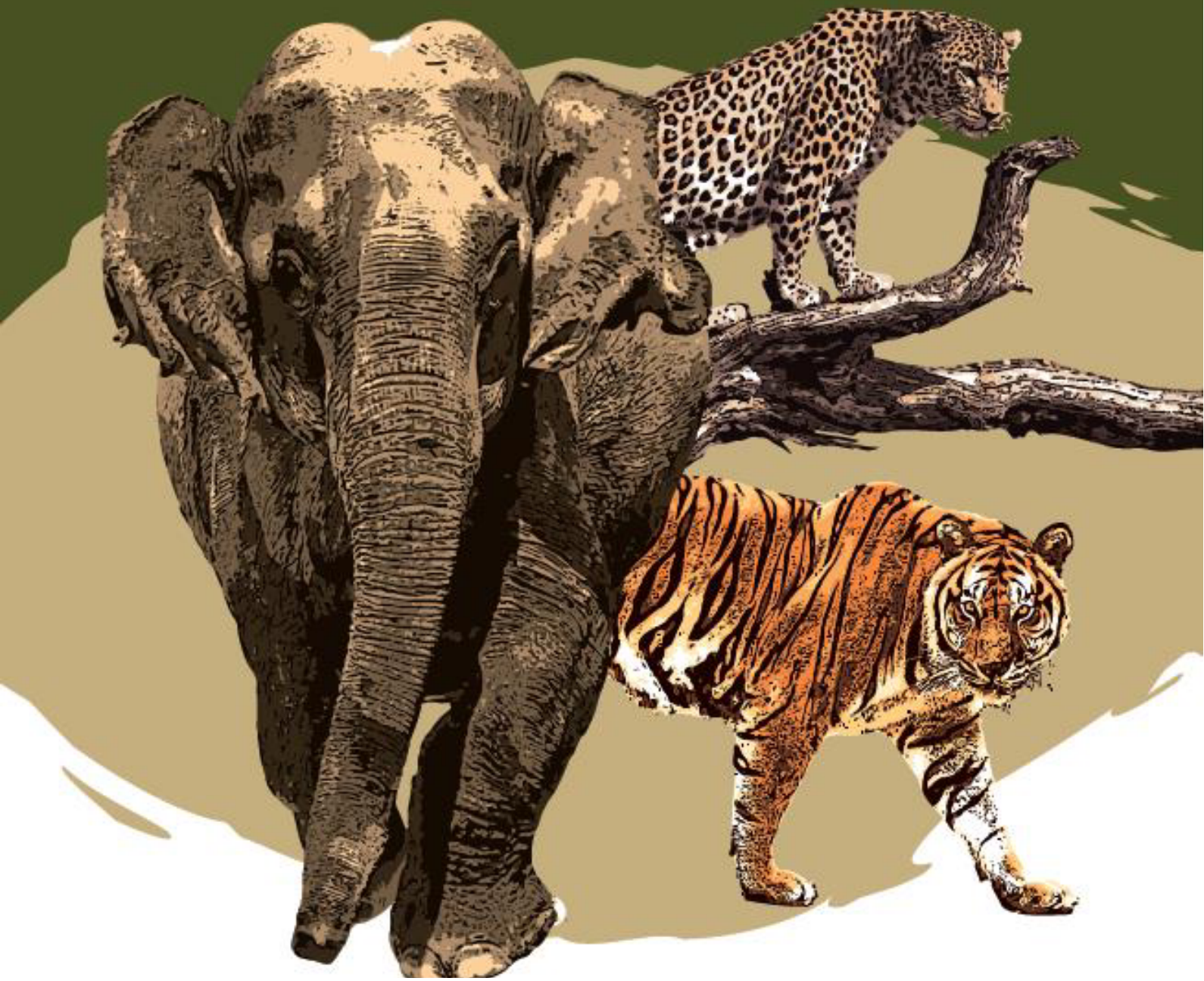
# ALL INDIA ELEPHANT TIGER AND LEOPARD ESTIMATION



## PROGRESS REPORT - 2023

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

In India, where elephants are an integral part of the ecosystem and a cultural symbol, several methods have been used to estimate their population. Nation wide elephant population estimation has been conducted every five years by the forest department of elephant range states. All elephant range states, except Southern Indian states, conduct population estimation through direct count method. Southern states use dung based population estimation, which was introduced in 2002. The total/direct count method has no scientific basis for large landscapes and elephant population, hence it was modified to sample block counts with restricted areas, to maximise the probability of detection of elephants with small team of enumerators (Project Elephant, August 2017). In 2017, total of 27,312 elephants were counted, of which 11,960 were in Western Ghats, 3,120 in Central India, 2,085 in Shivalik Terai landscape and 10,139 in Northeast India. It was recognised that total count and dung decay based counts are providing unreliable results and thus, new methodology should be adopted to ensure robust population estimation, like line transect, camera trapping, DNA based mark recapture and occupancy models. Though mentioned in Rangarajan et. al (2010), a combination of genetic identity along with modern approach to capture-mark-recapture has yet to be successfully demonstrated for elephants

In 2021, after discussions it was realised that robust scientific approach like dung based mark recapture and camera trap based distance sampling estimation will be feasible methods to enumerate elephant population. Further, by combining the efforts during All India Tiger Estimation, as the sampled area overlap for elephant and tiger presence is maximal, it would result in a prudent use of resources while hastening the process of estimation for tiger, leopard and elephant. Therefore, on 10th March, 2021 Project Elephant (PE) invited to submit a project proposal for a synchronised tiger and elephant population estimation (S1; Table1). A project proposal from WII was submitted to PE in April, 2021 (S2; Table1). The methodology for enumeration was discussed with PE, NTCA and elephant ecology experts on 17th June, 2021 (S3; Table 1) and it was decided to go ahead with this enumeration exercise. In October, 2021 PE requested WII for a submission of proposal with budgetary requirement to CAMPA through PE, which was sanctioned in July, 2022 and funds released in August, 2022.

The elephant enumeration is also divided into three phases of which Phase 1 and 2 are common, wherein during Phase 1, data on occupancy of carnivores, mega herbivores and habitat quality is collected by forest department staff across all the forested habitats of elephant and tiger bearing states. Phase 2 consists of remotely sensed data collection of habitat co-variates that influence animal distribution. Phase 3 is the intensive site monitoring for collecting data to calibrate the models for population estimation of elephants. This phase involves collection of dung samples for mark recapture and camera trapping for distance sampling. A sample area of 200 sq km block is chosen, and a camera trap along with a sign survey and dung collection walk is carried out in every 4 sq. kms within the sampling unit **(Appendix 1)**. This Phase 1 training for collection of dung samples during the sign survey walk was explicitly instructed during September, 2021, along with datasheet and instructions, when training of trainers was completed for the All India Tiger, leopard and Elephant estimation.

Phase 1 data collection was initiated in October, 2021 and completed by December, 2022. In December, 2021 advertisement for recruitment of researchers for field and limited lab work for the AITE exercise was hired, wherein researchers joined by February, 2022. Following this, a study site for standardising of genetic protocols, was taken up in Karnataka where the density of elephants was known. The genetic mark recapture for large scale sampling was standardised and yielded robust estimates, was completed by August, 2022 **(Appendix 2).**

On continuous review of Phase 1 data in June, 2022, dung samples were collected **(Appendix 3)** and it was found that data was not collected as per protocol and is inadequate, hence several reminders were sent to states from PE and NTCA (S11, S15, S16, S17; Table1). On release of funds in August, 2022, advertisement for lab researchers was put up and researchers were employed by December, 2022. In November, 2022, researchers were deployed in Bandhavgarh for intensive site sampling, which was completed in January, 2023, by collecting a total of 329 dung samples. In December, 2022

researchers were sent to Bandipur for sampling and finished camera trapping and sampling by March, 2023, after collecting 250 samples.

Table 1: Timeline of Activities for Elephant population estimation

| S.no | Activity | Date | Comments |
|---|---|---|---|
| 1 | Preliminary Discussion about converging Tiger and Elephant estimation | 10th March, 2021 | |
| 2 | Proposal submitted by WII reg the elephant estimation census | 9th April, 2021 | Letter from DWII to IGF, Project elephant |
| 3 | Presentation on methodology to be adopted for elephant estimation to Project Elephant Committee | 17th June, 2021 | Broader framework for elephant population estimation is accepted. Chair requested to submit method. |
| 4 | Timeline for Tiger, leopard and elephant estimation communicated | 25th August, 2021 | With caveats of budget and timely collection of field data. As per initial submitted timeline, April 2023 is the intended time if start is from September, 2021 and field data submission will be completed by February, 2022, but it was submitted later, see point 6 |
| 5 | Request from elephant cell to to submit proposal for CAMPA funding | 12th October, 2021 | Proposal was submitted for funding |
| 6 | Phase I data collection initiation and completion | October, 2021 - December, 2022 | Data has been collected |
| 7 | Advertisement to hire field personnel and limited lab personnel for tiger, leopard and elephant estimation | December, 2021 | For field work and standardisation of molecular markers to estimate elephant population |
| 8 | Standardisation of genetic mark recapture protocol | January - June, 2022 | Protocols were developed for the mark recapture after screening of 20 microsatellite loci, on a known population of elephants in Karnataka. Field work entailed transects, and dung collection and genetic analysis. |
| 9 | After due process of exam, and interview, researchers have joined | February-March, 2022 | |
| 10 | Evaluation of Phase I data | June, 2022 | Continuous evaluation of Phase I data has been done, as received at WII and it has been found that elephant data collected is not appropriate for Phase I for population estimation. |
| 11 | Letter from Project Elephant to Chief Wildlife Wardens of states to address issue of poor dung collection | July, 2022 | Letter sent to several states emphasising for appropriate data collection |
| 12 | Sanction order to Pay and Account to release fund to WII for elephant estimation | July, 2022 | Letter sent to PAO to release 1.5 crores for conducting elephant estimation, to WII |
| 13 | Receipt of funds at WII | 19th August, 2022 | 1.5 crores received at WII |

| S.no | Activity | Date | Comments |
|---|---|---|---|
| 14 | Advertisement to recruit researchers for mainly lab work | September, 2022 | Advertisement to recruit lab researchers issued, and subsequently examination conducted |
| 15 | Communication with PE, regarding status of Phase I and 3 | 8th September, 2022 | It was informed that sampling for Phase I and 3 is inadequate, therefore researchers will sample areas from second week of October as per protocol |
| 16 | Reminder letter from Project Elephant for appropriate dung collection of elephant population estimation to all state | 15th September, 2022 | 2nd reminder sent to all states emphasising the lack of appropriate dung sample collection |
| 17 | Review meeting for Phase I at WII by NTCA | 14th October, 2022 | It was presented that timeline is of two years, from the receipt of fund, i.e., September, 2022, and since dung collection is not happening according to protocol, researchers will be sent to field to collect samples in the 20 sites |
| 18 | Deputed genetics and field team to Bandhavgarh for deployment of camera traps and genetic sample collection | 23rd November, 2022 | Permission received, and team deployed - Sampling completed in January, 2023 |
| 19 | After due process of exam, and interview, lab researchers have joined | December, 2022 | After exam and interview, researchers have joined |
| 20 | Deployment of team to Bandipur(and permission requested for Bhadra and Nagarhole, Karnataka - as season for sampling in Western Ghats) | 19th December, 2022 | Team received permission on 27th January, 2023 |
| 21 | Data receipt completed and cleaned | January, 2023 | All Phase I data, cleaned, crosschecked |
| 22 | Completed sampling in Bandipur | March 1st Week, 2023 | Camera trapping and genetic sampling completed, data organisation is in progress |
| 23 | Nagarhole Sampling initiation | Mid march | On removal of cameras from Bandipur, team is moving to Nagarhole |

**Phase 1:** Phase 1 data was received by December, 2022 and cross-checked, cleaned by February, 2023. A total of 11,004 grids of 100 sq.km were sampled (figure 1) during this cycle of Phase 1, of which 1,562 were occupied by elephants (figure 2), i.e., 14.19% of sampled area was occupied by elephants.

**Phase 2:** The remotely sensed co-variates were collected for use in occupancy analysis

**Phase 3**: A total of 579 dung samples were collected from two intensive sites and processed for genetic analysis (figure 3 & 4). The team is currently in the process of sampling Nagarhole, once camera traps are completely removed from Bandipur.

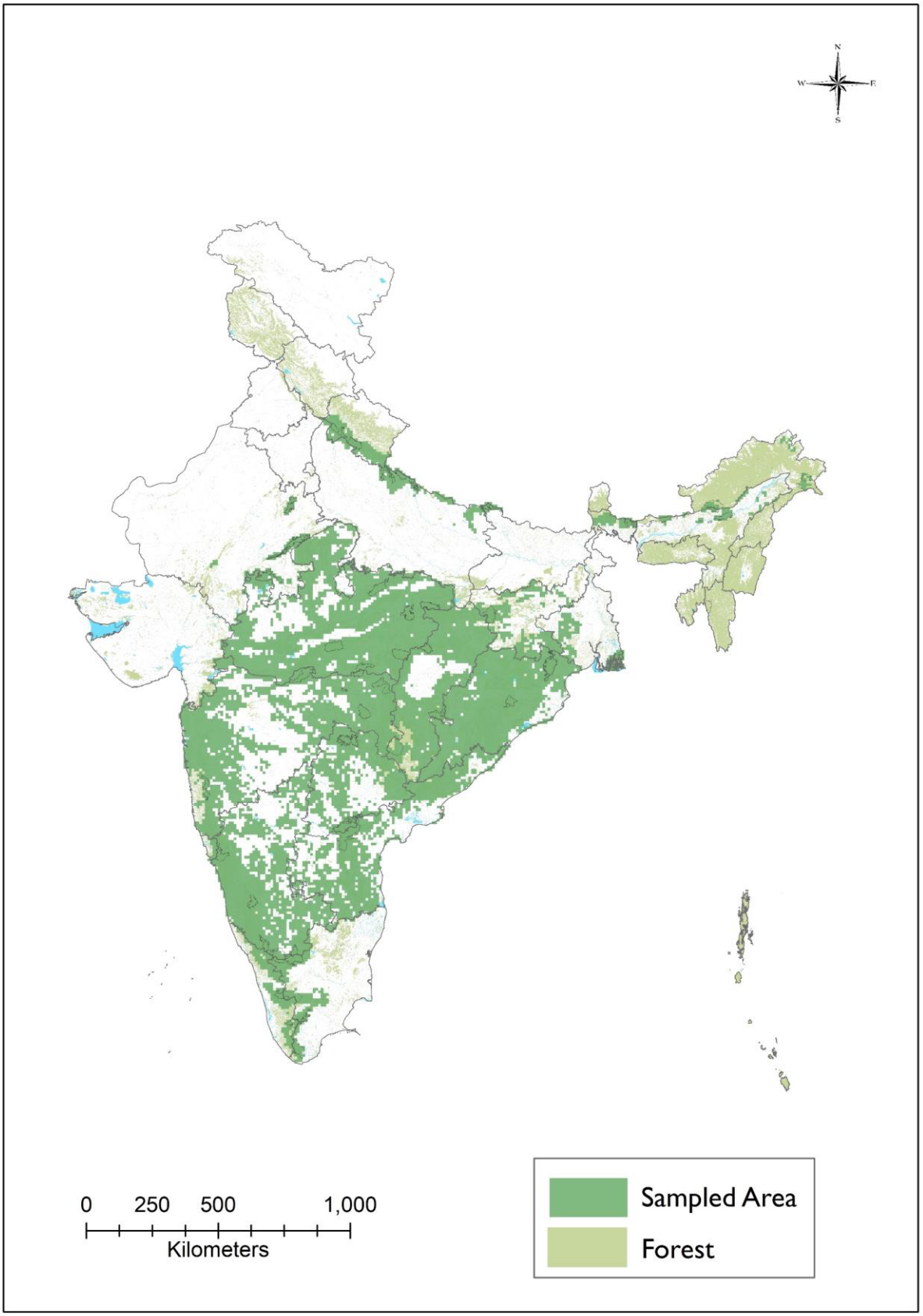



*Figure 1: Sampled area under Phase 1 of AITE cycle 2022*

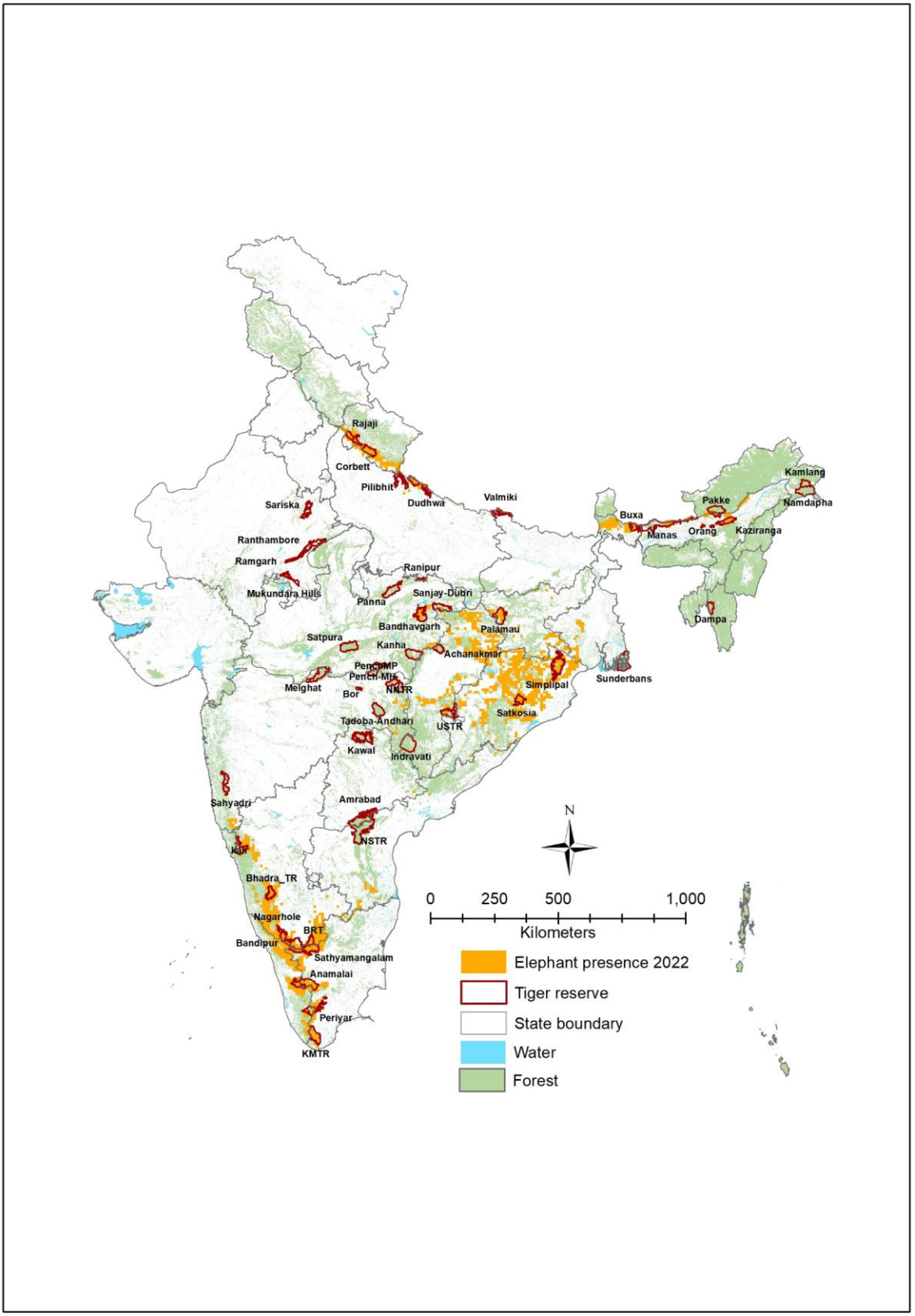



*Figure 2: Elephant presence in the sampled grids during Phase I of AITE – 2022*

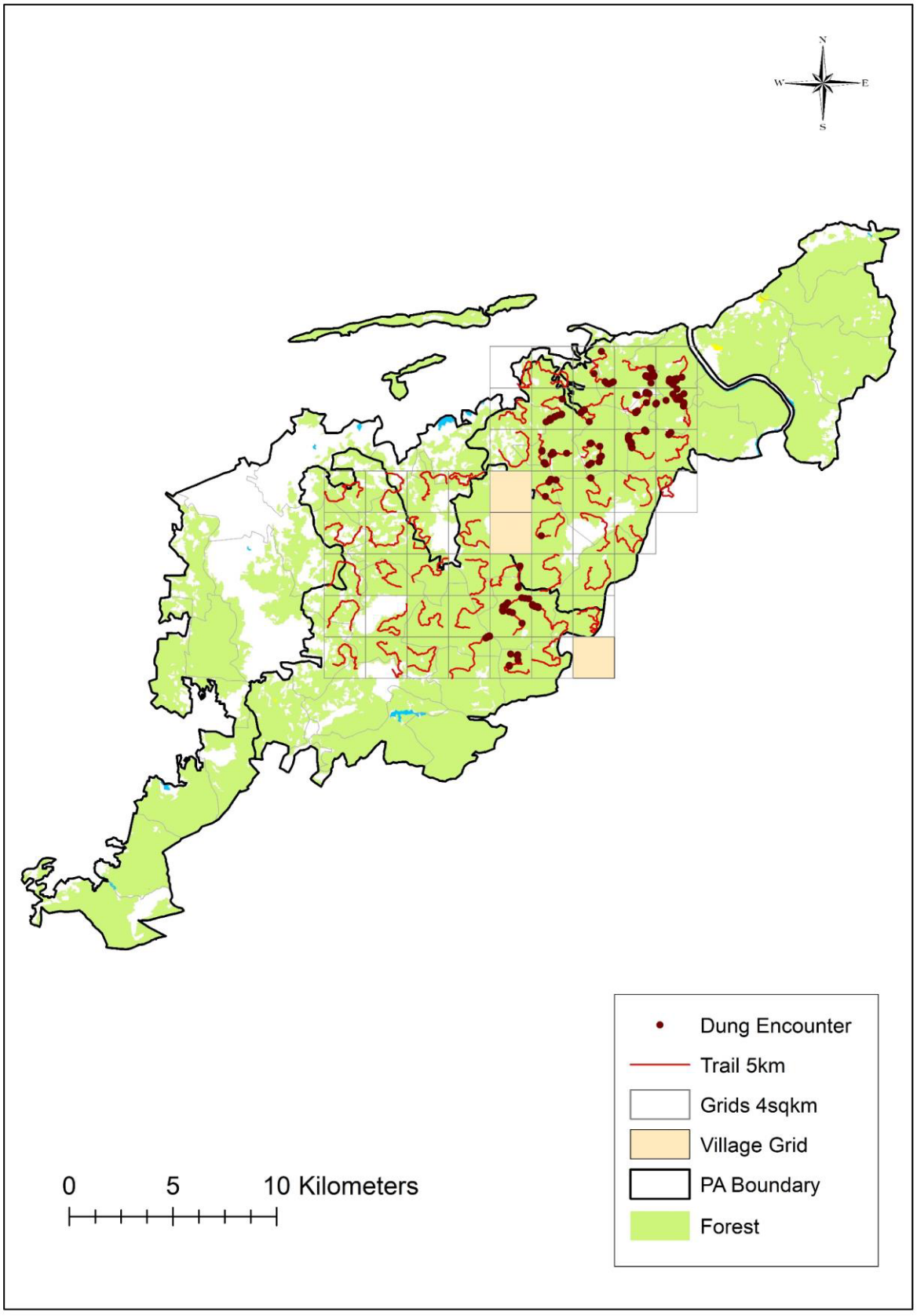



*Figure 3: Survey effort on trail walks, grids sampled and dung encounter in Bandhavgarh during December, 2022 – January, 2023*

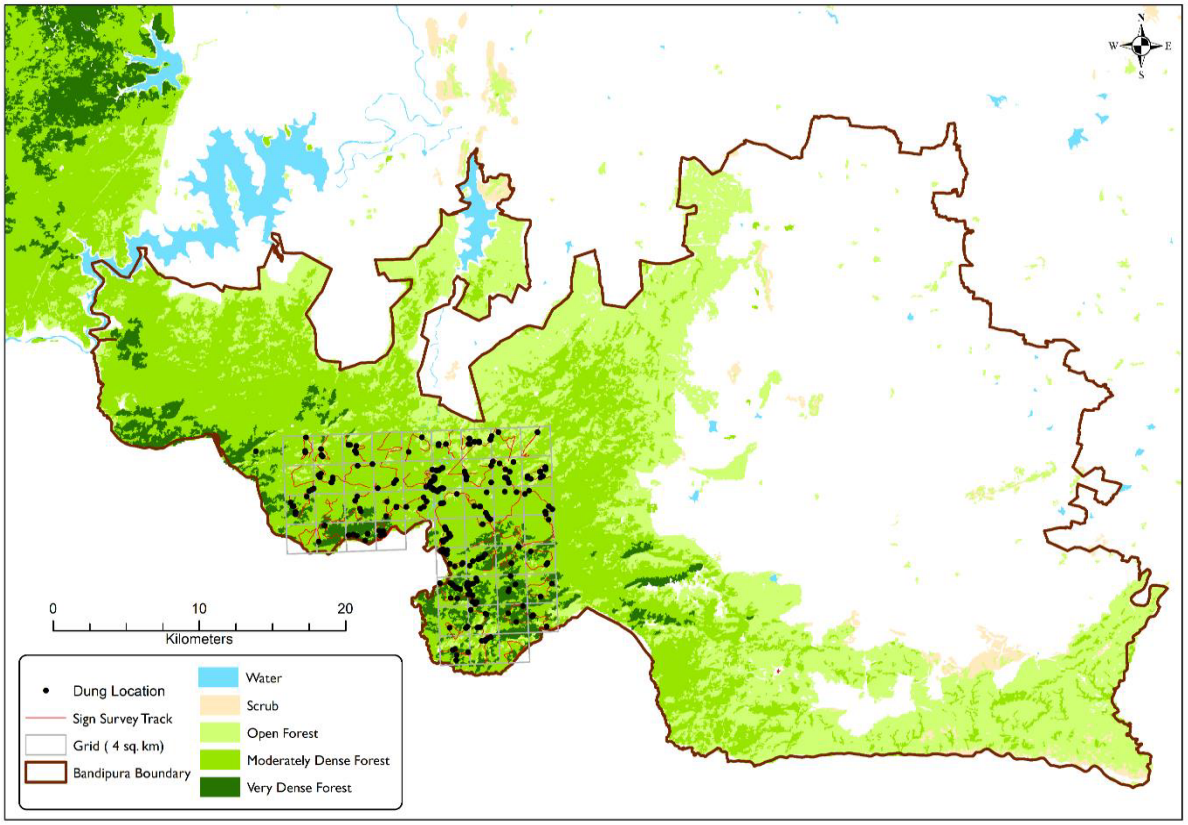



*Figure 4: Survey effort on trail walks, grids sampled and dung encounter in Bandipur, during January – February, 2023*

## Way ahead:

As per plan, 20 more sites need to be sampled for Phase 3 data collection, which amounts to 4,000 sq.km of sampling area. We have planned to sample area in April - May 2023 and October – December, 2023. Elephant movements are largely regulated by the availability and distribution of water, which in turn influence the cropping pattern and availability of food plants in the landscape (Williams et al. 2006). It has been observed that, in the onset of monsoon, elephant populations are distributed over larger landscape, while in summer, elephants are congregated in larger groups, restricted in smaller areas (Sukumar 1989). This movement will substantially influence the abundance of elephants locally. Thus, it is prudent to align Phase 1 data collection time period, with that of Phase 3. Monsoon data collection is not appropriate as availability of water everywhere changes the distribution and density of elephants locally, hence, modelling this aspect will not be possible to arrive at population estimation.

## Following is the plan for Phase 3 data collection:

It takes a total of 66 man months to complete the work involved for population estimation. With adequate manpower and timely funding, this can be ideally completed by June, 2024. However, after completion of first half of the sampling by June, we will be in a better position to revise the timeline as necessary and evaluate whether there is a possibility of completion of this work earlier than stated. We will seek equipment and field manpower resource from forest department to assist our research team in timely completion of data collection.

*Table 2: Timeline of Elephant estimation activities planned*

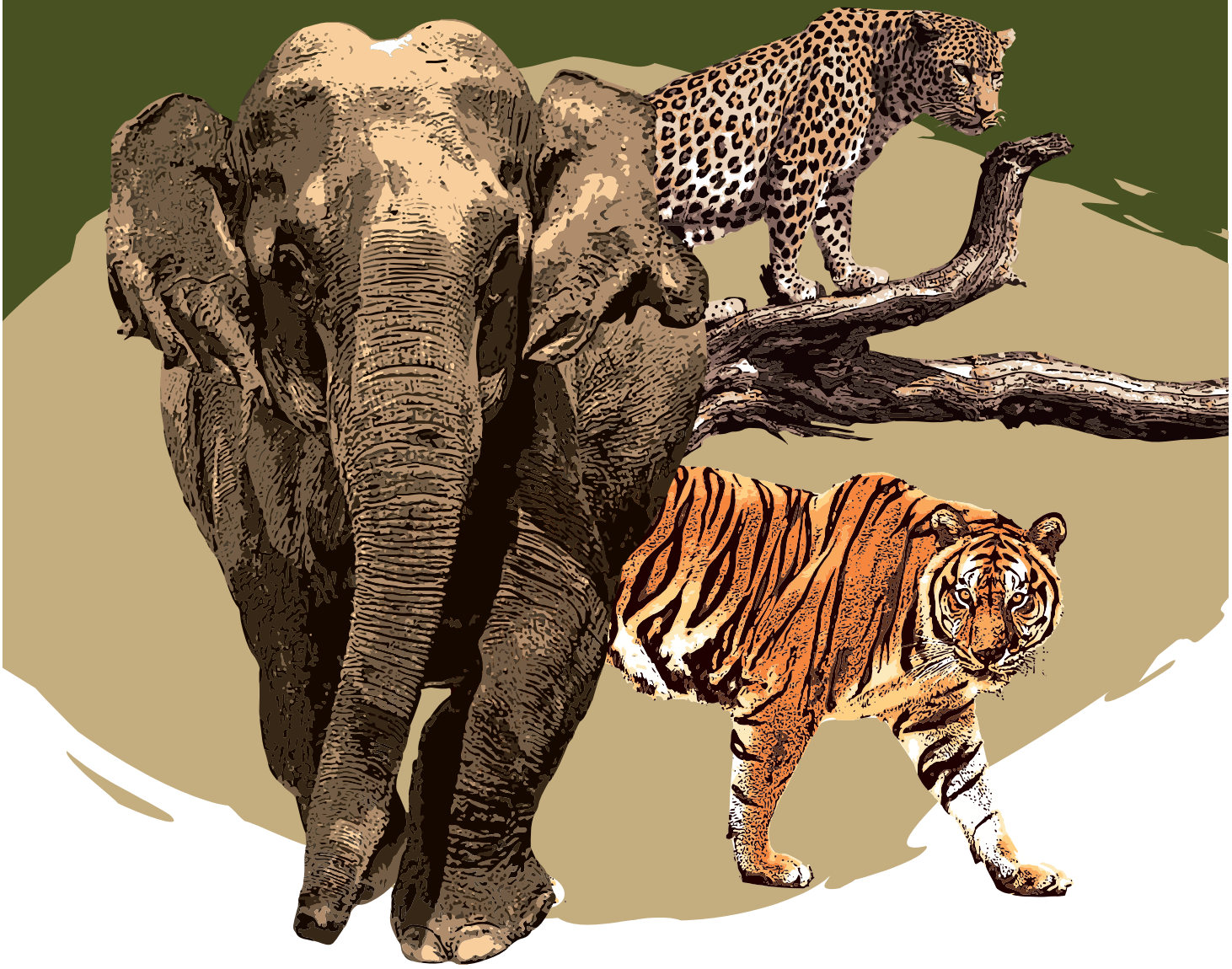
| Sno | Activity | Time | Remarks | Caveats |
|---|---|---|---|---|
| 1 | Sampling in 8 sites parallely | 15 April - May(last), 2023 | It takes 45 days to complete one site | Conditional on timely permissions and facilitation by local park, given it is fire season |
| 2 | Completion of data sorting of 10 sites, and genetic analysis | June - September, 2023 | In this time period, the data collected will be sorted and used for analysis, it takes 45 man days for each site for genetic analysis, and camera trap data | Adequate manpower and timely release of funds to engage additional researchers |
| 3 | Sampling in 10 sites | October – February, 2023 | It takes 45 days to complete one site | Conditional on timely permissions and facilitation by local park |
| 4 | Completion of data sorting of 10 sites, and genetic analysis | February - June, 2024 | Data sorting, genetic analysis and report writing | |
| 5 | Status report | July, 2024 | Status report | |

References:


- Sukumar, R. (1989). Ecology of the Asian elephant in southern India. I. Movement and habitat utilization patterns. Journal of tropical Ecology, 5(1), 1-18.
- Williams, A. C., Johnsingh, A. J., Krausman, P. R., & Qureshi, Q. (2008). Ranging and habitat selection by Asian elephants (Elephas maximus) in Rajaji National Park, north-west India. Journal of the Bombay Natural History Society, 105, 24-33.

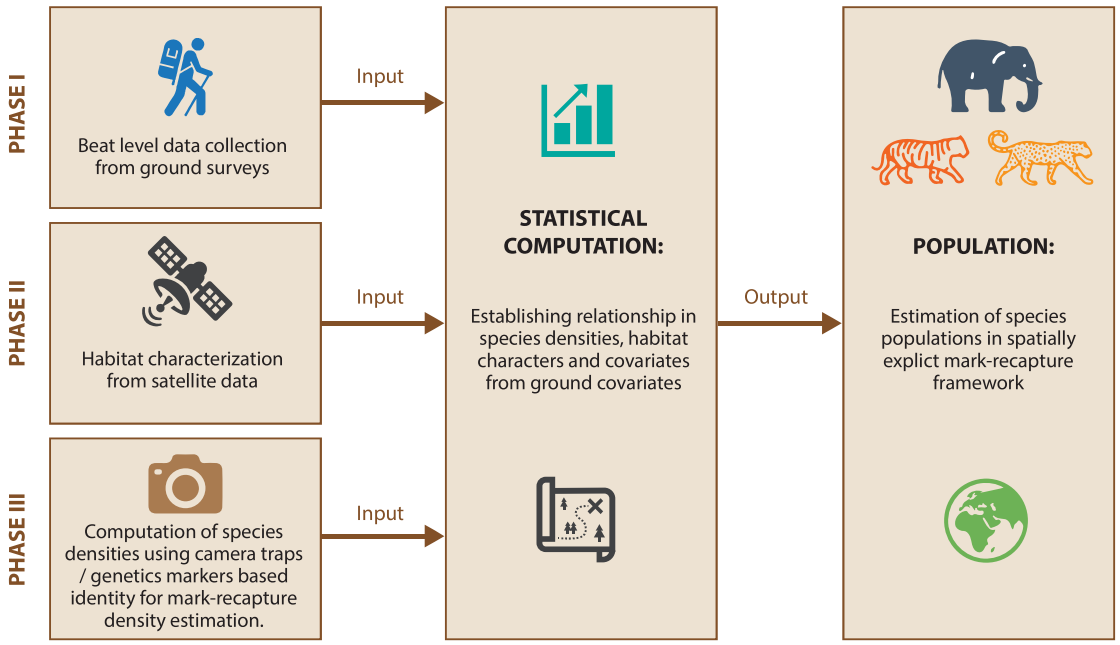
APPENDIX-I

# ALL INDIA ELEPHANT TIGER AND LEOPARD ESTIMATION



भारतीय वन्यजीव संस्थान
Wildlife Institute of India

# POPULATION ESTIMATION PROTOCOL




This procedure involves rigorous statistical analyses "of ground data on animal signs, human impacts, habitat attributes and absolute density; it is far more accurate than earlier methods. It is conducted in three phases and involves ground surveys, analyses of remotely sensed data and camera traps. Elephant populations using this method will be assessed for first time. The procedure is routinely used for estimating tiger and leopard populations in India.

# THE THREE PHASES OF SPECIES POPULATION ESTIMATION

**Phase I:**

Replicate ground surveys in a beat in an occupancy and spatially explicit polygon search design. Allows for computing detection corrected occupancy and population estimation from scat/dung DNA in a spatially explicit capture-mark-recapture (SECR) statistical framework. This data is digitally recorded using mobile phones on M-STrIPES application.

**Phase II:**

a) Remotely sensed human footprint indices,

b) Landscape characteristics, and

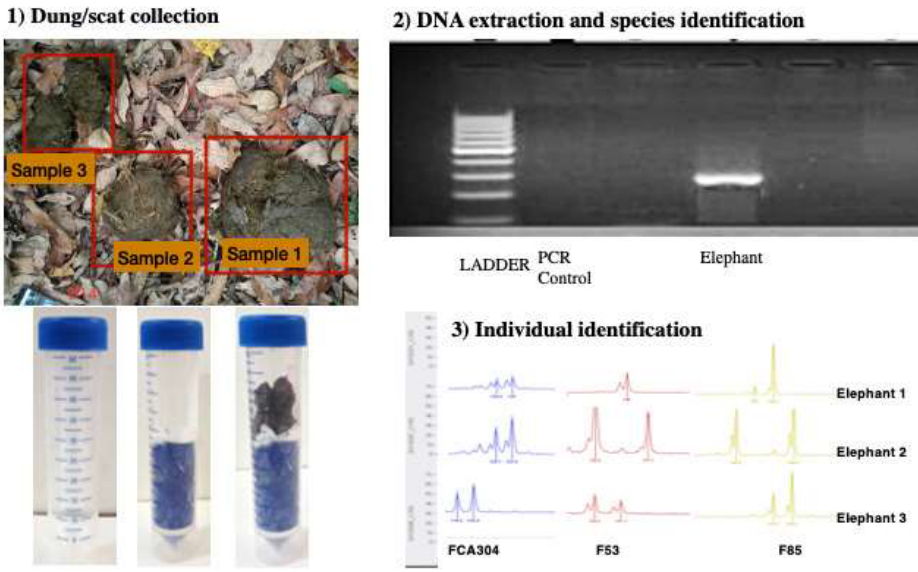
c) Habitat quality are processed for use as covariates in the SECR framework for population modelling and prediction by the Wildlife Institute of India.

*All data will be spatially explicit and digitally recorded on M-STrIPES application.*

**Phase III:**

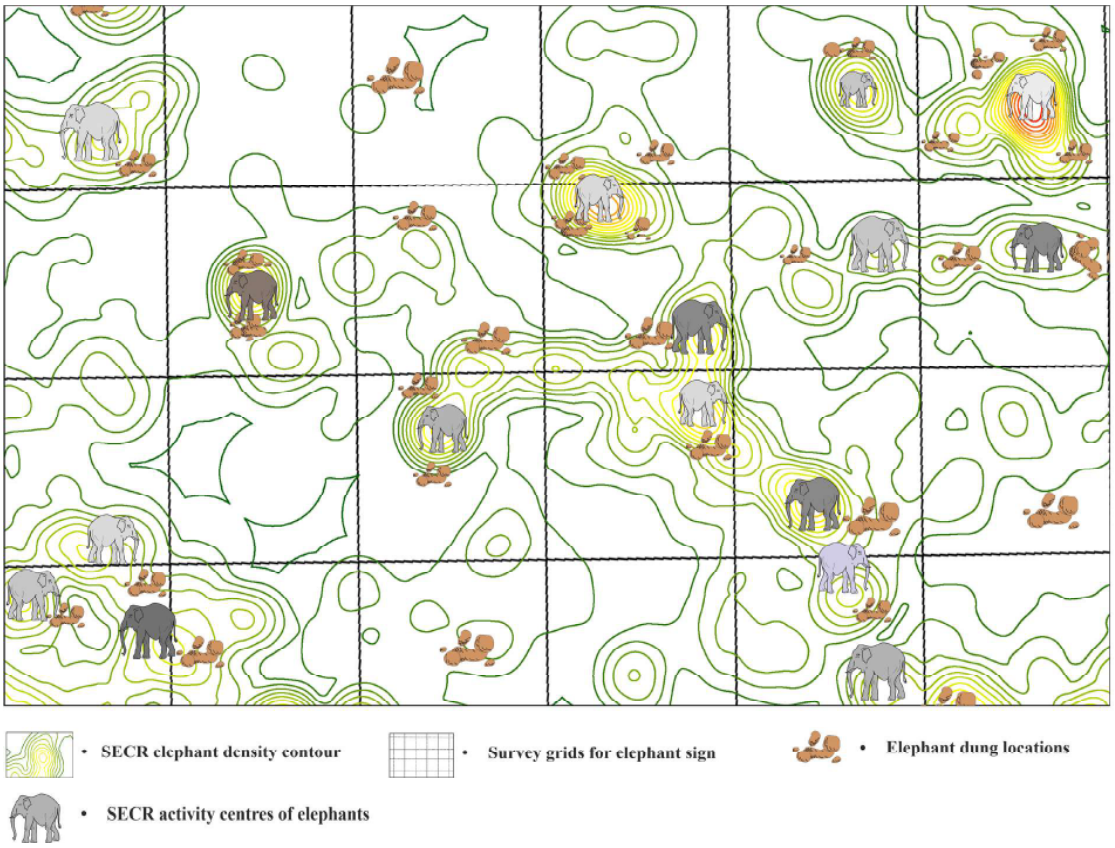
Sampling by forest department/WII/NGOs. Remote camera traps are deployed across wildlife habitats to record images of tigers, leopards and other wildlife. Individual elephants will be identified from their dung based DNA profile using a panel of microsatellite markers, Tigers and leopards are identified to individuals from their unique stripe and rosette patterns using a computer software Extract Compare.

Individual elephants will be identified using a panel of microsatellite markers from dung DNA.

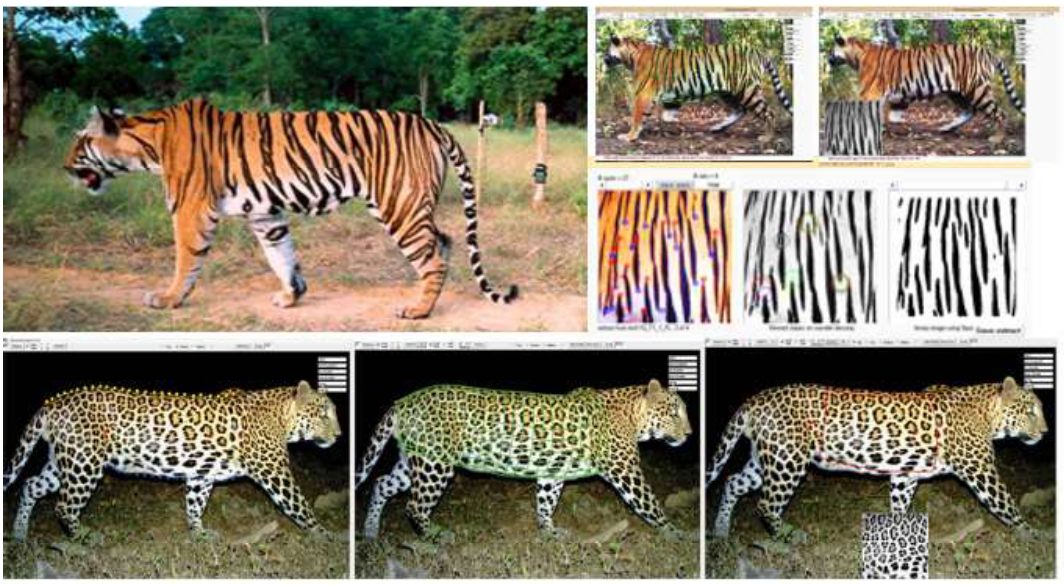



Based on genetic mark- recapture from dung samples elephant density will be estimated in SECR framework.

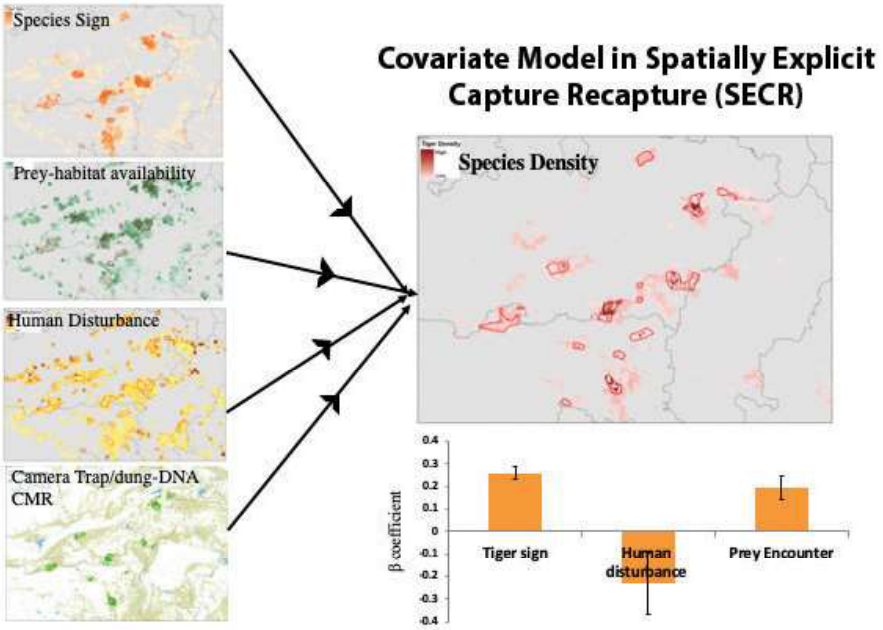
Spatially explicit density of elephants from sampled sites obtained by mark-recapture from Dung DNA.



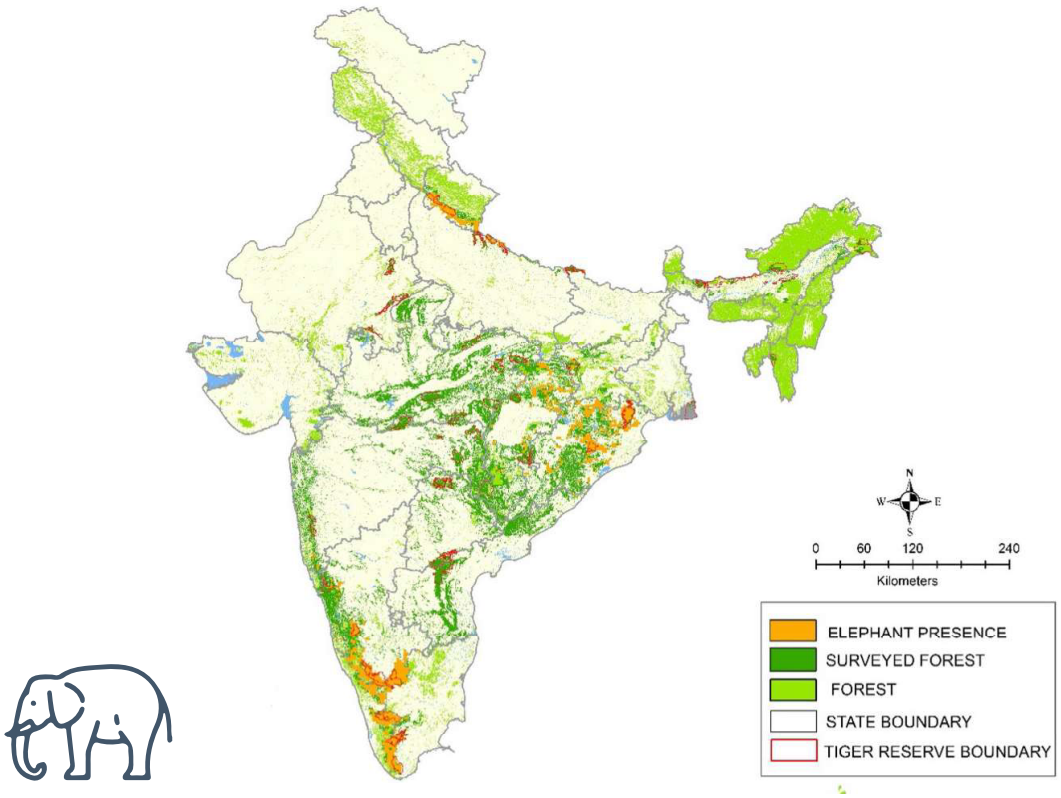

Individual tigers and leopards identified from camera trap images using software Extract-Compare



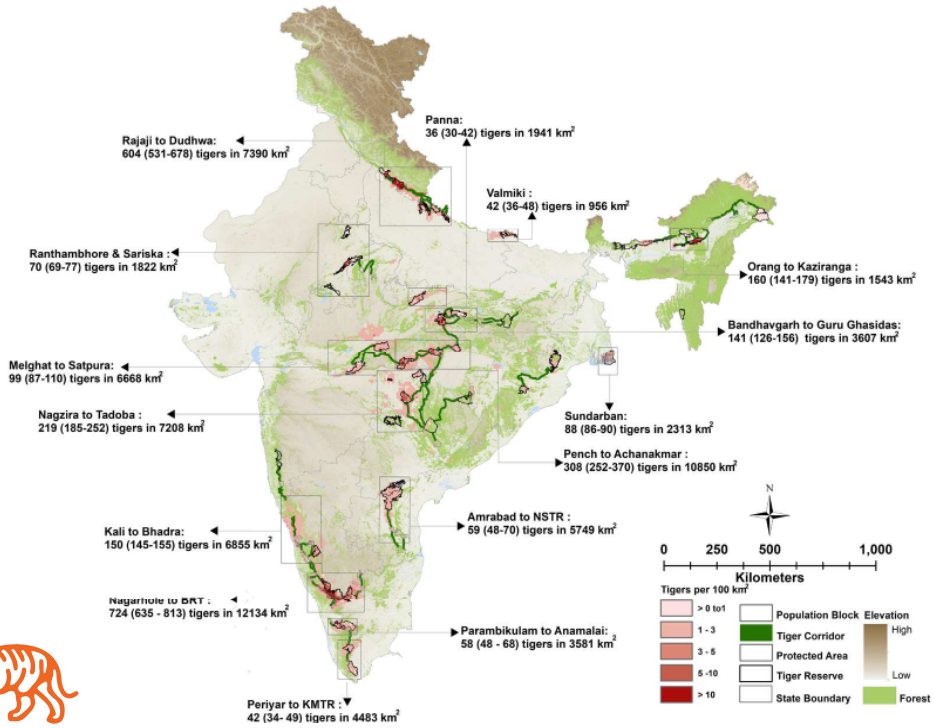
# POPULATION ESTIMATION



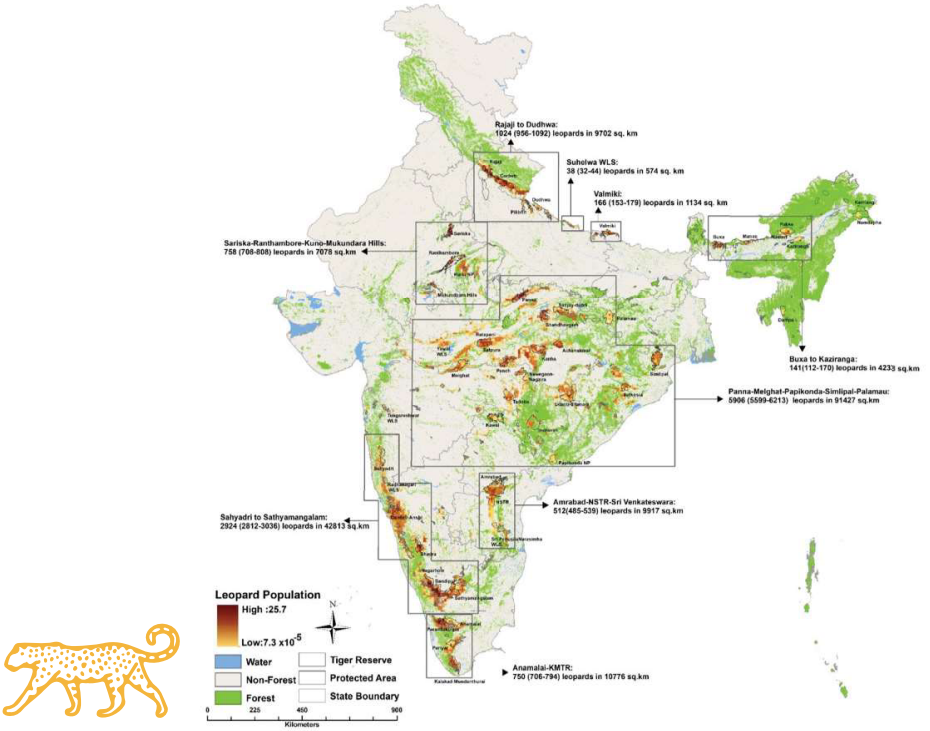

# ELEPHANT DISTRIBUTION IN 2018



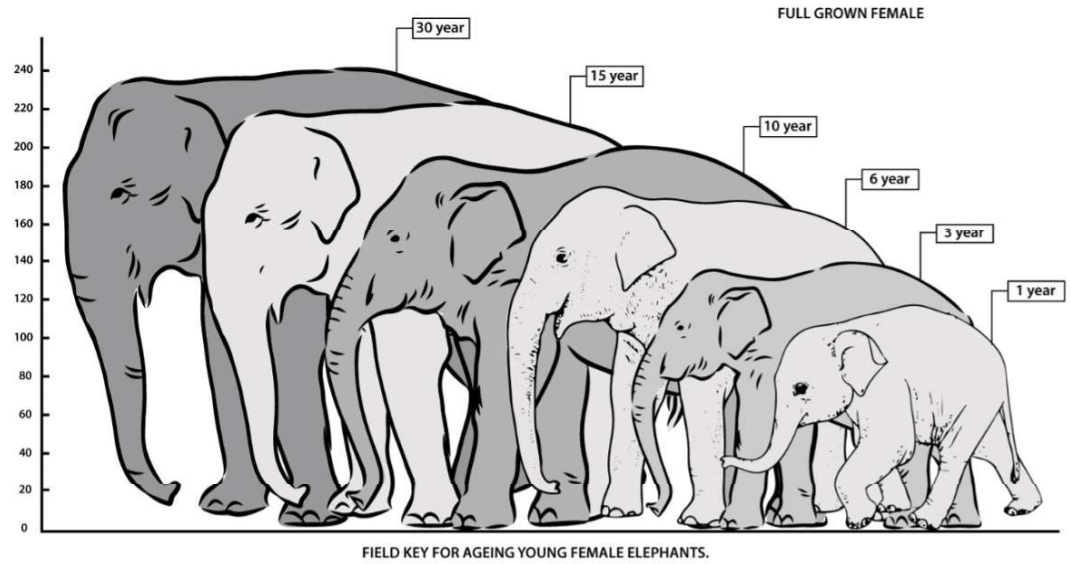
# TIGERS POPULATION IN 2018



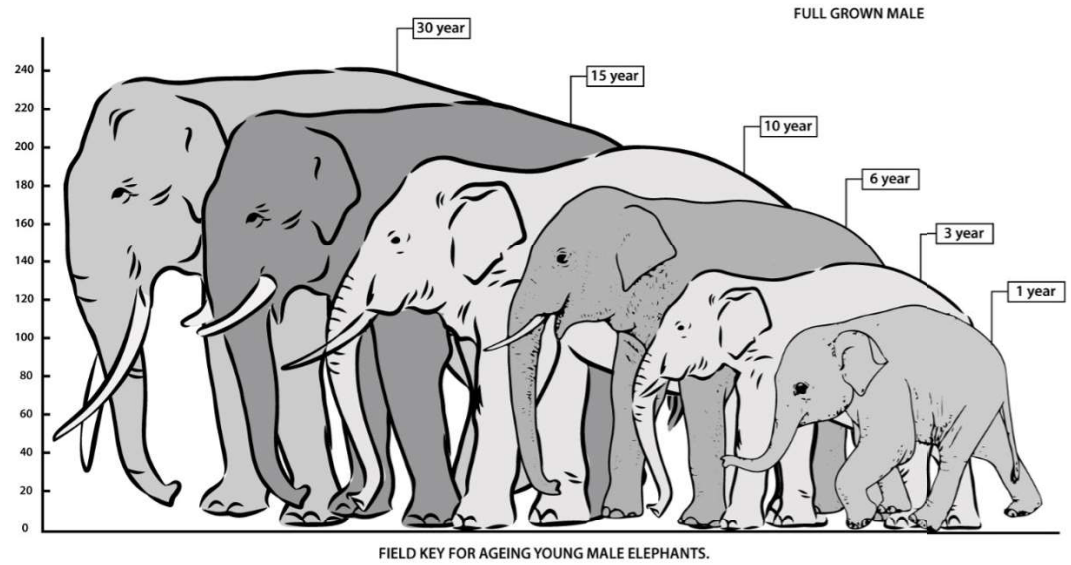

# LEOPARD POPULATION IN 2018



As part of Phase III, trained biologists and department personnel will sample elephant groups for demographic parameters and body condition. Elephants will be aged based on size, body characteristics like ears and tusks. Other demographic parameters like lactation, musth and gestation will be recorded. Animals will be scored for nutritional status based on body condition.




Female elephant aging (Adopted from Varma et al 2014)




Male elephant aging (Adopted from Varma et al 2014)

***The above standardized protocols when used to sample all potential habitat of elephants, tigers, and leopards across India will provide a scientific assessment of their status and population estimates required for policy formulation and conservation management.***

# ALL INDIA ELEPHANT, TIGER AND LEOPARD ESTIMATION

**FOR MORE INFORMATION, CONTACT:**


ADG & Member Secretary, National Tiger Conservation Authority,
Ministry of Environment and Forests, Government of India, New Delhi,

www.projecttiger.nic.in
Email: ms-ntca@nic.in

Inspector General Of Forests Project Elephant Division
Ministry of Environment and Forests, Government of India, New Delhi

Email: projectelephant.moef@gmail.com
Email: igpe-mef@gov.in

Nodal Officer, NTCA-WII Tiger cell
Wildlife Institute of India, Dehradun

Email: tigercell@wii.gov.in



**Photographs:** Sanjay Shukla, Shibu Nair, Y.V.Jhala

## Appendix 2: Standardising methods for abundance estimation of elephant using Genetic mark recapture methods

### Abundance estimation of Elephants:

The main aim of this exercise was to develop a correction factor for existing abundance estimation of elephants using DNA based mark-recapture. To achieve this objective, we aim to a) to establish a panel of microsatellite markers for identification of individual elephants, b) to cross validate DNA extracted from 'Dung' and 'Blood' samples in identification of individual elephants and c) test the population estimate using Genetic capture-mark-recapture (CMR) method in a known population and further d) estimate the abundance of elephants from select field sites of Karnataka. For the standardization of molecular markers, work was carried out in Dubare and Mattigodu semi captive elephant camps of Karnataka as the population size is known and error rates, if any, while using the genetic mark-recapture method can be quantified.

A total of 35 blood and dung samples have been collected from Dubbare, Mathigodu and Doddaharve camps were collected. For the isolation of DNA, several manual and kit-based protocols were tested. Finally, DNA was isolated using silica column-based kit method (Qiagen). A panel of Twenty-two already published microsatellite markers *viz.,* EMX-1, LA3, LA4, LA5, LA6, EMU01, EMU02, EMU03, EMU04, EMU06, EMU07, EMU08, EMU09, EMU10, EMU11, EMU12, EMU13, EMU14, EMU15, EMU17, EMU18 and EMU19 as reported by Eggert *et al*. (2000) and Kongrit *et al*. (2008) were initially tested to understand the success of individual identification. This panel has been narrowed down to ten loci (LA04, EMU13, EMU07, EMU08, EMU14, EMU18, EMU02, EMU01, EMU11, and EMU03) for individual identification from blood and dung samples, and we were able to assign the samples to different elephants.

Table 1 : Details of microsatellite marker panel for individual identification of Asian elephants.

Highlighted set of markers are been used for individual identification

| S.No. | Primer Name | Repeat Motif | Reference |
|---|---|---|---|
| 1 | EMX1 | di | Eggert *et al.*, 2000 |
| 2 | LA3 | di | Eggert *et al.*, 2000 |
| 3 | LA4 | di | Eggert *et al.*, 2000 |
| 4 | LA5 | di | Eggert *et al.*, 2000 |
| 5 | LA6 | di | Eggert *et al.*, 2000 |
| 6 | EMU01 | di | Kongrit *et al*., 2008 |
| 7 | EMU02 | di | Kongrit *et al*., 2008 |
| 8 | EMU03 | di | Kongrit *et al*., 2008 |
| 9 | EMU04 | di | Kongrit *et al*., 2008 |
| 10 | EMU06 | di | Kongrit *et al*., 2008 |
| 11 | EMU07 | di | Kongrit *et al*., 2008 |
| 12 | EMU08 | di | Kongrit *et al*., 2008 |
| 13 | EMU09 | di | Kongrit *et al*., 2008 |
| 14 | EMU10 | di | Kongrit *et al*., 2008 |
| 15 | EMU11 | di | Kongrit *et al*., 2008 |
| 16 | EMU12 | di | Kongrit *et al*., 2008 |
| 17 | EMU13 | di | Kongrit *et al*., 2008 |
| 18 | EMU14 | di | Kongrit *et al*., 2008 |
| 19 | EMU15 | di | Kongrit *et al*., 2008 |
| 20 | EMU17 | di | Kongrit *et al*., 2008 |
| 21 | EMU18 | di | Kongrit *et al*., 2008 |
| 22 | EMU19 | di | Kongrit *et al*., 2008 |

Dung samples for the blind test, to understand the efficacy of the standardized protocol are collected in Polygon search method (Efford, 2015), Nineteen line transects of approximately 2 km were walked within the 5 km radius of Mathigodu Elephant Camp a total of 138 dung samples were collected for CMR study. The transects were walked on a compass bearing counting all dung piles seen by measuring the distance from the survey line to the dung pile. The dung count-based survey was done from 21.06.2021 to 12.07.2021, to determine elephant dung-pile density (Buckland *et al*., 2001; Hedges and Lawson, 2006).

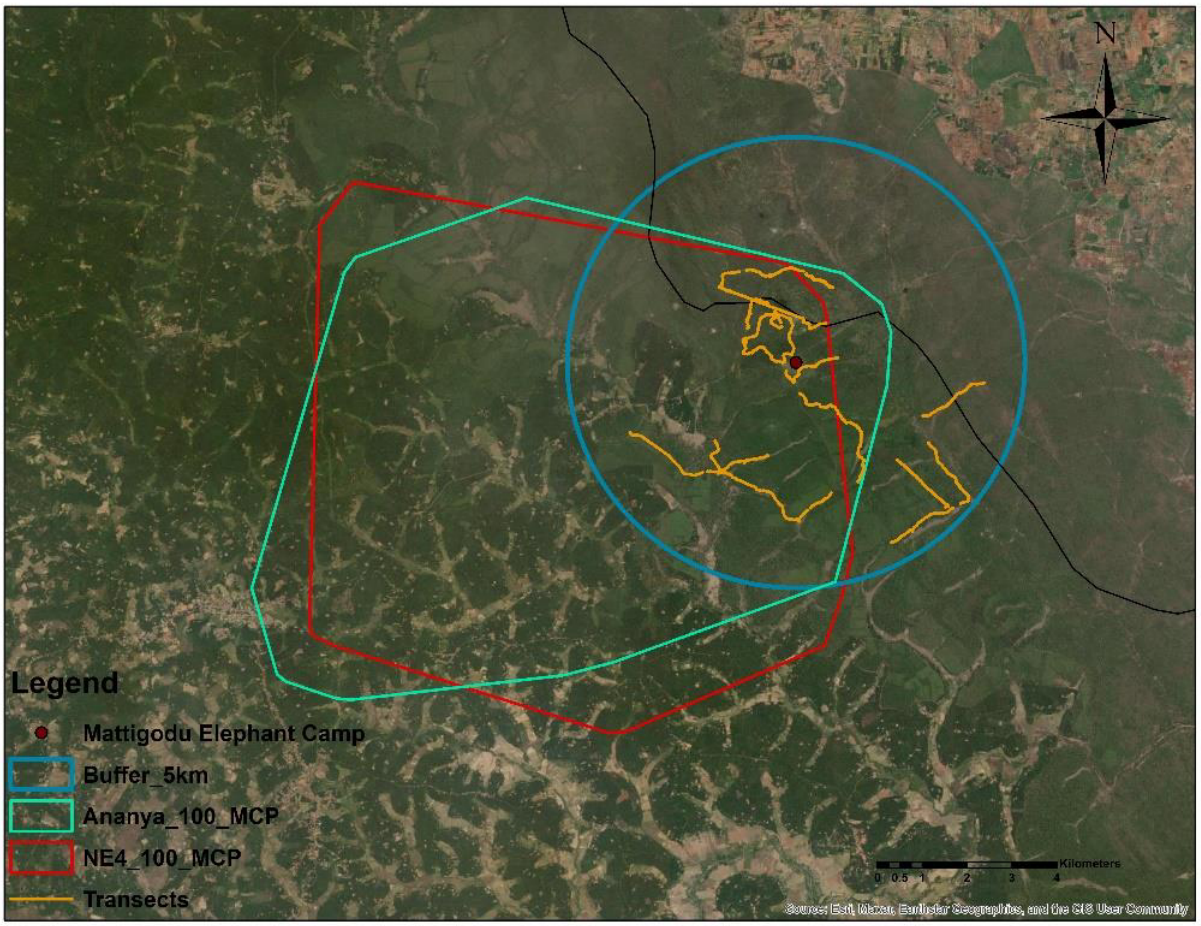



**Figure 1. Map showing Mathigodu camp, line transect, a buffer of 5km radius, home ranges of Ananya and NE4.**

**Result**

Genetic analysis

The PCR amplification of DNA isolated from blood sample and dung sample showed similar results. Which indicates that purity didn't interfere with amplification of DNA. All the ten microsatellite loci used for DNA isolated from the blood and dung were found to be polymorphic. The total combined Probability of identity across all the loci was found to be 4 x 10-8 and 1.5 x 10-6 for blood and dung samples respectively, indicating a very small probability of wrongly identifying two different animals as the same animals.

**Table 2.** Observed and expected heterozygosities, PIC, PID and F(Null) values of ten microsatellite loci for DNA isolated from blood

| Locus | Ho | He | PIC | PID | F(Null) |
|---|---|---|---|---|---|
| **LA04** | 0.676 | 0.673 | 0.589 | 0.188 | -0.014 |
| **EMU13** | 0.970 | 0.675 | 0.601 | 0.176 | -0.202 |
| **EMU07** | 0.765 | 0.650 | 0.593 | 0.176 | -0.106 |
| **EMU08** | 0.912 | 0.651 | 0.568 | 0.202 | -0.207 |
| **EMU14** | 0.588 | 0.596 | 0.550 | 0.208 | 0.012 |
| **EMU18** | 0.912 | 0.714 | 0.648 | 0.144 | -0.137 |
| **EMU02** | 0.706 | 0.641 | 0.559 | 0.208 | -0.083 |
| **EMU01** | 0.345 | 0.763 | 0.707 | 0.106 | 0.367 |
| **EMU11** | 0.559 | 0.532 | 0.475 | 0.276 | -0.053 |
| **EMU03** | 0.500 | 0.651 | 0.574 | 0.196 | 0.121 |
| **Mean±SE** | 0.693±0.06 | 0.654±0.019 | 0.586 ± 0.019 | - | - |
| | | | **Combined PID** | **$4x10^{-8}$** | |

Note: Ho= Observed Heterozygosity, He= Expected Heterozygosity, PIC= Polymorphic information Content, PID= Probability of identity and F(Null)= Frequency of null allele.

**Table 3.** Observed and expected heterozygosities, PIC, PID and F(Null) values of ten microsatellite loci for DNA isolated from Dung

| Locus | Ho | He | PIC | PID | F(Null) |
|---|---|---|---|---|---|
| **LA04** | 0.471 | 0.585 | 0.504 | 0.250 | 0.106 |
| **EMU13** | 0.600 | 0.571 | 0.495 | 0.258 | -0.070 |
| **EMU07** | 0.600 | 0.701 | 0.631 | 0.152 | 0.064 |
| **EMU08** | 0.935 | 0.588 | 0.489 | 0.267 | -0.258 |
| **EMU14** | 0.929 | 0.638 | 0.550 | 0.216 | -0.216 |
| **EMU18** | 0.853 | 0.627 | 0.546 | 0.218 | -0.184 |
| **EMU02** | 0.643 | 0.527 | 0.416 | 0.334 | -0.116 |
| **EMU01** | 0.227 | 0.449 | 0.405 | 0.349 | 0.326 |
| **EMU11** | 0.600 | 0.458 | 0.384 | 0.369 | -0.166 |
| **EMU03** | 0.389 | 0.579 | 0.473 | 0.281 | 0.199 |
| **Mean±SE** | 0.624±0.073 | 0.572±0.024 | 0.489±0.023 | - | - |
| | | **Combined PID** | | **$1.5x10^{-6}$** | |

Note: Ho= Observed Heterozygosity, He= Expected Heterozygosity, PIC= Polymorphic information Content, PID= Probability of identity and F(Null)= Frequency of null allele.

SECR analysis

Out of 138 dung samples collected for density estimation by the genetic-CMR framework only 115 samples that could be genotyped successfully corresponded to 21 unique individuals with a detection probability of 3 to 4 dung samples/ km. Using the SECR analysis we obtained the density estimate of 13.64 ± 3.68 elephants per 100 Sq. km. with Upper Confidence Limit (UCL) and Lower Confidence Limit (LCL) of 22.7, and 8.2, respectively. The detection probability at the home range centre was lambda = 0.48 ± 0.10 and the scale parameter was sigma= 21.00 ± 2.77. As the total area accounted for the elephants to estimate the abundance is 165.63 km. The abundance is calculated from density per sq. km obtained from SECR. (Density x Area) which gives us results of 23 animals [LCL-13, UCL-38]. So, the known population is 34 elephants which lies within our confidence limit of 13 to 38 elephants as calculated from the SECR density estimates.

We applied several models to deduce the line transect based density of dung piles and the best fit model with the lowest AICc value was the Half normal Cosine model by making necessary cut-points of the interval to fix the curve and after truncation to make the model the best fit. The elephant dung density was found to be 7264.021 [ LCL- 4710.42, UCL- 11201.98] with an AICc value of 383.12 with group size (DS) of 4045.7 [ 2643.9, 6190.7], giving an effective strip width of 0.683 meters, and p (detection probability) of 0.341. The percentage of CV (Coefficient of Variation) was reported to be 21.2%. The elephant density can be calculated by (Dung density* Decay Rate)/ Defecation Rate. The decay rate and defecation rate were taken from the published literature to estimate elephant density. The Elephant density was calculated as 4.31/km2, where the decay rate was taken to be 0.0097 and the defaecation rate as 16.33 (Watve 1992; Varman et. al. 1995).

**Discussion**

As line transect based dung counts and fecal CMR is one of the recommended methods to assess elephant population size, there have been very few studies comparing CMR surveys with other methods. We evaluated both the methods in the given area to assess the accuracy of our population estimates, since the actual size of the surveyed population is known (approximately 34 elephants). The elephant density obtained from Line transect based dung survey is 4.31 per sq. km. which gives us an abundance of approximately 700 elephants in the given area whereas SECR estimates were 13-38, so there is an overestimation of the numbers as every dung pile from the initial point of the line when the dung piles are detected were

recorded irrespective of their freshness and it is difficult to identify if the dung piles recorded are of the same elephant or different individual. After all, the Line transect-based density estimation assumes that objects on the line are detected with certainty (Owusu, 2019). Therefore, it can be stated that fecal based CMR method is a more robust method than the Line transect-based dung estimation as the latter integrates estimates of the decay rate, defaecation rates, and detection rates, which are highly variable (Hedges, 2012; Kuehl *et al*., 2007; Plumptre, 2000). It is clear that there is growing demand for fecal DNA-based CMR studies which requires appropriate study design, adequate sample collection, genetic and statistical analysis. Our study shows that DNA-based CMR method is likely to become the method of interest for wildlife researchers and managers. The advancement can also help biologist to assess not only elephant but also assess population sex structure, fecundity, genetic diversity, gene flow, and other parameters without any intervention (Hedges et. al, 2013). Hence, advance methodologies are likely to contribute significantly to the management and conservation of elephants and other species.

**References**

EGGERT, L. S., RAMAKRISHNAN, U., MUNDY, N. I. and WOODRUFF, D. S., 2000. Polymorphic microsatellite DNA markers in the African elephant (*Loxodonta africana*) and their use in the Asian elephant (*Elephas maximus*). *Mole. Eco.*, **9**(12): 2223-2225.

KONGRIT, C., SIRIPUNKAW, C., BROCKELMAN, W. Y., AKKARAPATUMWONG, V., WRIGHT, T. F. and EGGERT, L. S., 2008. Isolation and characterization of dinucleotide microsatellite loci in the Asian elephant (*Elephas maximus*). *Mole. Eco. Reso.*, **8**(1): 175-177.

EFFORD, M., 2015. secr 2.9-spatially explicit capture–recapture in R.

BUCKLAND S. T., ANDERSON D.R., BURNHAM K.P., LAAKE J.L., BORCHERS D.L. and THOMAS L. 2001. *Introduction to distance sampling: estimating abundance of biological populations.* Oxford University Press, Oxford

HEDGES, S. and LAWSON, D., 2006. Dung survey standards for the MIKE programme. CITES MIKE Programme, Nairobi, Kenya.

WATVE, M. (1992). *Ecology of host-parasite interactions in a wild mammalian host community in Mudumalai, southern India*. Phd thesis, indian institute of science, bangalore, India.

VARMAN, K. S. and SUKUMAR, R. (1995). The line transect method for estimating densities of large mammals in a tropical deciduous forest: An evaluation of models and field experiments. *Journal of Biosciences*, *20*(2), 273-287.Wilson,

HEDGES, S. (2012). Monitoring elephant populations and assessing threats.

KUEHL, H. S., TODD, A., BOESCH, C. and WALSH, P. D. (2007). Manipulating decay time for efficient large-mammal density estimation: gorillas and dung height. *Ecological Applications*, *17*(8), 2403-2414.

PLUMPTRE, A. J. (2000). Monitoring mammal populations with line transect techniques in African forests. *Journal of Applied Ecology*, *37*(2), 356-368.

HEDGES, S., JOHNSON, A., AHLERING, M., TYSON, M. and EGGERT, L. S., 2013. Accuracy, precision, and cost-effectiveness of conventional dung density and fecal DNA based survey methods to estimate Asian elephant (*Elephas maximus*) population size and structure. Biological Conservation. 159: 101-108.

# APPENDIX-3

| SI NO. | LANDSCAPE | STATE | TIGER RESERVE | Number of samples | REMARKS |
|---|---|---|---|---|---|
| 1 | WESTERN GHATS | KARNATAKA | BANDIPUR TIGER RESERVE | 141 | Dung not collected during sign survey |
| | | | BANNERGHATTA | 4 | Sample size(<) |
| | | | BHADRA TIGER RESERVE | 74 | Sample size(<) |
| | | | BILIGIRI RANGANATITTU TIGER RESERVE | 98 | Dung not collected during sign survey |
| | | | KARNATAKA TIGER RESERVE | 228 | Dung not collected during sign survey |
| | | | NAGARAHOLE TIGER RESERVE | 121 | Dung not collected during sign survey |
| | | KERALA | SILENT VALLEY | 12 | No sign survey |
| | | | PARAMBIKULAM TIGER RESERVE | 19 | Dung not collected during sign survey |
| | | TAMILNADU | ANAMALAI TIGER RESERVE | 111 | |
| | | | SRIVILLIPUTHUR MEGAMALAI TIGER RESERVE | 64 | Dung not collected during sign survey |
| | | | SATYAMANGALAM TIGER RESERVE | 30 | Dung not collected during sign survey |
| | | | KALAKKAD MUNDANDURAI TIGER RESERVE | 5 | Dung not collected during sign survey |
| 2 | CENTRAL INDIA AND EASTERN GHATS | JHARKHAND | PALAMAU TIGER RESERVE | 15 | Sample size(<) |
| | | MADHYA PRADESH | KANHA TIGER RESERVE | 8 | Sample size(<) |
| | | | SANJAY DUBRI TIGER RESERVE | 7 | Sample size(<) |
| | | CHATTISGARH | ACHANAKMAR | 4 | Sample size(<) |
| | | | BANWAPARA | 23 | Sample size(<) |
| | | | UDANTI SITANADI TIGER RESERVE | 6 | Sample size(<) |
| | | ODISHA | DHENKANAL_ODISHA | 16 | Dung not collected during sign survey |
| | | | SIMILIPAL TIGER RESERVE_ODISHA | 140 | Dung not collected during sign survey |

| Sl NO. | LANDSCAPE | STATE | TIGER RESERVE | Number of samples | REMARKS |
|---|---|---|---|---|---|
| 3 | Terai Arc Landscape | Uttar Pradesh | Dudhwa Tiger Reserve | 32 | Sample size(<) |
| | | Uttarakhand | Rajaji Tiger Reserve | **167** | Sample size(<) |
| | | | Corbet Tiger Reserve | **335** | |
| 4 | NORTH EAST INDIA | WEST BENGAL | BAIKUNTHAPUR FOREST DIVISION | **27** | Sample size(<) |
| | | | BUXA TIGER RESERVE | **90** | |
| | | | GARUMARA NATIONAL PARK | **14** | Sample size(<) |
| | | | JHARGRAM DIVISION | **179** | |
| | | | KALIMPONG FOREST DIVISION | **25** | Sample size(<) |
| | | | MAHANANDA WILDLIFE SANCTUARY | **23** | Sample size(<) |
| | | ASSAM | KAZIRANGA NATIONAL PARK | **22** | **Dung not collected during sign survey** |
| | | | NAMERI TIGER RESERVE | **28** | **Dung not collected during sign survey** |
| | | | ORANG TIGER RESERVE | **23** | Sample size(<) |
| | | | RUKMINIGAON | **16** | Sample size(<) |
| | | MIZORAM | DAMPA | 2 | Sample size(<) |
| | | NAGALAND | INTANKI NATIONAL PARK | **220** | **Samples cannot be processed for DNA extraction** |
| | | ARUNACHAL PRADESH | PAKKE TIGER RESERVE | **225** | Degraded samples |