

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 km² 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, Uphyrkina 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 km²) has now expanded to 50 tiger reserves (~72,749 km²) 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 km² (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 km² (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.

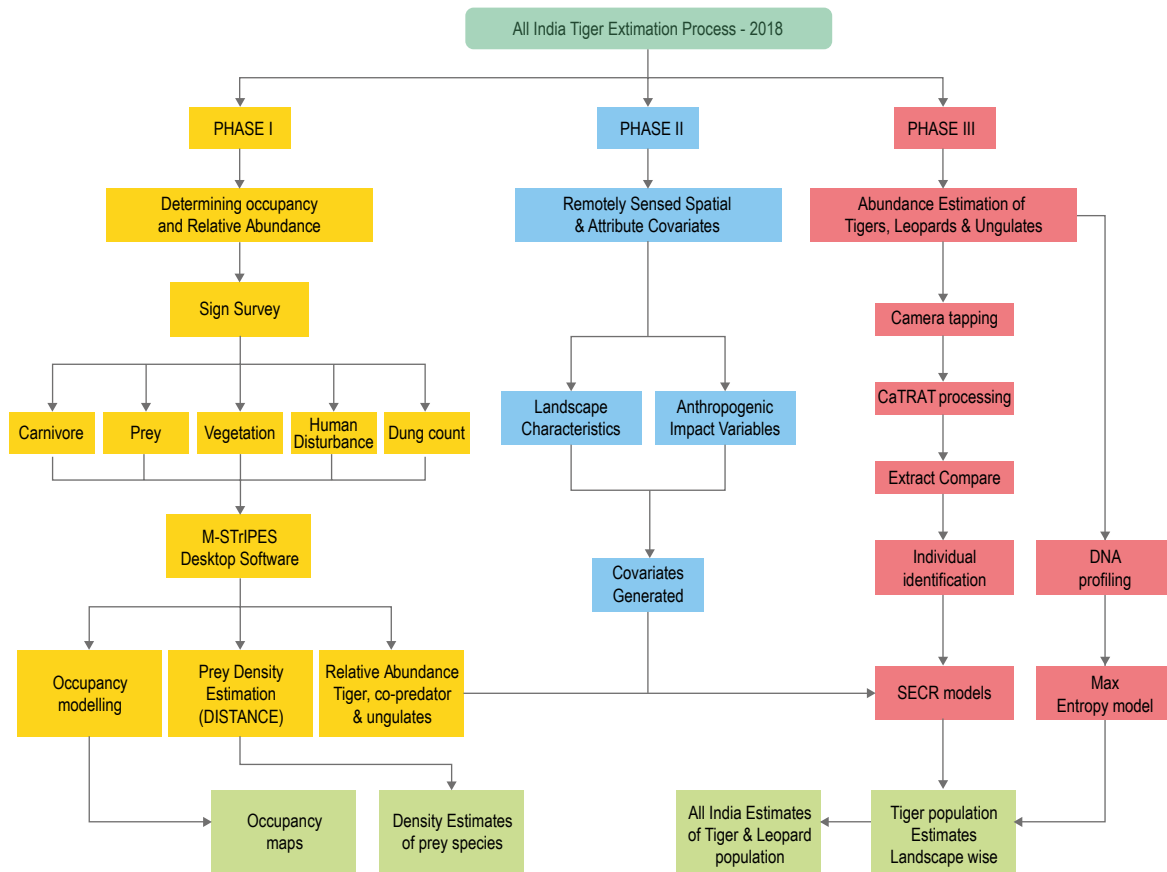
Phase I - Determining occupancy and relative abundance:

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 km². 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 40m² 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 km² 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 km² 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.



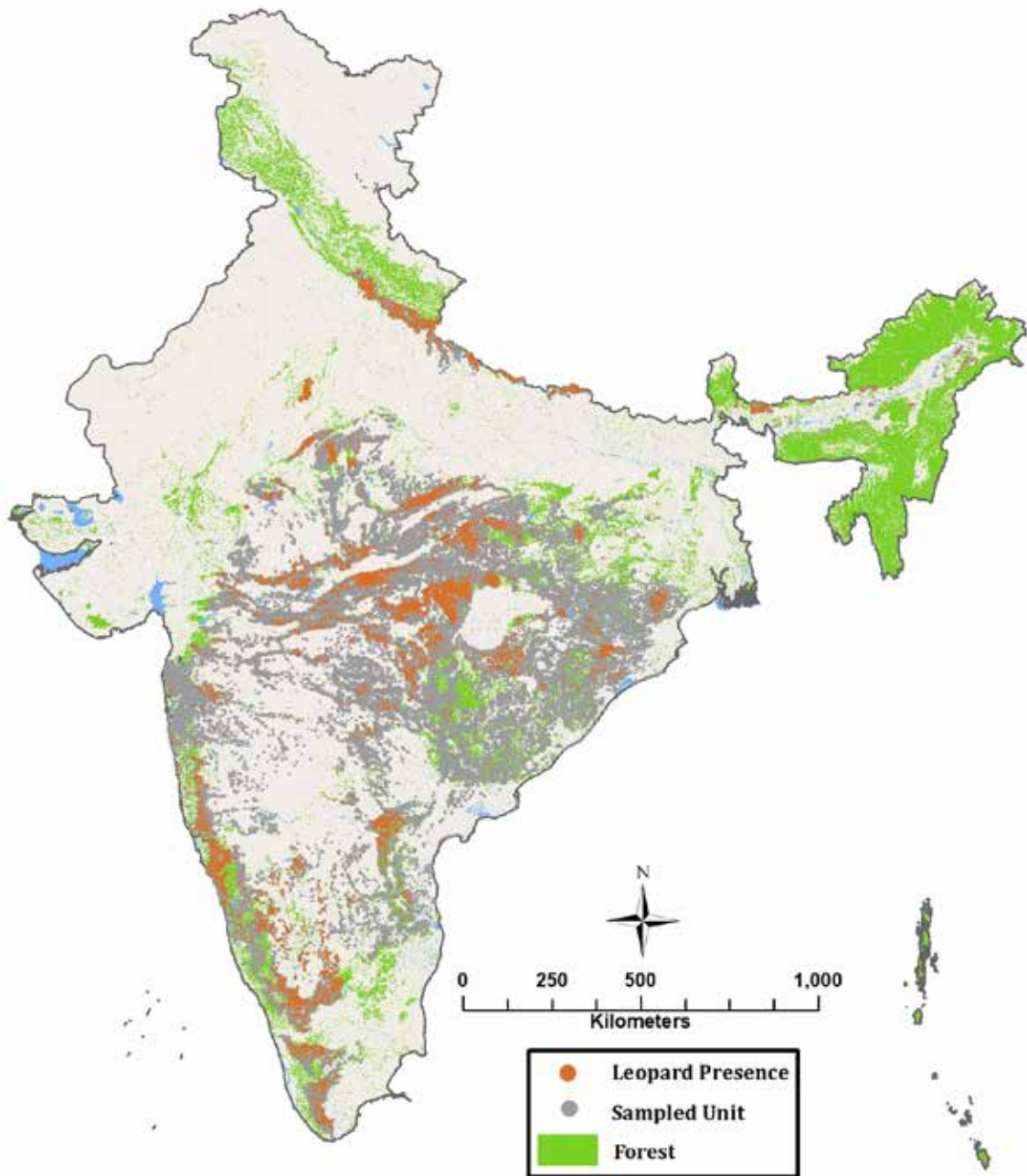


Figure 2. Spatial coverage of sampled forests for carnivore signs, ungulate abundance, habitat characteristics and anthropogenic impacts. Sites where leopard evidence was recorded is shown in red and provides a range map of leopard distribution within tiger bearing forests in India for 2018

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 km² 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 km² 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 km². If more number of camera traps were available to cover > 200 km², 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 km².

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.

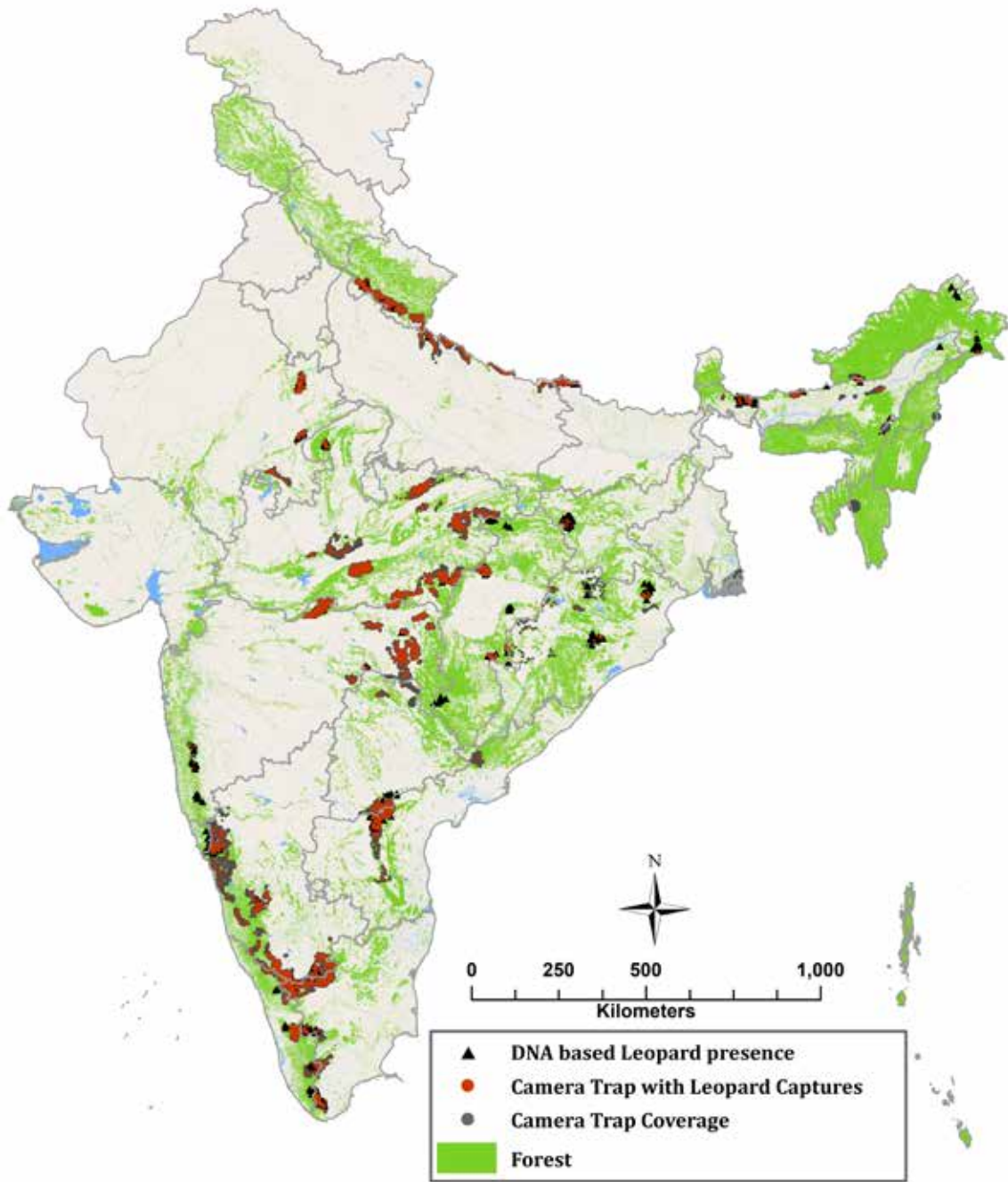
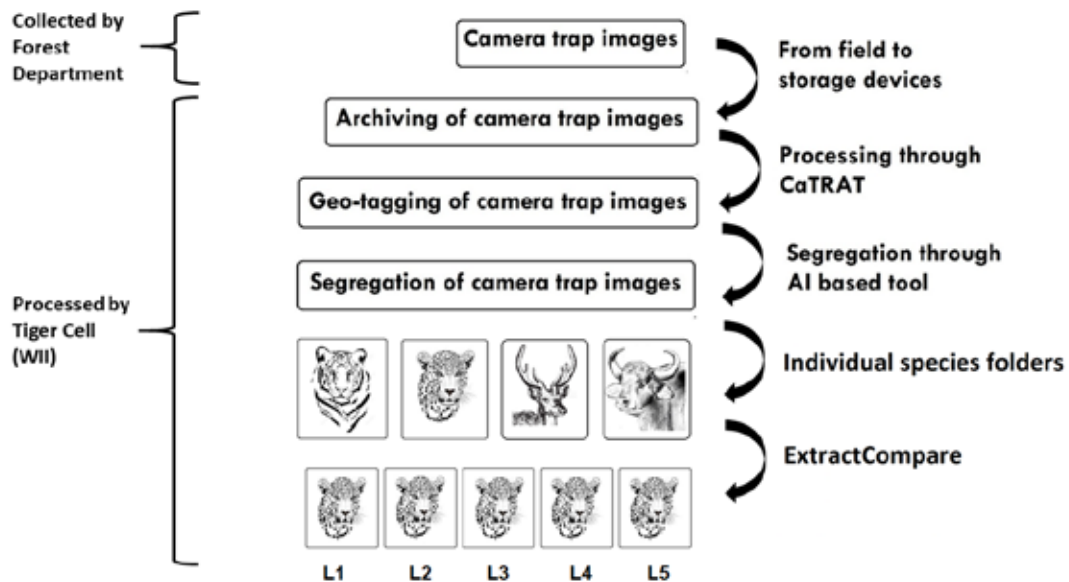


Figure 3. Camera trap locations, cameras with leopard captures and leopard positive scat locations across tiger bearing forests of India in 2018



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



Individual identification of leopards:

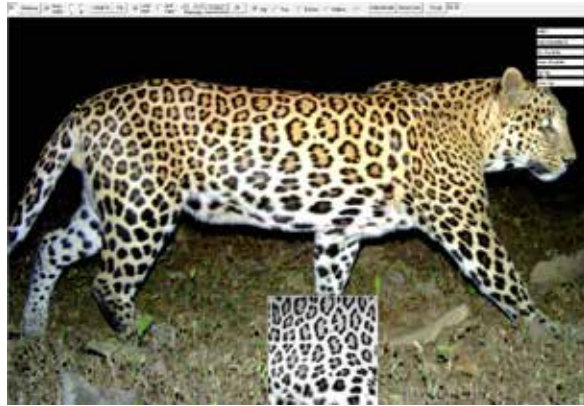
We grouped leopard images using Hotspotter (Crall et al. 2013) and used ExtractCompare (Hiby et al. 2009) for final leopard identification. A total of 51,337 leopard photographs were obtained from camera traps. In ExtractCompare, a three-dimensional surface model of a leopard is superimposed on a leopard 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.



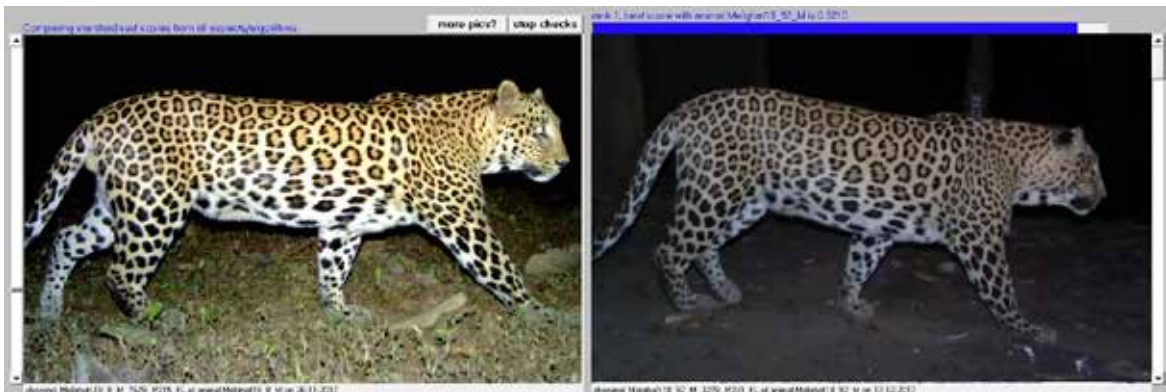
a) Placing seeds on prominent body parts (mid shoulder, tail, hip)



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 (Maraju 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 (Corumara, 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.

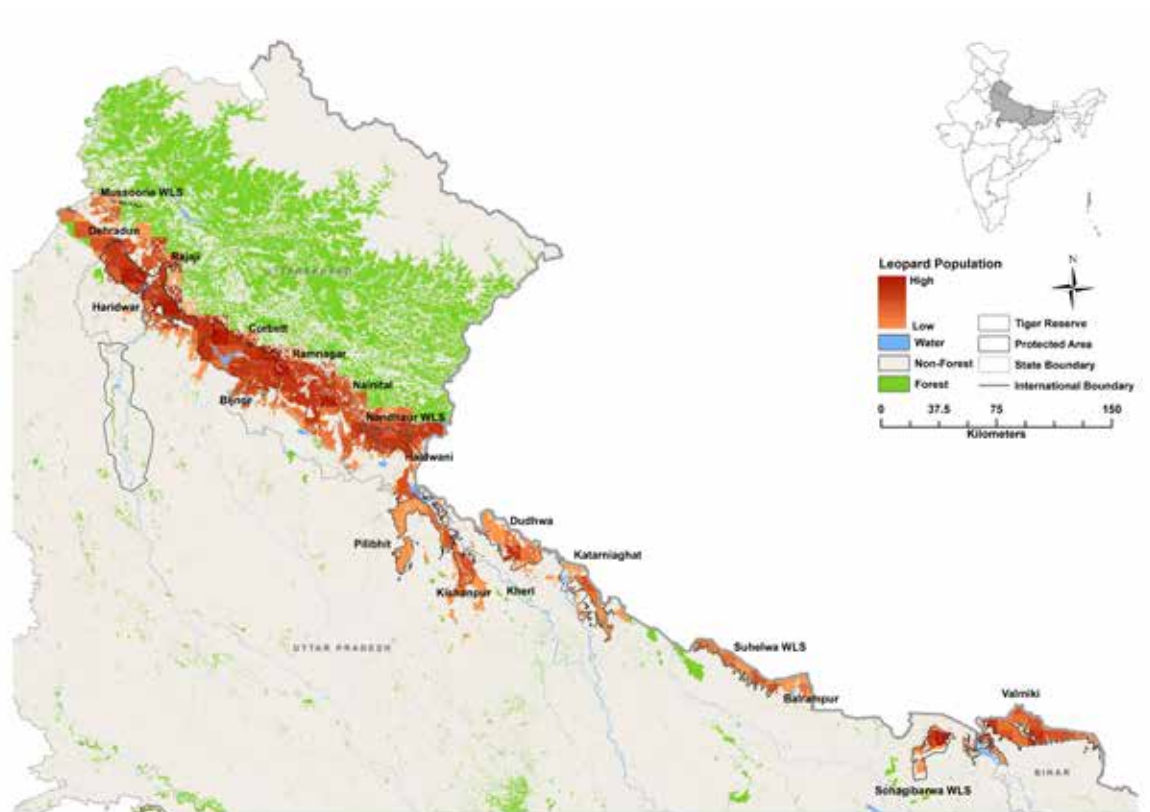


Figure 6. Leopard distribution and density surface for Shivalik Hills and Gangetic Plains landscape 2018

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.

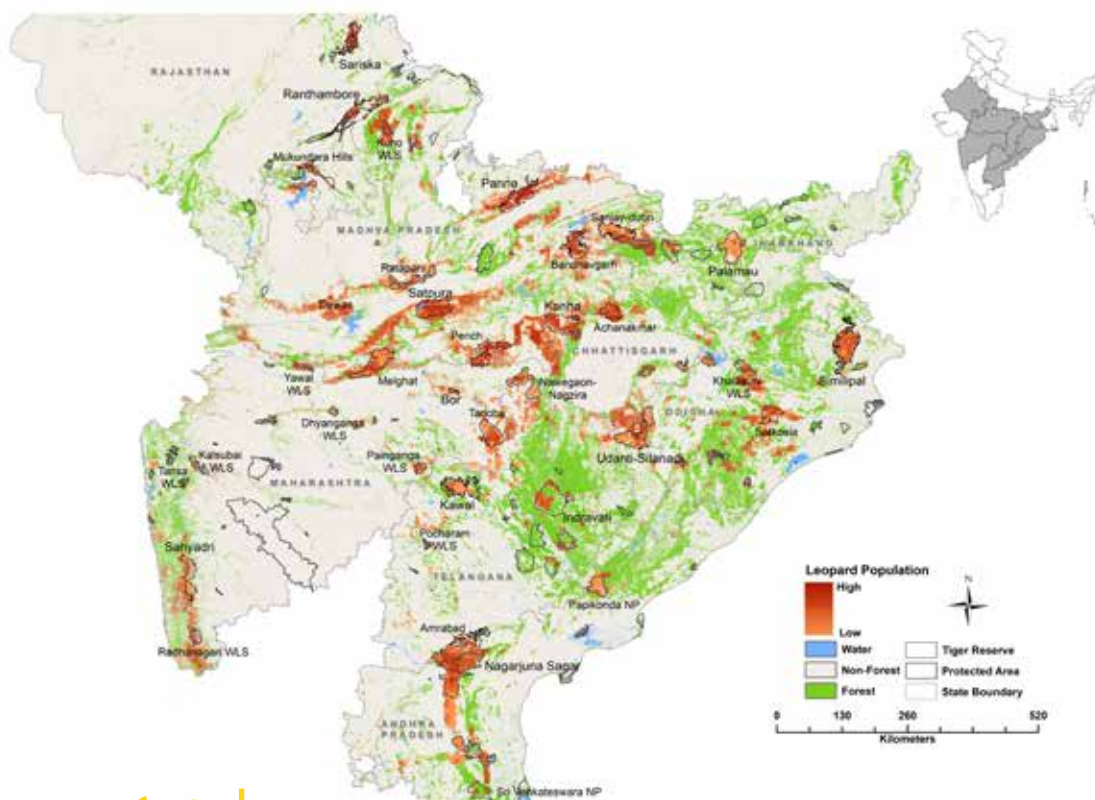


Figure 7. Leopard distribution and density surface for Central India and Eastern Ghats landscape 2018

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- Bannerghatta NP. A second central cluster covering central Kerala and Tamil Nadu composed of the Parambikulam-Anamalai-Eravikulam-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 141 with SE range 115-170 (**Table 1**).

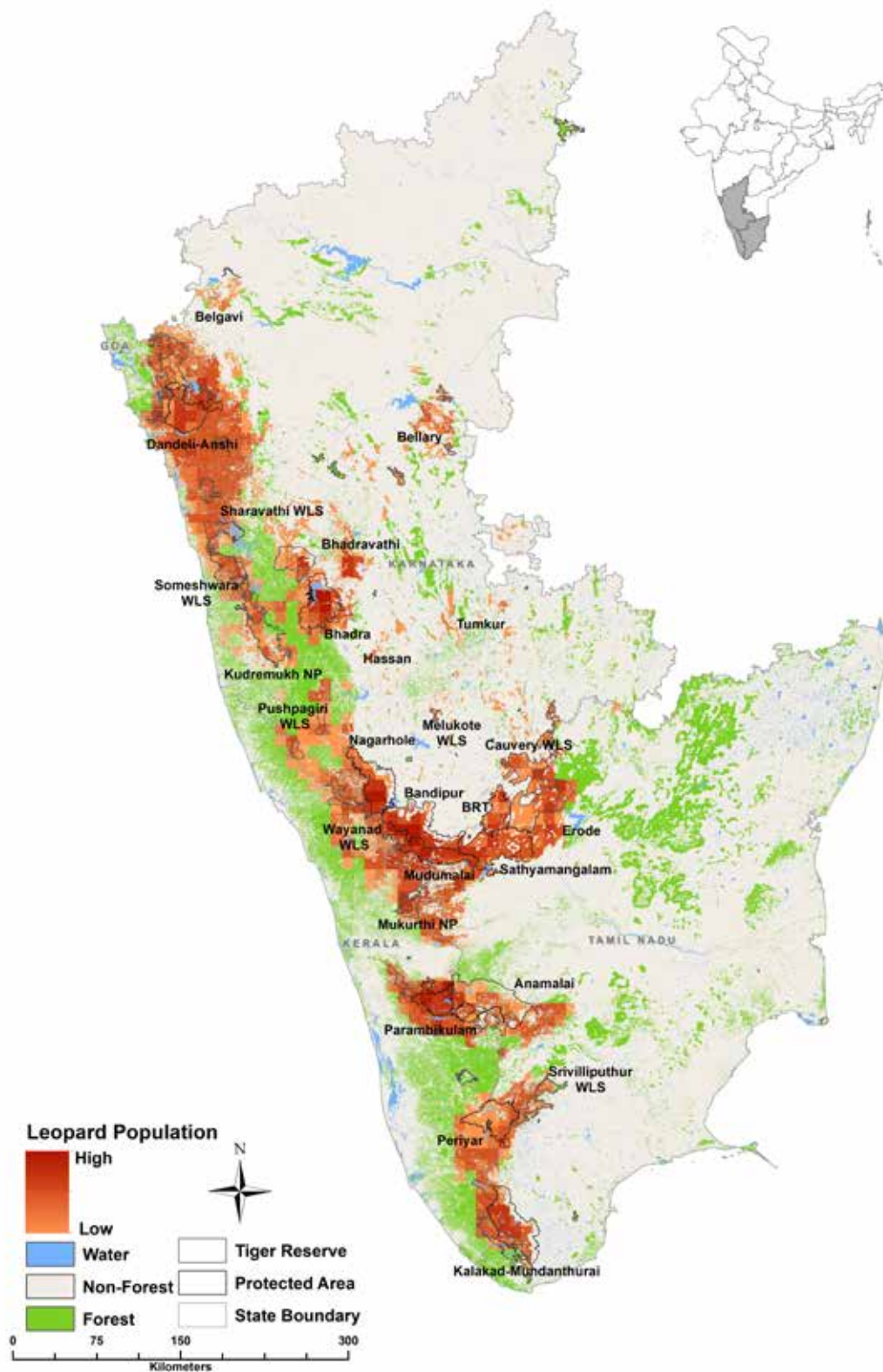
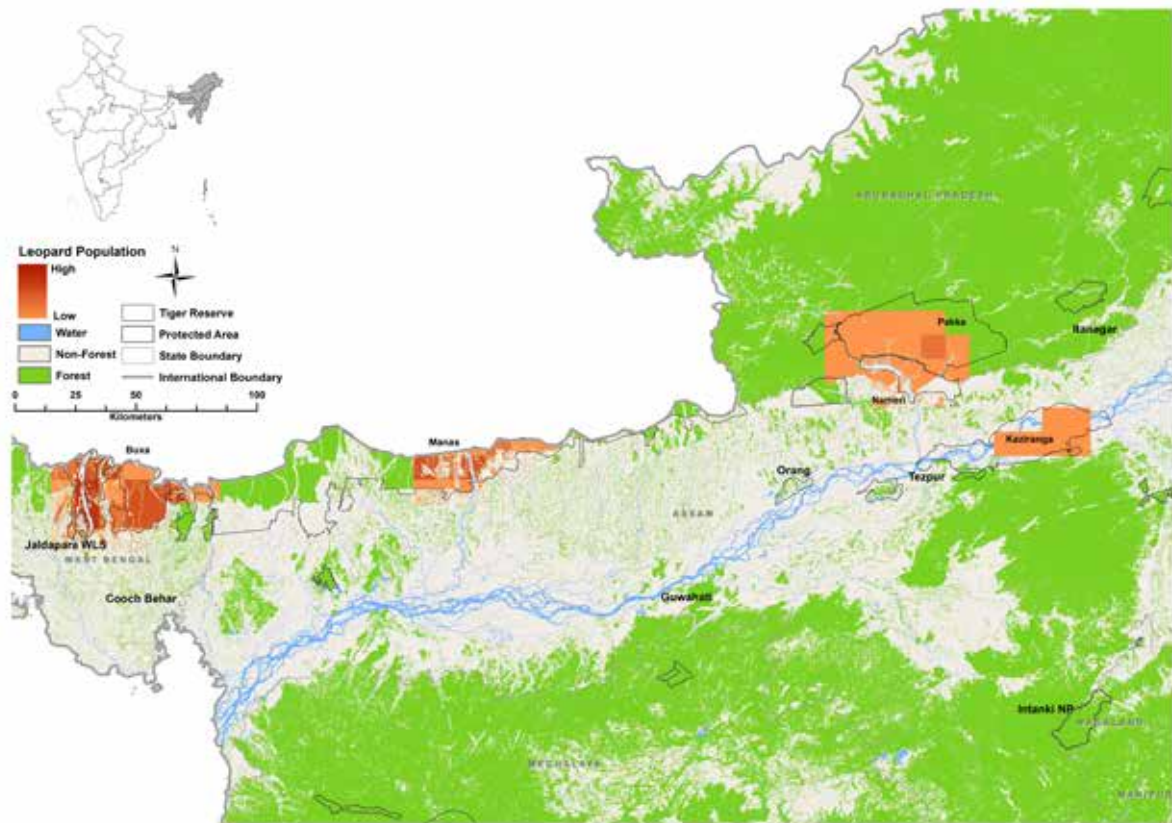


Figure 8. Leopard distribution and density surface for Western Ghats landscape 2018



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

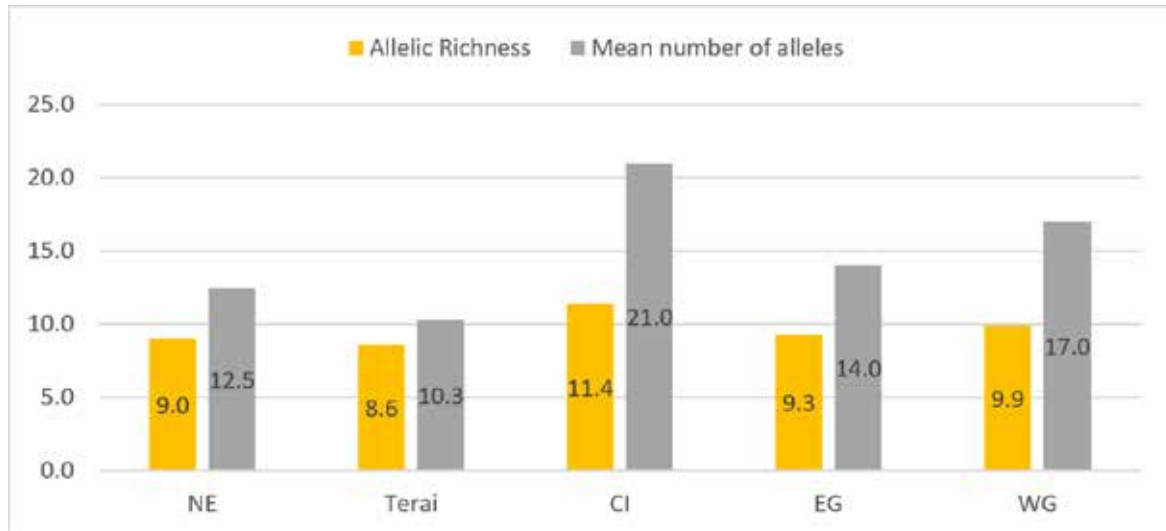


Leopard Population Structure

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 a priori 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 Chat populations share allelic space with Western Chat 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 leopards across landscapes at K=2, 3, 4 & 8. Each individual is represented by a vertical bar, and the coloured length of each bar indicates the probability of membership in each cluster.

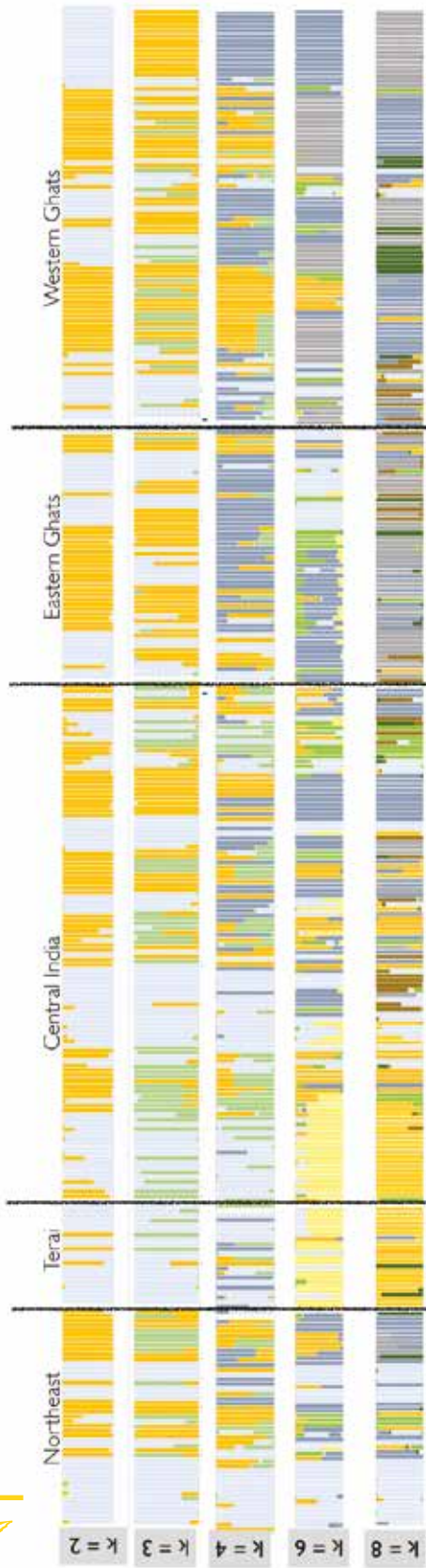
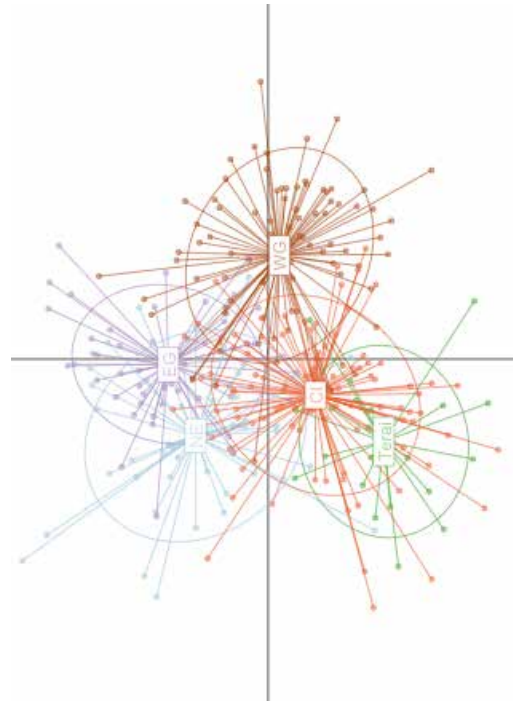


Figure 12. Discriminant analysis of principal components of 317 leopard individuals from the five landscapes (Terai, CI = Central India, NE = North East, EG = Eastern Ghats, WG = Western Ghats.)



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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Appendix # 1

WII Team Leaders:

Dr. Y.V. Jhala and Prof. Qamar Qureshi

NTCA Team Leaders:

Dr. S.P. Yadav, Dr. Anup Nayak (Retd), Dr. D. Swain (Retd)

NTCA Nodal Officer:

Dr. Vaibhav C. Mathur

Faculties involved in all India leopard estimation:

Dr. Y.V. Jhala, Prof. Qamar Qureshi, Dr. Vishnupriya Kolipakam

NTCA-WII Tiger Cell Team:

Kausik Banerjee, Ujjwal Kumar, Swati Saini, Shikha Bisht and Ayan Sadhu

Collaborators:

Rajan Amin (Zoological Society of London)

Lex Hiby (Conservation Research Ltd., Cambridge, UK)

Priya Singh, Rufford fellow

Saket Anand, (Indraprastha Institute of Information Technology, New Delhi)

Saurabh Shanu (University of Petroleum and Energy Studies, Dehradun)

Mike Meredith (Biodiversity Conservation Society Sarawak, Malaysia) and Murray Efford (University of Otago, New Zealand) are acknowledged for assistance in data analysis

M-STrIPES Team:

Rajan Amin and Kevin Dave for conceptualization. Team members are Ashok Kumar, Ashish Prasad, Anup Kumar Pradhan, Ninad Mungi, Deb Ranjan Laha, Kainat Latafat, Krishna Mishra, Anchal Bhasin, Akshay Jain, Papori Khatonier.

Extract Compare Team:

Lex Hiby (program developer), Ahana Dutt, G. Muthu Veerappan

Senior Research Biologists:

Manjari Roy, Sudip Banerjee, Neha Awasthi, Shravana Goswami, Jayanta Kumar Bora, Shweta Singh, Ritesh Vishwakarma, Gullal Singh Cheema

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Dr. V.B. Mathur, Dr. G. S. Rawat, Dr. Pratap Singh, Dr. Dhananjai Mohan, Directors (WII); Dr. G.S. Rawat, Dean (WII); Dr. Bitapi Sinha, Research Coordinator (WII); Dr. V.P. Uniyal, Nodal Officer Externally Aided Projects (WII) and Shri P.K. Agarwal, Deputy Registrar (WII) are acknowledged for their support and facilitation. Dr. Bilal Habib, Dr. K. Ramesh and Dr. Gopi G.V. are acknowledged for providing data.

Research Biologists:

Abhilasha Harendra Shrivastava	Kesha Patel	Sagarika Das
Adarsh Martandrao Kulkarni	Maitry Mayurkumar Jani	Samuel George
Aishwarya Bhandari	Manish Ashok Singanjude	Satemmaula Longchar
Ajay Chauhan	Mohammad Mairaj	Shalu Mesaria
Anish Kumar	Monika Saraswat	Soufil Sharifmiya Malek
Anjali Mehra	Mouli Bose	Sourabh Pundir
Ankita Sharma	Moulik Sarkar	Sourabh Verma
Ashish Kumar Panda	Nanka Lakra	Suhas S.N.
Azam Khan	Nilanjan Basu	Suman Koley
Bhawana Pant	Nishant Nandkumar Zajam	Susmita Khan
Chiranjivi Sinha	Nupur Rautela	Swaroop Rajendra Patankar
Devesh Kumar Mishra	Parul Sen	Tehlu Singh
Farha Usmani	Pooja Choudhary	Thilagavathi M
Gaurav P.J.	Prashant Mahajan	Tishya Dasgupta
Genie Murao	Pratik Pramod Pansare	Upamanyu Chakraborty
Haritha V Mohanan	Pritam Kumar Dey	Vikas Verma
Indranil Bhowmick	Priyadarshini Mitra	Vishwapriya, H.M
Indranil Paul	Rameshwar Pandurang Ghade	Vivekanand Kumar
Jyoti Sheoran	Ravi Kumar Sharma	Vyshakh A
Kamakshi Singh Tanwar	Riddhi Sondagar	

Research Assistants and Interns:

Aarthi Kannan	Mrigank Goel
Abhijeet Gurung	Mukul Rawat
Abhimanyu Bhardwaj	Naved Ansari
Abhishek	Neha Yadav
Abhishek Saraswat	Patrick Bell
Abhishek Verma	Pratikshya Mishra
Amir Mohiuddin Lone	Prateek Savita
Anjali Mishra	Rahul Tomar
Anuroop Singh	Ronit Bohra
Aparna Bhagat	Rutu Prajapati
Arati Gawari	Samridhi Dixit
Arif Ahmed	Siddharth Singh
Asif Hussain	Some Tsering Tamang
Avinash Yadav	Sugandha Gupta
Ayushi Khanduri	Sumit Saha
Deepak Suyal	Suraj Gairola
Devashish Saurav	Swati Dagar
Genius Teron	Swati Singh
Himangshu Borah	Vaishnavi Gusain
Himanshu Matta	Vishant Saini
Ishit Hansoti	Vishnu Vardhan
Jirsong Bey	Yangkeela Bhutia
Kasif Mohammad	Yash Dabholkar
Meera Makwana	Yash Sharma
Mohammad Shaan	Yuyutshu Bhattacharya

Volunteers

Arpit Aggarwal	Santoshi Negi
Dhananjay Jhala	Siddharth Rajmohan
Doli Borah	Sunil Patel
Garima Bhatt	Supragya Dimri
Keshab Gogoi	Tetseo Vetavolu
Luxmi Hina	Tiazula Imchen
Priyanka Kaushik	William Zanthansanga
Sakshi Tomar	Urvi Gupta
Salmaan Khan	Yukta Singh

Laboratory Assistant: Naveen Negi

Office Assistants: Gyanesh Chhibber, Vijay Prakash Baloni, Pallavi Sharma

Data Archival and Management: G. Muthu Veerappan

IGIS (GIS Firm) team: Prabir De (Consultant), Arun Kumar (M-STriPES app developer)

Rahul Khot, Bombay Natural History Society is acknowledged for providing data.

Office Attendants: Devender Singh, Shambhu Prasad Kimothi, Iswar Bahadur Rana

National Tiger Conservation Authority (NTCA) team

Name	Designation
Headquarter	
Dr. S.P. Yadav	ADG (PT) & MS (NTCA)
Dr. Anup Kumar Nayak	ADG (PT) & MS (NTCA) – Retd.
Dr. Debabrata Swain	ADG (PT) & MS (NTCA)- Retd.
Dr. Amit Mallick	IG
Dr. H.S. Negi	ex-IG
Shri Surender Mehra	DIG
Shri Nishant Verma	ex-DIG
Shri Sanjay Pathak	ex-DIG
Shri Rajendra Garawad	DIG
Dr. Vaibhav C. Mathur	AIG
Dr. Rajaram Singh	ex-AIG
Regional Office Eastern Zone	
Shri W. Longvah	IG
Shri D.P. Bankhwal	IG – Retd.
Ms. Agatha Momin	Biologist
Regional Office Central Zone	
Shri Hemant Kamdi	AIG
Shri Anil Dashare	Biologist
Regional Office Southern Zone	
Shri N.S. Murali	IG
Shri P.S. Somasekhar	IG – Retd.

Chief Wildlife Wardens in the States involved in tiger and leopard status estimation 2017-19

S. No.	States	Name
1	Andhra Pradesh	Shri. N. Prateep Kumar, Shri P. Mallikarjuna Rao, Dr. Mohd Ilyas Rizvi, Shri D. Nalini Mohan
2	Arunachal Pradesh	Dr. R. Kemp, Dr. Rabindra Kumar, Dr. Bipin Behari
3	Assam	Shri Niranjan Vasu, Shri D.P. Bankhwal, Dr. Ranjana Gupta
4	Bihar	Shri Bharat Jyoti, Shri A.K. Pandey
5	Chhattisgarh	Dr. R.K Singh, Shri Kaushlendra Singh, Shri S.C. Agarwal, Shri Rakesh Chaturvedi
6	Goa	Shri Ajay Saxena, Shri Santosh Kumar
7	Jharkhand	Shri Lal Ratnakar Singh, Shri P.K. Verma
8	Karnataka	Shri C. Jayaram, Shri Sanjay Mohan
9	Kerala	Shri A.K. Bhardwaj, Shri P.K. Keshavan, Shri Surendra Kumar
10	Madhya Pradesh	Shri Jitendra Agrawal, Shri Shahbaz Ahmed, Dr. U. Prakasham
11	Maharashtra	Shri A. K. Mishra, Shri N.H. Kakodkar
12	Mizoram	Dr. C.H. Muralidhar Rao
13	Nagaland	Shri Satya Prakash Tripathi
14	Odisha	Shri Siddhanta Das, Dr. Sandeep Tripathi, Dr. Ajay Kumar Mahapatra
15	Rajasthan	Dr. G.V. Reddy, Shri Arindam Tomar
16	Tamil Nadu	Shri P.C. Tyagi, Shri T.P. Raghunath
17	Telangana	Dr. Manoranjan Bhanja, Shri P.K. Jha
18	Uttar Pradesh	Shri S.K. Upadhyay, Shri Pawan Kumar, Shri Sunil Pandey
19	Uttarakhand	Shri D.V.S. Khati, Shri Rajiv Bhartari, Shri Jai Raj, Shri Monish Mullick, Ms. Ranjana Kala
20	West Bengal	Shri Ravi Kant Sinha

All India tiger estimation Nodal Officials in the States

S. No.	States	Name
1	Andhra Pradesh	Shri S. Sarvanan, Shri Anand Kumar Jha, Shri K. Gopinatha
2	Arunachal Pradesh	Shri Tana Tapi, Shri C. Loma, Shri T. Riba, Shri Koj Tassar
3	Assam	Dr. Satyendra Singh, Shri Utpal Bora
4	Bihar	Shri S. Chandrasekhar, Shri Hem Kant Roy
5	Chhattisgarh	Dr. S.K. Singh, Shri J.A.C.S Rao
6	Goa	Dr. A. Anil Kumar
7	Jharkhand	Dr. M.P. Singh, Shri Mohan Lal
8	Karnataka	Shri Manoj Kumar

9	Kerala	Shri George P Mathachen, Shri K. Vijayanath, Shri B.N. Anjankumar, Ms. Silpa V Kumar, Shri C.K. Haby, Shri P.K. Vipin Das, Shri M. Unnikrishnan
10	Madhya Pradesh	Shri Alok Kumar
11	Maharashtra	Dr. Rambabu, Shri Sunil Limaye, Shri M.B. Naikwadi, Shri Sachin M. Thakare, Shri G.K. Washishth
12	Mizoram	Sh. Lalthlamuana Pachuau
13	Nagaland	Shri Suman Shivashankar Sivachar W M
14	Odisha	Dr. Jagyandatt Pati, Shri Bhakta Padarbinda Rath, Dr. Nimain Charan Palei
15	Tamil Nadu	Dr. Sekhar Kumar Niraj, Shri A. Venkatesh
16	Telangana	Shri Munindra, Shri A. Shankaran
17	Uttar Pradesh	Dr. S.P. Yadav, Shri A.K. Dwivedi, Shri Pawan Kumar Sharma
18	Uttarakhand	Dr. Dhananjai Mohan, Shri Surendra Mehra, Shri Ranjan Mishra
19	West Bengal	Shri N.S. Murali, Shri Nilanjan Mallick, Shri Subhankar Sengupta, Shri Kalyan Rai

Officials and biologists who coordinated training in the states

State	Name
Andhra Pradesh	Shri S. Sarvanan, Dr. K. Suryanarayana, Shri P. Ramohan Rao Shri N. Nageswara Rao, HYTICOS, Hyderabad
Arunachal Pradesh	Shri Umesh Kumar, Shri Chandan Ri, Shri Taru Habung
Assam	Shri Sudip Banerjee (WII), Shri Deb Ranjan Laha (WII), Shri Rabindra Sarma, Shri Himanshu Gogoi, Shri Papul Rabha
Bihar	Shri Gaurav Ojha, Shri Ambarish Kumar Mall, Dr. Kamlesh Maurya (WWF India), Shri Shariq Shafi (WWF India)
Chhattisgarh	Dr. S.K Singh, Shri A.K Sonwani, Shri M.K Chaudhary, Shri Loknath Patel, Shri S.K Sinha, Shri R.K Rayast, Shri K.L Nirmalkar, Shri T.R Jaiswal, Shri Shyam Singh Dev, Shri Vivek Shukla, Shri Narendra Katara, Ms. Sailaja Nayak, Shri Naveen M, Shri Suraj M, Shri Krishnendu Basak , Shri Moiz Ahmad
Jharkhand	Dr. M.P. Singh, Shri Mohan Lal, Shri Sanjay Xaxa, Shri Manish Bakshi
Karnataka	Information and Communications Technology (ICT) cell and Tiger cell, Aranya Bhavan, Bengaluru, Shri. Shantaram D. Kamat, Sh. Francis
Kerala	Dr. M. Balasubramanian, Shri M. Ramesh Babu, Dr. Patrick David, Shri R. Rahul, Shri C. Sivakumar, Shri B. Karthik, Shri Vishnu Vijayan, Shri Shiju, Shri Aneesh C.R.
Madhya Pradesh	Dr. Dharmendra Varma – SFRI, Shri Vivek Jain, Shri Subharanjan Sen, Shri Sanjay Shukla, Shri B.S. Annigeri, Shri L. Krishnamoorthy, Shri H.S. Mohanta, Shri M. Pathak, Shri Ravikant Mishra, Shri Rajnish Kumar Singh, Dr. Anjana Rajput – SFRI, Dr. Aniruddha Majumdar – SFRI, Shri Gyan Prakash Shukla

Maharashtra	Shri R.S. Govekar, Shri M.S. Reddy, Shri Mukul Trivedi, Dr. Ben V Clement, Dr. Vinita Vyas, Shri Rishikesh Ranjan, Shri, N.R. Praveen, Shri Amlendu Pathak, Shri Vishal Mali, Shri G.V. Sanap, Shri Kolhankar, Shri Kavitar, Shri L.N. Patil, Shri P.B. Panchbhai, Shri M. Toro, Shri Y. Bahale, Shri S. Pardikar, Shri M. Khairnar, Shri Tushar Pawar, Shri Kishore Mankar, Shri Manohar Gokhale, Shri M. Motghare, Shri Bobde, Ms. Morkute, Shri V. Khedkar, Shri Azim Mujawar, Ms. Neenu Somarji, Shri R.K. Chavan, Shri B.P. Rathod, Ms. G.S. Nannware, Shri S.S. Bhagawat, Shri G.P. Bobade, Shri G.H. Luche, Shri D.V. Raut, Shri R.H. Kotrange, Shri P.R. Rathod, Shri S.S. Pande, Shri A.H. Gore, Shri G.D. Thombare, Shri K.Y. Talwekar, Shri Amaz Sidam, Shri Mohan Chati, Shri P. Humane, Shri, R. Bhongade, Shri P.N. Naik, Shri P. Sathwane, Shri N.R. Gawande, Shri D.T. Dude, Shri A.R. Deokar, Shri R.R. Sagir, Shri P.E. Patil, Shri C.R. Tambe, Shri S.L. Bilolikar, Shri V.B. Kamble, Shri R.K. Bhawar, Shri K.M. Abharna, Shri S.R. Dumare, Shri R.M. Wakde, Shri P.V. More, Shri S. Thipe, Shri A.K. Mishra, Shri V.K. Borade, Shri S.G. Badhekar, Ms. Priyanka Bajaj Tahaliyani, Shri Ashwini Buche, Ms. Nisha Sharma, Shri Rahul Kale, Ms. Pallavi Ghaskadbi (WII), Ms. Lynette Gomes, Shri Nilanjan Chatterjee (WII), Shri Zehidul Hussain (WII)
Nagaland	Shri Y M Jami, Ms. K Caroline Angami, Shri Suman Shivashankar Sivachar W M, Shri Jongpong Walling, Shri Kenlumtatei, Shri R. Aaron Yimchunger
Odisha	Shri P. K. Sahoo, Dr. Jagyandatt Pati, Shri Bhakta Padarbinda Rath, Dr. Nimain Charan Palei
Rajasthan	Shri Y.K. Sahu, Dr. G.S. Bhardwaj, Shri Ghanshyam Prasad Sharma, Shri. Anand Mohan, Shri Seduram Yadav, Shri Mukesh Saini, Dr. T. Mohan Raj, Shri Hemant Shekhawat, Shri Girish Arjun Punjabi, Shri N. Gokulakkannan, Shri Saket Agasti, Ms. Urvashi Sharma
Tamil Nadu	Dr. Sekhar Kumar Neeraj, Shri A. Venkatesh, Shri Srinivas R Reddy, Shri V Ganeshan, Shri. Peter Prem Chakravarthi, Dr. Mahesh Kumar, Shri. Sridharan, Ms. Agnes Jeya Pakiavathi, Shri. Kanthasamy, Shri. Parthiban, Shri. Karthik, Shri Yogesh, Shri. Palanisamy, Dr. Santhosh Kumar, Shri.Dalson Mani, Mr.Vijaya Kumar, Shri. Sakthivel
Telangana	Shri C.P. Vinod Kumar, Shri C. Sarvanan, Shri Jogu Yellam
Uttar Pradesh	Shri V.K. Singh, Dr. Semmaran, Shri Manish Singh, Shri Adarsh Kumar, Shri Kailash Prasad, Shri Samir Kumar, Shri Devendra Chaturvedi, Shri R.K.P. Singh, Shri S.N. Yadav, Shri D.P. Shrivastava, Shri Ashok Kashyap, Shri Ram Baran Yadav, Shri Ashok Chandra, Shri Dilip Shrivastava, Shri Asish Bista (WWF India)
Uttarakhand	Shri Surendra Mehra, Shri Sanatan, Dr. Parag Dakate, Shri Amit Verma, Shri G.S. Karki, Shri Ajay Sharma, Shri Yogesh Kumar, Shri Vijay Singh, Ms. Prema Bisht, Ms. Rukmini Devi
West Bengal	Shri Kalyan Rai, Shri Manish Yadav, Shri Durga Kant Jha, Shri Mayukh Ghosh, Shri Ajoy Kumar Das, Shri Deepak M., Shri Kanu Chakraborty, Shri Anindya Guhathakurta, Ms. Dolan Sarkar, Shri Dibyadeep Chatterjee, Shri Souritra Sharma
Wildlife Institute of India	Dr. Sutirtha Dutta, Dr. Amit Kumar

List of Contributors

Contribution is based on work done for field sampling, data analysis, supervision and writing up; there is no order in the contributor list; the data presented belongs to the NTCA, WII, and State Forest Departments as per the respective MoU's

Shivalik Hills & Gangetic Plains Landscape

NTCA Team:

Nishant Verma, Vaibhav C. Mathur

WII Team:

Y.V. Jhala, Qamar Qureshi, Shikha Bisht, Ujjwal Kumar, Swati Saini, Kausik Banerjee, Ayan Sadhu, Sudip Banerjee, Kainat Latafat, Ninad Avinash Mungi, Ahana Dutt, Deb Ranjan Laha, Adarsh Kulkarni, Nupur Rautela, Shalu Mesaria, Maitry Jani, Ajay Chauhan, Ritesh Vishwakarma, Pooja Choudhary, Ashish Panda, Indranil Bhowmick, Monika Saraswat, Suman Koley, Tehlu Singh, Sagarika Das, Genius Teron, Manish Singhanjude, Priyadarshini Mitra, Vyshakh A., Nanka Lakra, Swaroop Patankar, Moulik Sarkar, Upamanyu Chakraborty, Prashant Mahajan, Indranil Bhowmick, Azam Khan, Jyoti Sheoran, Genie Murao, Riddhi Sondagar, Haritha Mohanan, Susmita Khan, Abhimanyu Bhardwaj, Yash Dabholkar, Sumit Saha, Arti Gawari, Meera Makwana, Neha Yadav, Yuyutshu Bhattacharya, Swati Singh, Deepak Suyal, Rahul Tomar, Siddharth Singh, Swati Dagar, Himangshu Borah, Sunil Patel, Vishant Saini, Ayushi Khanduri, Asif Hussain, Kasif Mohammad

State Forest Departments & NGO Partners:

S.P. Yadav, Dhananjai Mohan, Bharat Jyoti, Surendra Mehra, Ranjan Mishra, A.K. Dwivedi, Pawan Kumar Sharma, S. Chandrasekhar, Hem Kant Roy, Sanatan, Ajay Sharma, Pradip Kumar, Komal Singh, Anil Penyuli, Dinesh Uniyal, Vikash Rawat, Jwalaprasad, Vijay Saini, Anup Singh Gussain, Rajendra Mohan Nautiyal, Rakesh Negi, Pramod Dhyani, Sharanpal Singh Kunwar, Yogesh Kumar, Vijay Singh, Rahul, Amit Verma, Chandrasekhar Joshi, Anjani Kumar Tripathi, Shivraj Chand, R.K. Tiwari, Lachhi Ram Nag, Dharmnad Dhyani, Rajkumar, Pankaj Sharma, Prashant Hindban, Rakesh Kumar Bhatt, Mahavir Singh, Navin Chandra Joshi, Neha Chowdhuri, Harish Chandra Bhatt, Sandeep Giri, Bharat Singh Sajwan, Prema Bisht, Rukmani Devi, M Semmaran, Prajakta Hushangabadkar, Pranav Chanchani, Meraj Anwar, Adarsh Kumar, Kailash Prakash, P.P. Singh, Raja Mohan, Ashish Bista, Mudit Gupta, Naresh Lodhi, Kandhai Lal, Tarun Singh, Anukriti Singh, Mahaveer Kaujalagi, Sunil K Choudhary, Ramesh K Pandey, Anil Kumar Patel, Sunil K Choudhary, G. P. Singh, Dabeer Hasan, Sameer Kumar, Praveen Rao Koli, Rajnikanth Mittal, Ram Kumar, G.D Mishra, S K Awasthi, Manish Singh, A.K. Pandey, Rakesh Kumar, Prashant Kumar Gupta, Gaurav Ojha, Ambarish Kumar Mall, Kamlesh K. Maurya, Shariq Shafi, Anil Singh, I.P. Bopanna, Devavrat Pawar, Jakka Amarnath, Ankit Sanhotra, Arjun Kamdar, Ali Arzan, Aleem Khan, Sujit Chakravarty, Pooran Singh Rana, Sidhant Umariya, Jyoti Antil, Soumya Bakshi, Sher Singh Bisht, Rajendra Bisht, Saloni Salaria, V.S. Tomar, H.S. Maindola

Central India & Eastern Ghats Landscape

NTCA Team:

Amit Mallick, Rajendra Garawad, Vaibhav C. Mathur, Raja Ram Singh, Hemant Kamdi

WII Team:

Y.V. Jhala, Qamar Qureshi, Vishnupriya Kolipakam, Bilal Habib, K. Ramesh, Ujjwal Kumar, Ayan Sadhu, Swati Saini, Kausik Banerjee, Shikha Bisht, Ashish Prasad, Anup Pradhan, Ninad Avinash Mungi, Ashok Kumar, Krishna Mishra, Kainat Latafat, Ahana Dutt, Akshay Jain, Jayanta Kumar Bora, Neha Awasthi, Shravana Goswami, Adarsh Kulkarni, Nupur Rautela, Kamakshi Tanwar, Sourabh

Pundir, Ravi Sharma, Jyoti Sheoran, Soufil Mahek, Prateek Pansare, Ankita Sharma, Moulik Sarkar, Riddhi Sondagar, Tishya Das Gupta, Parul Sen, Anjali Mehra, Kesha Patel, Nishant Zajam, Manish Singanjude, Rajsekhar, Sankarshan Chowdhury, Genie Murao, Rameshwar Ghade, Nilanjan Basu, Haritha Mohanan, Abhilasha Shrivastava, Upamanyu Chakraborty, Swaroop Patankar, Sourabh Verma, Chiranjivi Sinha, Indranil Paul, Ashish Kumar Panda, Vivekanand Kumar, Vyshakh A., Sagarika Das, Pallavi Ghaskadbi, Lynette Gomes, Zehidul Hussain, Nilanjan Chatterjee, Gaurav P.J., Maitry Jani, Vikas Verma, Monika Saraswat, Ajay Chauhan, Shalu Mesaria, Susmita Khan, Indranil Bhowmick, Nanka Lakra, Nilanjan Basu, Aishwarya Bhandari, Suman Koley, Abhilasha Shrivastava, Patrick Bell, Swati Singh, Suraj Gairola, Meera Makwana, Abhishek Verma, Aparna Bhagat, Yuyutshu Bhattacharya, Mukul Rawat, Sidhharth Singh, Deepak Suyal, Neha Yadav, Sunil Patel, Himangshu Borah, Asif Hussain, Abhishek Saraswat, Arif Ahmed, Shantanu Sharma, Swati Dagar, Ishit Hansoti, Salman Khan, Supragna Dimri, Kasif Mohammad, Naved Ansari, Mrigank Goel, Avinash Yadav

State Forest Departments & NGO Partners:

Manoranjan Bhanja, P.K. Jha, D. Nalini Mohan, Alok Kumar, L.R. Singh, M.P. Singh, S.K. Singh, J.A.C.S Rao, R. Munindra, Rambabu, Sunil Limaye, Mohan Lal, S. Sarvanan, Anand Kumar Jha, K. Gopinatha, M.B. Naikwadi, Sachin M. Thakare, G.K. Washishth, Jagyandatt Pati, Bhakta Padarbinda Rath, Nimain Charan Palei, A. Shankaran, Rajasthan Forest Department, Madhya Pradesh Forest Department, Vivek Jain, Bharat Singh Gaur, Vijendra Khowagade, Veerbhadra Singh Parihar, Martanday Singh Marabi, Chhotelal Kale, Jagdish Chandra Uike, Sharad Singh, Rajendra Singh Paraste, V.K. Tiwari, K.K. Dhurve, A.K. Pandre, R.S.S. Yadav, S.K. Jambhare, Pavan Marscole, Pradeep Tembhre, B.R. Sirsham, H.L. Dahiya, Basant Kumre, Aniruddha Dhamorikar, Upendra Dubey, Jyotirmay Jena, Snehit Kumar Rahul, Ravikiran Govekar, R.B. Gawai, G.P. Bobade, G.F. Luche, K.Y. Talwekar, Aditya Joshi, Vivek Tumsare, Vikrant Jathar, Vikrant Wankhade, Rovhin Todankar, Aniket Sayam, Adwait Keole, Alok Wankhede, Rajesh Bhendarkar, Dinesh Khate, Vishal Bansod, Subbaiah K., M.S. Reddy, Vishal H. Mali, M.N. Khalrnar, S. Shivbala, Vinod Shivkumar, T. Beula Ezhil Mathi, Jayant Kulkarni, Shubham Badratiye, Prachi Mehta, Ramanujan R.M., Amlendu Pathak, Pradip E. Patil, U.S. Savant, Priya R. Mhasikar, Rajendra R. Sadgir, Shrikant S. Pawar, Sachin N. Shinde, Balaji S. Digole, P.R. Nikalje, M.B. Chopade, R.P. Rathod, V.V. Dhande, A.G. Shendge, Neenu Somraj, S.S. Bhagwat, Geeta Nannaware, A.R. Deokar, P.S. Pakhale, P.L. Sathwane, P. Naik, Ankita Telang, R.N. Bhongade, S. Jadhav, V. Clement Ben, Arvind Aapte, Suresh Salunke, A.D. Patil, Rahul Kale, Mukul Trivedi, Praveen N.R., Kishor Mankar, Ladkat N.S., Manohar Gokhale, Shatanik Bhagwat, Ramarao, S.V., Gajendra Hire, Kulraj Singh, P.B. Panchbhai, S.H. Gore, S.S. Paandey, P.R. Rathod, Priyanka Bajaj Tahaliyani, Amar Sidam, R.B. Gawai, G.P. Bobade, D.V. Raut, G.D. Thombare, R. Kotrange, Sundeep Balaga, Sailaja Nayak, R.K. Sidar, Jyotirmay Jena, Rahul Talegaonkar, Upendra Dubey, Sandeep Singh, Alok Sanjay Nath, N.M. Mishra, Rohitash Rathor, Rajkumar Yadav, Vinay Sharma, O.P. Yadav, B.V. Reddy, Naveen M., Suraj, Moiz Ahamad, Aminuddin, R.K. Rayast, P.R. Dhuruw, R.N. Sori, R.L. Patel, Nilkanth Gangber, Tularam Nretee, Bhopal Singh Rajput, Gopal Kasayap, J.R. Markam, L.B. Bhileparia, Mukesh Varma, Romesh Banchhor, Mangal Vadde, Shiv Patel, Ashok Yadaw, Uttam Yadu, Jageshwar Sandily, Umesh Kumar Sahu, Dinesh Kumar, M.K. Mahaling, A.K. Mishra, Sanjay Xaxa, Ashok Singh, M.K. Bakshi, Prakash Kumar, Prajwal Kumar Sinha, Om Prakash, Upendra Kumar, Umesh Oraon, Mamta Kumari, Bipin Kumar, Deepak Kumar, Rahaman, Anshu Pragyan Das, Biranchi Narayan Mishra, Pankaj Kumar Das, Sisir Behera, P.K. Sahoo, C.P. Vinod Kumar, M. Joji, Shantharam, Venkateshwarlu, G. Ravi, Y. Rameshwar Reddy, C. Manohar, C.P. Renuka, Parveez Ahamed, J. Prabhakar, Sridevi Saraswathi, G. Vanikumari, Muralidhar, Bhavani Shankar, Sarveshwar, Imran Siddiqui, Bapireddy, Sathvik. K., Md. Umarsharif, Anjaiah, Suresh, Mahesh, J. Eadaiah, Nupurdani, Yogeshbydani, Basha, Saleem, Narasimha, Ravindra Babu, Narasimha, Dasaratham, Khaja Baba, Ravi Kumar, Praveen Kumar, HYTICOS, Ranjeeth Nayak, G. Ramalingam, Ravinder Rathod, K. Damodar Reddy, N. Vijay Kumar, K. Ravinder, Jogu Yellam, A. Venkateshwar Rao, G. Devidas, R. Srinivasa Rao, Rathod Ramesh, Shabbir Ahmed Khan, Nagaiah, Praneet Kour, Gulam Moinuddin, Wahab Ahmed, Chandra Kumar, Kaleeluddin, Mazaruddin, Y. Ramesh Babu, Shyam Kumar, Mohd. Waseem, D. Raja Rao, K. Anitha, A. Aravind, R. Ravi, Dharmaraj, Anil Kumar, Raja Babu, Ranjeeth Nayak, Narsimha Reddy, Nagawath Swamy, Purnachander, K. Ram

Mohan, N. Rajender, Pavan Kumar, Chakradher, Srinivas, M. Ravikanth, N. Nageshwara Rao, G.N. Pavan Kumar Rao, S. Venkatesh, B. Jaya Chandra Reddy, P. Siva Sankar Reddy, Y. Sanyasi Naidu, V. Jaya Ramulu, S. Chandra Sekhar, T. Bala Subbaiah, M. Dattathreya, M. Sankaraiah, K. Suneel Kumar, M. Naga Raja, G. Gnana Prakash Rao, S.V. Subba Rao, S. Abdul Khadar, P. Praveen Kumar, K. Rami Reddy, H. Jeevan, M. Ramesh, R. Mallikarjuna Naik, S. Kranthi Kumar

Western Ghats Landscape

NTCA Team:

P.S. Somasekhar, Amit Mallick, Rajendra Garawad

WII Team:

Y.V. Jhala, Qamar Qureshi, Kausik Banerjee, Ayan Sadhu, Ujjwal Kumar, Swati Saini, Shikha Bisht, Ashok Kumar, Ninad Avinash Mungi, Ahana Dutt, Krishna Mishra, Kainat Latafat, Akshay Jain, Adarsh Kulkarni, Nupur Rautela, Abhilasha Shrivastava, Thilagavathi M., Viswapriya, H.M., Suhas S.N., Samuel George, Chiranjivi Sinha, Sourabh Verma, Thilagavathi M., Vyshakh, A., Nishant Zajam, Haritha Mohanan, Kamakshi Tanwar, Sourabh Pundir, Prashant Mahajan, Vivekanand Kumar, Gaurav P.J., Nanka Lakra, Monika Saraswat, Pooja Choudhary, Genie Muraio, Azam Khan, Riddhi Sondagar, Rameshwar Chade, Kesha Patel, Maitry Jani, Sagarika Das, Shalu Mesaria, Ravi Sharma, Ajay Chauhan, Manish Singanjude, Swaroop Patankar, Vikas Verma, Aishwarya Bhandari, Susmita Khan, Parul Sen, Vishant Saini, Meera Makwana, Neha Yadav, Abhishek Verma, Yuyutshu Bhattacharya, Swati Singh, Aparna Bhagat, Deepak Suyal, Himangshu Borah, Yukta Singh, Mukul Rawat, Arati Gawari, Jirsong Bey, Sugandha Gupta, Pratikshya Mishra, Supragya Dimri, Avinash Yadav, Kasif Mohammad

State Forest Departments & NGO Partners:

Sekhar Kumar Niraj, A. Venkatesh, Manoj Kumar, A. Anil Kumar, George P Mathachen, K. Vijayanath, B.N. Anjankumar, Silpa V Kumar, C.K. Haby, P.K. Vipin Das, M. Unnikrishnan, O. Palaiah, Shantaram D. Kamat, Y.N. Munavalli, K.S. Goravar, Shivanand Todkar, Ambady Madhav, Mohankumar, C. Anilkumar, Srinathreddy, Abdul Javeed, K.N. Manjunath, D. Srinivas, G. Puttaraju, H. Puttaswamy, A. Suneelkumar, Shylendarkumar, N.P. Naveenkumar, M. Sandeep, Lokesh, S.L., H. Hanumantharaju, K.G. Manjunath, Mani, Praveen, Siddaraju, H.R., Mallikarjuna Konthikal, Radeesh, Ashoka, Prakash, H.C. Kantharaju, P. Shankara, Abhimanyu, V., M. Nagaraju, P. Ruthren, H.Y. Manjunath, S.H. Naveen Kumar, R.K. Gopi, Praveen T. Jeevaragi, S.S. Raghavendra, Ananya Kumar J., Tiger Cell Bengaluru, Javed Mumtaz, V. Ganesh, Amarnath, Shivanand Magadum, M. C. Cheluvvaraj, Ramesh Kumar, Yatish Kumar, Vasanth Reddy, Ganapathy K., Takth Singh Ranavat, Ganesh Bhatt, Francis, Surya Sen, K.P. Ranjan, V.K. Vinod Kumar, M. M. Jaya, Maria Christu Raju, Shashi Mishra, K.M. Mariswamy, Srinivas Nayak, Ananda M.A., Umesh H.J., Yamanuri Kolur, Satish R., Srikanth M Biradhar, Shivanand, Kiran K. A., Belliyappa K.A., Deviprasad P., Suresha H.J., Jayaprakash B.D., Jayakumar. K.P., P.B. Arunakumar, Jeevan Kumar K.T., B.M. Ranjan, Vijaya, K.M., S.M. Prakash, Dhananjaya B.G., K.C. Rajesh, K.N. Kushallappa, Jinnu T., Pradeesha K.L., Poonacha K.C., Changappa, Vijaya M.C., Sachin K.G., Aiyappa, Ganesha, Pradeep Kumar, Ravichandra K.T., Vikram, Yedukondalu V., Malathi Priya M., Rajesh Gawal A., Syed Sab Nadaf, Vijaykumar, Sudarshan, Veerabhadra Swamy T.M., Venkatesha S., M. N. Vijaykumar, Shivaram Babu M., Lingaraja, Vinay, Niveditha, Anthony Rego, Vinayaka Solabannanavar, Rajesh D., Praveen Kumar Sasvehalli, Sangamesh, Satish, Vinod Angadi, N. D. Sudarshan, Maria Christu Raju, Prakash Allapur, J. Peter Prem Chakravarthi, K. Mahesh Kumar, V. Ganeshan, A.S. Marimuthu, P. Muhammed Shabab, Kayarat Mohan Das, I. Anwardeen, Kommu Omkaram, Arokiaraj Xavier, N. Sridharan, S. Agnes Jeya Pakiavathi, Venkatesh, Raja, Srinivas R. Reddy, V.A. Saravanan, J. Yogesh, M. Palanisamy, P. Santhosh Kumar, J. Jenish, J. Dalson Mani, L. Sivakumar, M. Dhayanathan, M. Bomman, K. Vijaya Kumar, N. Ravikumar, S. Buvanewari, APW experts, All Forest Range officers, Foresters, Forest Guards, Anti-poaching watchers, and WWF – India field Assistant of Mudumalai TR, V. Naganathan, C.H. Padma, P.G. Arunlal, C. Sakthivel, G. Jhonson, S. Bernad, S. Palanisamy, N. Manojkumar, V. Rajalingam, S. Murali, C. Sivakumar, K. Krishnakumar, K. Chinraj, Kristy Silvia, Balakrishnan, A. Joshi, R. Gowtham,

P. Gunalan, S. Manojkumar, A.K. Ulaganathan, Deepak Srivastava, S. Senbagapriya, A. Pushpakaran, D. Venkatesh, B. Rajkamal, Beulah, S. Buvaneswari, Range officer, Forest Guards, Anti-poaching watchers of Sirumugai and Mettupalayam, Vismiju Viswanathan, C. Balakrishnan, K. Manikandan, K. Sengottaiyan, K. Krishnakumar, K. Chinraj, B. Sundar, Suresh, S. Senbagapriya, A. Pushpakaran, V.C. Rahul, B. Vijayan, APW experts, All Forest Range officers, Foresters, Forest Guards, Anti-poaching watchers, and WWF – India field Assistant of Gudalur Division, S. Anand, all forest rangers, foresters, forest guards and anti-poaching watchers of Kanyakumari WLS, Satish, Mahesh Kumar, S.N. Thejasvi, S. Kalanithi, T. Karthik, Boominathan, Ravikumar, Vinoth, all forest rangers, foresters, forest guards and anti-poaching watchers of Megamalai WLS, A. Pushpakaran, K. Krishnasamy, V. Suresh, Athurahiman, D. Bernad, N. Dharman, L. Stephen, APW experts of Mukurthi NP, K. Thirumal, R. Kanthasamy, all forest rangers, foresters, forest guards and anti-poaching watchers of Nellai WLS, Sumesh Soman, APW experts, Range officer, Forest Guards, Anti-poaching watchers of Nilgiri Forest Division, Parthiban, all forest rangers, foresters, forest guards and anti-poaching watchers of Srivilliputhur Grizzled Squirrel WLS, M. Balasubramaniam, Vishnu Vijayan, Shiju, Ramesh Babu, Patrick, T.T. Shameer, Aneesh C.R., Vishnu

North Eastern Hills & Brahmaputra Flood Plains Landscape

NTCA Team:

D.P. Bankhwal, W. Longvah, Vaibhav C. Mathur

WII Team:

Y.V. Jhala, Qamar Qureshi, Vishnupriya Kolipakam, Gopi, G.V., Ujjwal Kumar, Swati Saini, Kausik Banerjee, Shikha Bisht, Ayan Sadhu, Priya Singh, Deb Ranjan Laha, Ninad Avinash Mungi, Ashish Prasad, Krishna Mishra, Ahana Dutt, Akshay Jain, Papori Khatonier, Adarsh Kulkarni, Nupur Rautela, Satemmnela Longchar, Aishwarya Bhandari, Kesha Patel, Manish Singanjude, Pratik Pansare, Sourabh Verma, Ajay Chauhan, Anish Kumar, Bhawana Pant, Devesh Kumar Mishra, Farah Usmani, Mouli Bose, Shweta Singh, Nanka Lakra, Vikas Verma, Soufil Malek, Upamanyu Chakraborty, Chiranjivi Sinha, Nilanjan Basu, Pritam Dey, Samuel George, Susmita Khan, Genius Teron, Sourabh Pundir, Moulik Sarkar, Ankita Sharma, Swaroop Patankar, Priyadarshini Mitra, Rameshwar Ghade, Ashish Panda, Monika Saraswat, Maitry Jani, Gaurav P.J., Indranil Paul, Yuyutshu Bhattacharya, Arpit Aggarwal, Yangkeela Bhutia, Himangshu Borah

State Forest Departments & NGO Partners:

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