. Leopard population estimates in the forested areas of tiger states, 2018

State	2018 population estimates with SE limits
Shivalik Hills & Gangetic Plains	
Bihar	98 (90-106)
Uttarakhand	839 (791-887)
Uttar Pradesh	316 (277-355)
Shivalik-Gangetic	**1,253 (1,158-1,348)**
Central India & Eastern Ghats	
Andhra Pradesh	492 (461-523)
Telangana	334 (318-350)
Chhattisgarh	852 (813-891)
Jharkhand	46 (36-56)
Madhya Pradesh	3,421 (3,271-3,571)
Maharashtra	1,690 (1,591-1,789)
Odisha	760 (727-793)
Rajasthan	476 (437-515)
Central India & Eastern Ghats	**8,071 (7,654-8,488)**
Western Ghats	
Goa	86 (83-89)
Karnataka	1,783 (1,712-1,854)
Kerala	650 (622-678)
Tamil Nadu	868 (828-908)
Western Ghats	**3,387 (3,245-3,529)**
North East Hills, and Brahmaputra Flood Plains*	
Arunachal Pradesh (Pakke)	11 (8-14)
Assam (Manas, Nameri)	47 (38-56)
West Bengal (Gorumara, Jaldapara and Buxa)	83 (66-100)
North East Hills, and Brahmaputra Flood Plains*	**141 (115-170)**
TOTAL	**12,852 (12,172-13,535)**

* Estimates are only from camera trap sites

Shivalik Hills and Gangetic Plains Landscape

Leopards in North India are distributed from Trans-Himalayas to Gangetic plains, but the current leopards' assessment was limited to an altitude of 2,600 m in this landscape, where leopard signs were distributed across the forested areas of Uttarakhand, Uttar Pradesh and parts of Bihar. Leopards were reported from the higher reaches of Himalayas in Nainital and Champawat, which were sampled during the All India Tiger Estimation 2018. Leopards occupied 262 grids in 2018 **(Figure 6).** Leopard density was computed from 19 camera trapped sites within this landscape. A total of 5,298 leopard photo-captures were obtained from which 825 adult and subadult individuals were identified. Leopard population was found to have increased in tiger reserves in Uttar Pradesh and the Terai areas of Uttarakhand when compared to the previous estimates of 2014 **(Table 1)**. Main conservation issue in this landscape remains very high human-leopard conflict.

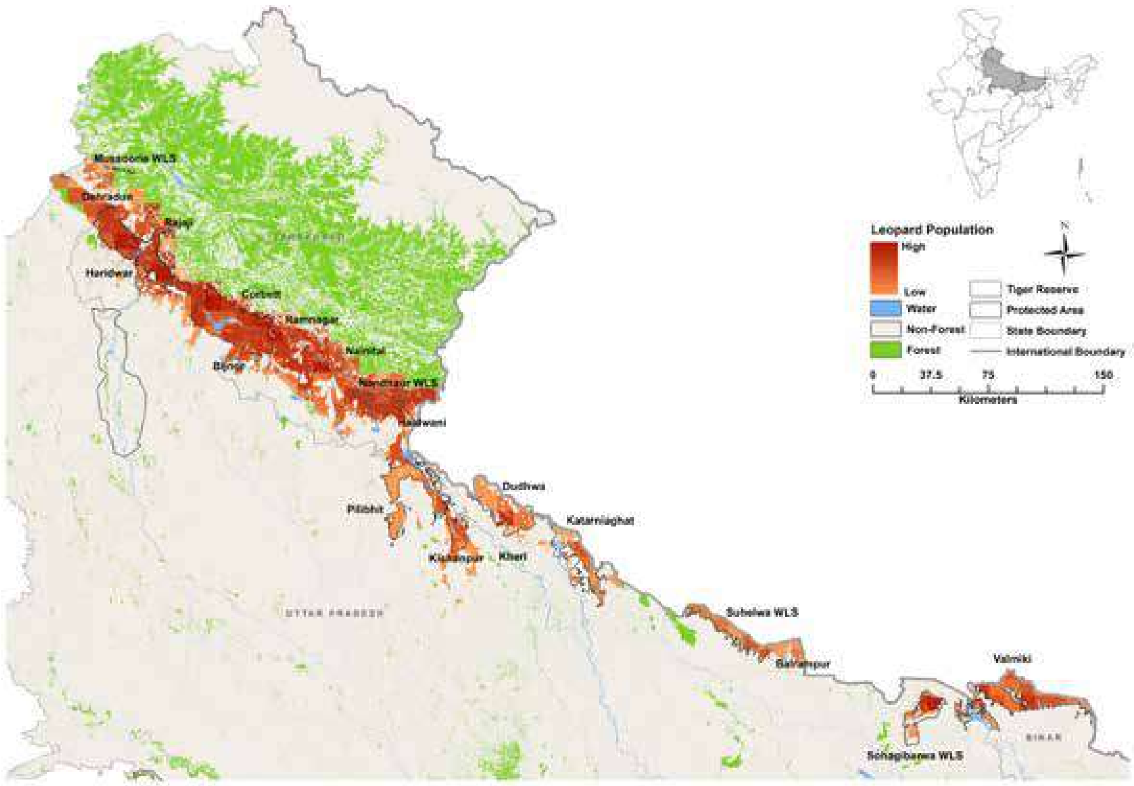


Figure 6. Leopard distribution and density surface for Shivalik Hills and Gangetic Plains landscape 2018

Central India and Eastern Ghats

Leopards are widely distributed in the forest of Central Indian landscape. The leopard population for Rajasthan is reported only for the tiger occupied Protected Areas i.e. the Mukundara, Ranthambore and Sariska Landscapes. Leopard population in central India can be distinguished into four large contiguous patches: (a) the central block which extends across entire Madhya Pradesh, Chhattisgarh, Jharkhand, Odhisa, Maharashtra and Northern Telangana. (b) the Southern block covering Amrabad Tiger Reserve, Nagarjunsagar –Srisailam Tiger Reserve, and extending into Sri Venkateshwara Wildlife Sanctuary. (c) the Western block which comprises of Western Ghats of Maharashtra (Sahyadri hills) and areas of adjoining Deccan. (d) the Northern block comprises of Sariska, Ranthambore, Mukundhara tiger reserves and northern Madhya Pradesh comprised of forests and Protected Areas in this part of state **(Figure 7)**. Leopards occupied 2,265 grids in 2018. During this estimation, a minimum 2,601 of adult and subadult unique individuals were identified from the 26,367 photographs. The total population of leopard within the sampled forest landscape was estimated at 8,071 (SE range 7,654-8,488). High densities of leopards were reported from Protected Areas and some forest tract comprising of corridors **(Figure 7)**. Leopard population has increased in all states of the central India when compared to previous estimates of 2014. The state of Madhya Pradesh had the largest leopard population in India. Due to its adaptive nature and behavioral plasticity they are reported to persist in human dominated landscape, and are more prone to human wildlife conflict. Other major threats for leopard in this landscape are habitat fragmentation and poaching.

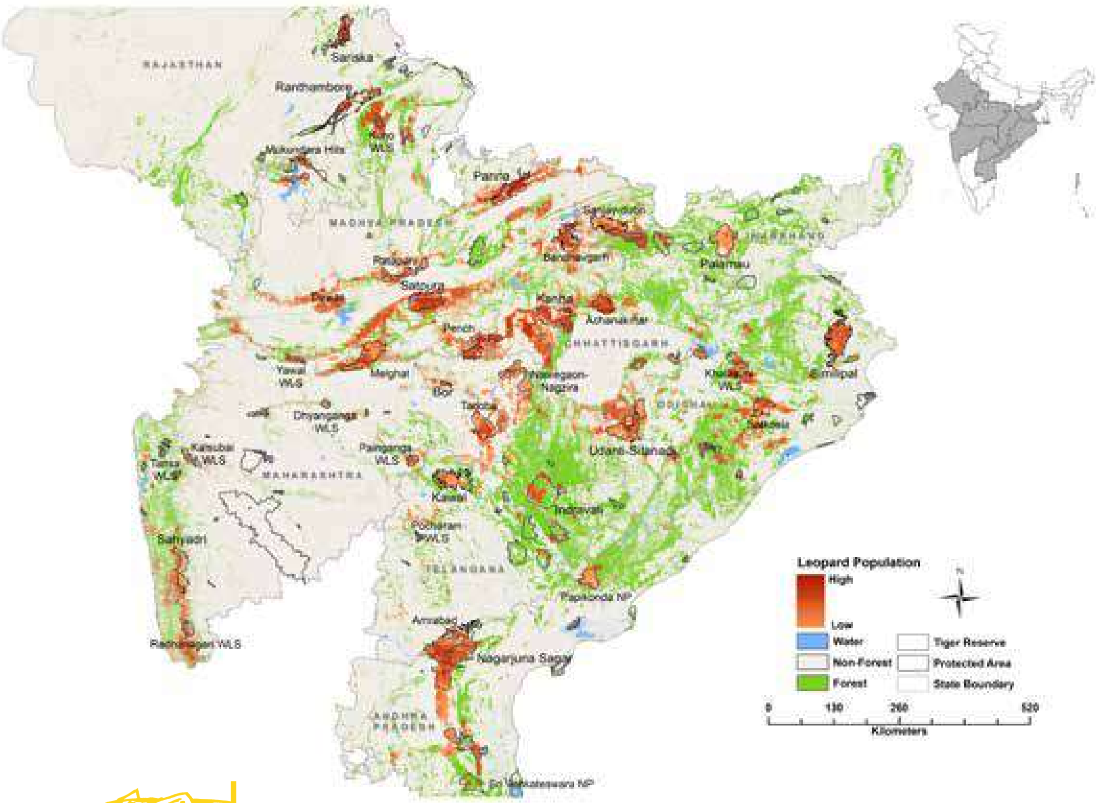


Figure 7. Leopard distribution and density surface for Central India and Eastern Ghats landscape 2018

Western Ghats

Leopard presence were recorded in the forested areas of Western Ghats, Nilgiris, and sporadically recorded across much of the dry forests of Central Karnataka **(Figure 8)**. Leopard population of the Western Ghats landscape was observed to occur in four distinct blocks. The Northern block contiguous with Radhanagari and Goa covering Haliyal- Kali Tiger Reserve- Karwar- Honnavar- Madikeri- Kudremukh- Shettihali WLS- Bhadra-Chikmagalur. The Central population covering southern Karnataka, Tamil Nadu, and Northern Kerala covering the forests of Virajpet- Nagarhole- Bandipur- Madumalai-Satyamangalam- Nilgiri- Silent Valley- Wayanad- BRT Hills- MM Hills- Cauvery WLS- Bannerghhata NP. A second central cluster covering central Kerala and Tamil Nadu composed of the Parambikulam-Anamalai-Eravikulum-Vazachal population. The Southern leopard population block in Southern Kerala and Tamil Nadu comprised of the forests of Periyar-Kalakad Mundanthurai-Kanyakumari.

Leopard occupied 826 grids in 2018. Leopard density was computed from 47 camera trapped sites within this landscape. A total of 6,758 leopard photo-captures (independent) were obtained from which 1,681 adult and subadult individuals were identified. The leopard population has increased in most of the Tiger Reserves in the Western Ghats landscape when compared to previous estimates of 2014 **(Table 1).**

Growing human population and increasing fragmentation in the landscape increased human-wildlife interactions. The coffee estates surrounded by forests, are frequently visited by leopards and are a major hub for human-leopard conflicts (Bali et al. 2007).

North East Hills and Brahmaputra Flood Plains

Leopards are distributed widely in the North Eastern landscape from high altitude of Eastern Himalayas to the forests adjacent to tea gardens in the flood plains (50m-3000m MSL), but due to sampling inadequacy, the leopard population was estimated only from the camera trapped sites of Northern West Bengal, Manas and Nameri tiger reserves of Assam and southern valley of Pakke tiger reserve of Arunachal Pradesh **(Figure 9).** Few photographs were obtained from Kaziranga, and Namdapha tiger reserves but due to low detection and low sample size, population was not estimated from these tiger reserves. Poaching, Human wildlife conflict and continuous land use change associated with agriculture, tea gardens, linear infrastructure are major threats to leopard populations in this region. The total population of leopard within the sampled forest landscape was estimated as 141with SE range 115-170 **(Table 1)**.

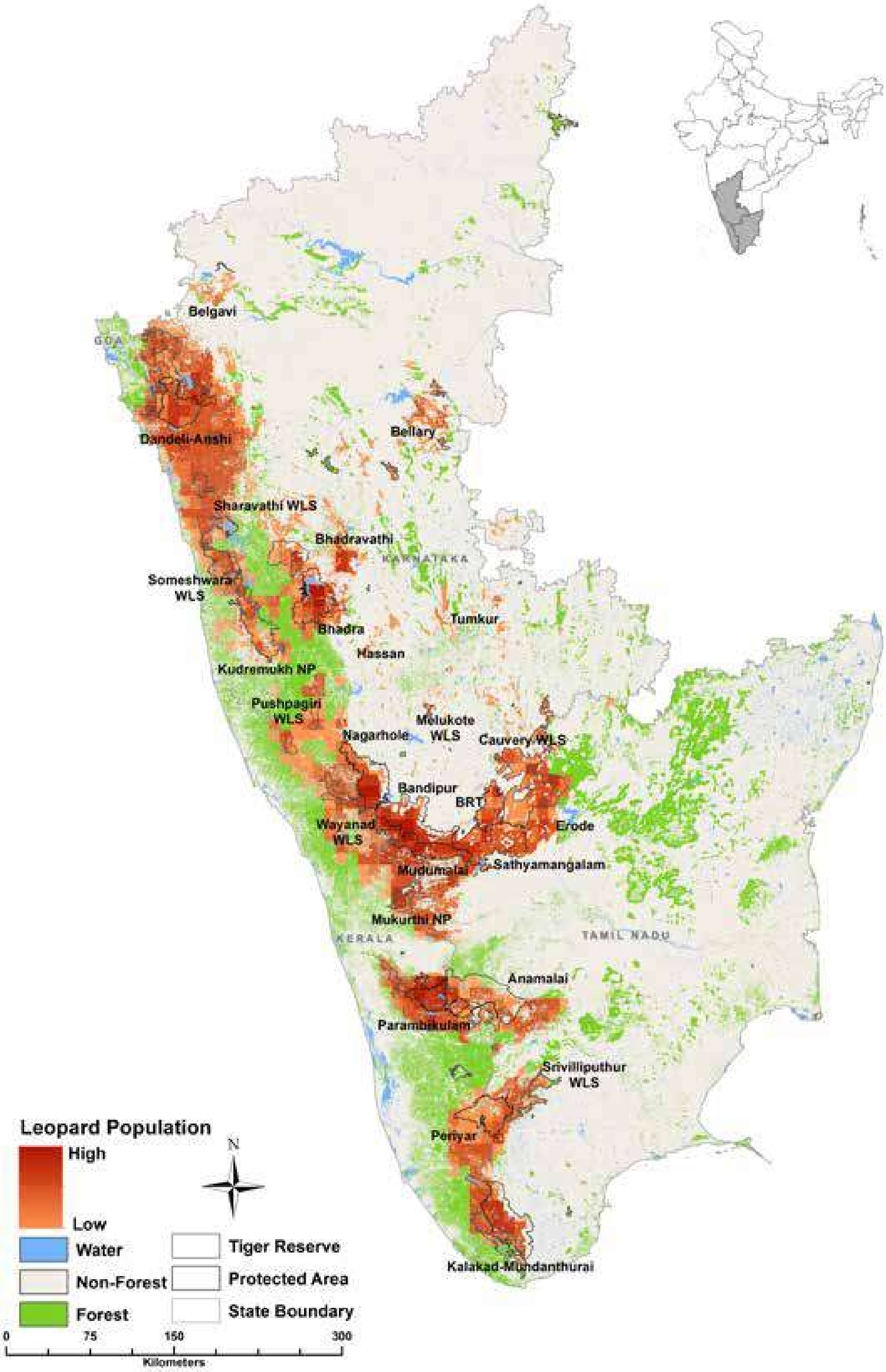
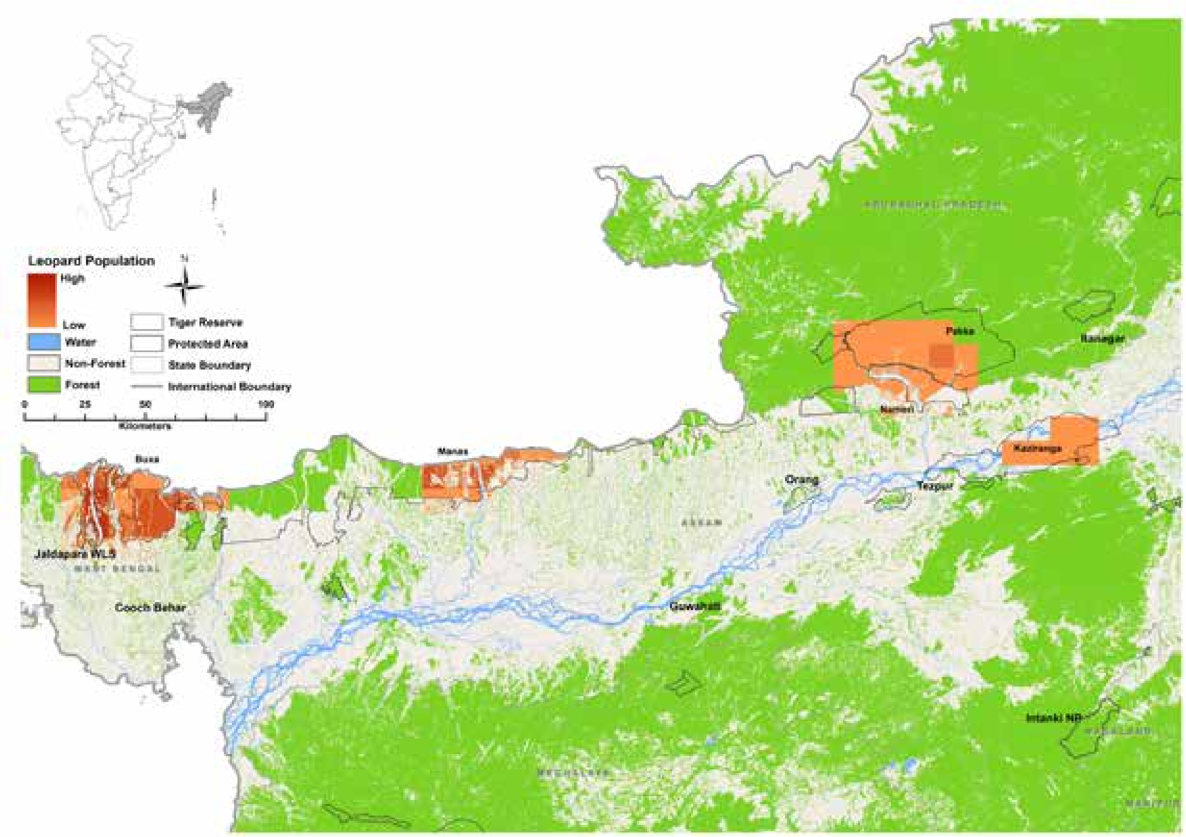


Figure 8. Leopard distribution and density surface for Western Ghats landscape 2018

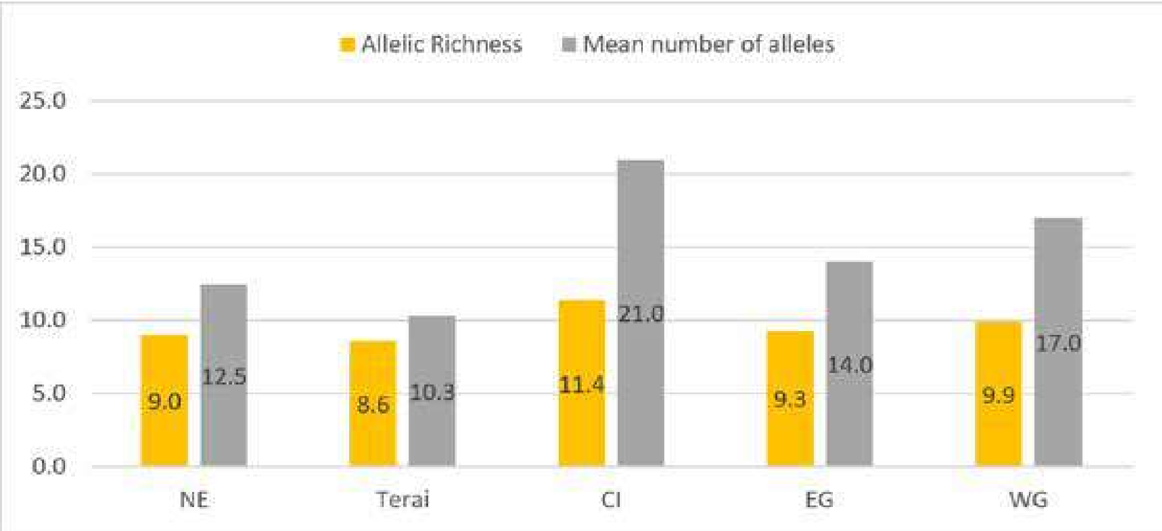
Figure 9. Leopard distribution and density surface for North East Hills and Brahmaputra Flood Plains landscape 2018



Leopard Population Structure

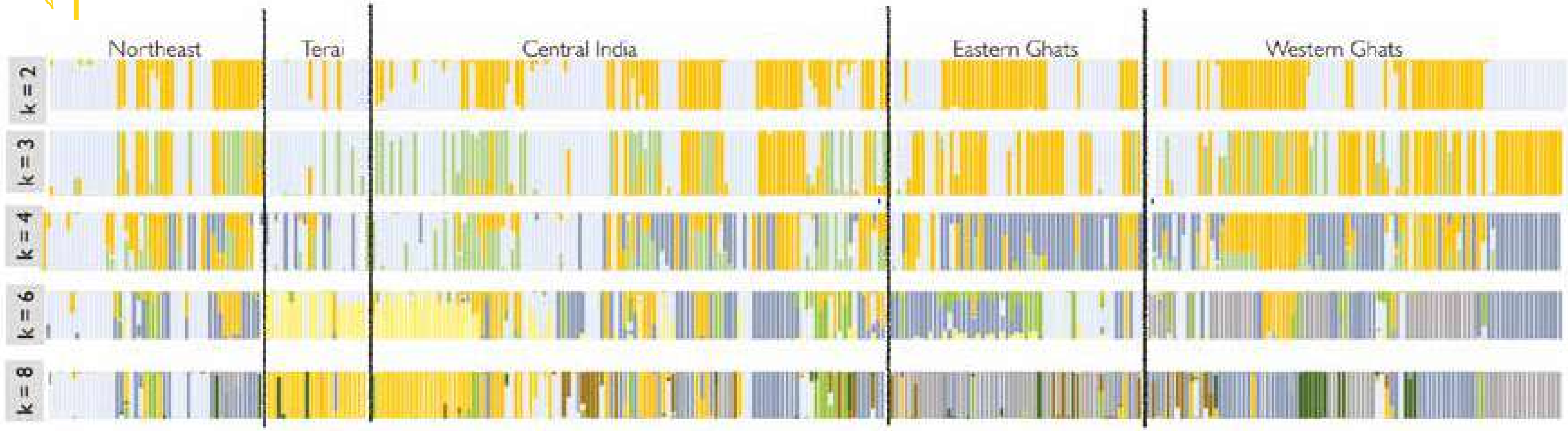
Of a total of 1871 carnivore positive samples that were extracted, 704 were positively identified as those belonging to leopard. From 704 leopard positive samples, we were able to identify 317 unique individuals, after removing samples that did not amplify well, as well as recaptures of individuals. Leopard individuals identified comprised of 45 leopard individuals from North East, 21 from Terai, 108 from Central India, 53 from Eastern Ghats and 90 from Western Ghats. The genetic diversity as measured by mean number of alleles and allelic richness, was maximum in central India, while variation in all other landscapes was comparable **(Figure 10)**. Genetic analysis of these individuals indicates that leopard populations across the country are not strictly genetically structured, as opposed to tiger populations which show structuring. Bayesian clustering approach, implemented through the program STRUCTURE (Pritchard et al. 2000) helps in determining the hierarchically higher most number of clusters present in the genetic data. For leopards, when sample location information is not incorporated in the analysis, then the number of clusters that are resolved is two **(Figure 11)**, and when apriori sample location information is added, even then the number of clusters inferred remains at three. To understand the extent of allele sharing, a discriminant analysis of principal components implemented through the package *adegenet* in R (Jombart et al. 2008; **Figure 12**).

Figure 10. Genetic diversity measures of Allelic richness and Mean number of alleles of 317 leopard individuals across tiger habitats in the country (NE = North East, Terai, CI = Central India, EG = Eastern Ghats, WG = Western Ghats)



Both these analysis reveal that leopards populations across the country are not very distinctly genetically structured, with only distance playing a role in differentiating populations. Genetic structure of leopards (from k=2, to k=8) revealed structuring that was evidence of isolation by distance. Across landscapes gene flow was evident, for eg., Terai leopard genepool shared with Central India, Eastern Ghats with West Bengal (clustered under North East), Central India with Northern Western Ghats. Through discriminant analysis also allele sharing across landscapes followed a similar pattern, with Terai leopard populations shared affinity mostly with Central Indian leopards, followed by North East leopard populations. There was a clear signal of shared affinity of genes between leopards of Eastern Ghats, and those of West & North Bengal. The connectivity of leopard population through Western Ghats seem contiguous. The Eastern Ghat populations share allelic space with Western Ghat populations. Through these results, it is interesting to note that while tigers across the same space are genetically structured, leopard populations are genetically diverse, with genetic structure seemingly driven only by separation in space.

Figure 11. Barplot indicating genetic structure of 317 individual leoaprds across landscapes at K=2, 3, 4 6 & 8. Each individual is represented by a vertical bar, and the coloured length of each bar indicates the probability of membership in each cluster.



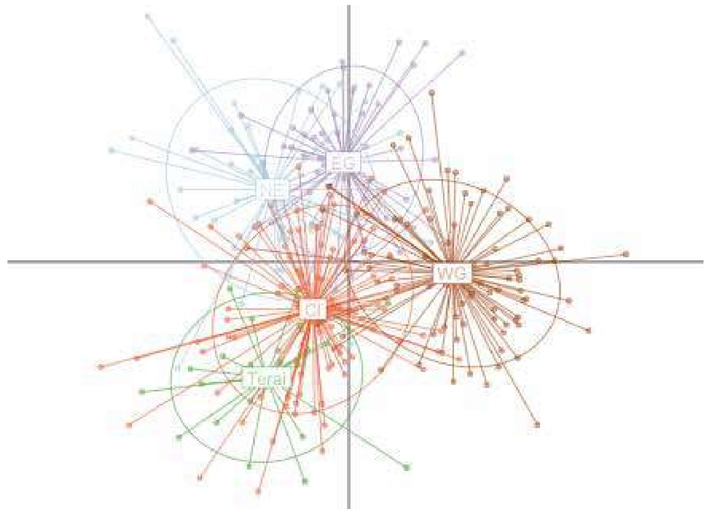


Figure 12. Discriminant analysis of principal components of 317 leopard individuals from the five landscapes (Terai, CI = Central India, NE = North East, EG = Eastern Ghats, WG = Western Ghats.)

Conservation Implications

Leopards are widely distributed species and in comparison to other large carnivores have been able to survive better in an increasingly human dominated landscape, largely due to its adaptable behaviour and due to protection. Leopards serve as apex predators in most of the forested landscapes in India, beyond the realm of tiger and lion. While leopards have been persecuted historically, we find them evoking a negative response in large parts of country due to negative interactions with humans all the more today. Despite their widespread distribution, leopard habitats are being increasingly fragmented, and such small fragmented areas with low wild prey densities cannot harbour a sizable population of leopards. This has resulted in leopards venturing out into human-dominated landscapes and ending up in conflicts. Intense conflicts are mostly reported from hills of Shivalik-Terai landscape and parts of Central India. The forests of Central Indian landscape harbours the largest population of leopards in its fragmented forest patches. While genetic data and population data suggest that leopard populations across is continuous, there is an increasing need for corridor connectivity, and improvement of habitat, to reduce interface with humans and thereby reducing the chance of conflict. With leopards venturing out into human habitations more often, developmental projects need appropriate mitigation measures and greener technology to sustain not only leopards, but also other carnivores and biodiversity in general. With the government's efforts towards increasing protection, along with a range of measures to improve habitat conditions (like village relocation), tiger and leopards have shown remarkable recovery. We are at that juncture where socio-economic development and conservation are at a critical point. It is now important, more than ever, to incorporate and implement a model of adaptive management of Protected Areas which are still in poor condition and can be improved, and explore possible models for coexistence of large carnivores with humans.

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