Elephant on the Zebra Crossing

Predicting human-elephant conflict to inform urban development in and around Bengaluru city

Final Report to the Bengaluru Sustainability Forum

by

Foundation for Ecological Research, Advocacy and Learning (FERAL) and

Frontier Elephant Programme (FEP)

Anisha Jayadevan, Rajat Nayak, Nishant Srinivasaiah and Srinivas Vaidyanathan

March 2023

Acknowledgements

We would like to express our sincere gratitude to the Bengaluru Sustainability Forum for their generous financial support in the Elephant on the Zebra Crossing Project. This project would not have been possible without their valuable contribution. We would like to extend a special thank you to Dr. Uma Ramakrishnan for her constant encouragement and advice and to Dr. Lena Robra and Dr. Manasi Pingle for their patience and cooperation that has helped us complete the project through a pandemic and multiple iterations of the movement models. The Bengaluru Sustainability Forum's support has enabled us to carry out extensive research and generate data that could help implement innovative land-use plans in the elephant habitats in the future. Through our project, we aimed to ensure the protection of elephants that cross highways in search of food and water and that have come to live in and around high human-density areas.

The financial support from the Bengaluru Sustainability Forum and WIPRO Foundation has not only helped us achieve our goals, but it has also given us the necessary resources to bring together a team of dedicated individuals who have worked tirelessly to make this project a reality. Once again, we would like to express my heartfelt gratitude to the Bengaluru Sustainability Forum for their unwavering support and belief in our project. We look forward to continuing our partnership with the Forum and creating a sustainable future for our community.

We would like to extend our sincere appreciation to all the team members at FERAL and FEP for their invaluable support in the Elephant on the Zebra Crossing Project. FERAL's expertise and guidance have been instrumental in shaping the project's research methodology, data analysis, and overall academic rigor. Their input has helped us produce a comprehensive report that sheds light on the challenges faced by elephants in human-use landscapes. FERAL's commitment to wildlife conservation and sustainable development has inspired us to continue our efforts towards creating a safer environment for both humans and animals.

We would like to express our deep appreciation to the Forest Department of Karnataka and Tamil Nadu for their unwavering support in the Elephant on the Zebra Crossing Project. Their logistical assistance and timely permissions have been crucial in conducting the project's fieldwork and research. The Forest Department's commitment to preserving wildlife habitats and ensuring the safety of both elephants and humans has been inspiring. We are grateful for their continued partnership and look forward to collaborating with them in future projects.

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INTRODUCTION

Asian elephants are one of the largest and most iconic land mammals in the world. They are known for their impressive size, intelligence, and social behavior. These gentle giants play a crucial role in maintaining the balance of ecosystems by shaping the landscape, dispersing seeds, and promoting the growth of vegetation. However, as human populations grow, and landscapes are increasingly dominated by human activities, elephants' survival has come under threat.

Human-dominated landscapes, such as agricultural areas, plantations, and urban centers, pose significant challenges to the survival of elephants. These landscapes provide limited access to resources such as food, water, and shelter, and often lead to elephants coming into conflict with people. Human-elephant conflict has become a significant conservation challenge worldwide, and the situation is particularly acute in Asia, where human populations are high, and landscapes are heavily modified.

In South and Southeast Asia, the Asian elephant is found in a range of landscapes, from dense tropical forests to agricultural lands and even urban areas. In India, for example, elephants live in a range of habitats, from protected forests to agricultural landscapes and even cities. These elephants have adapted to living in human-dominated landscapes, and their behavior has changed as a result.

One of the most significant challenges facing Asian elephants in human-dominated landscapes is habitat loss and fragmentation. Human activities such as agriculture and urbanization have led to the modification of elephant habitats, leaving the animals with less access to resources such as food and water. As a result, elephants are at times forced to travel long distances in search of resources, which increases the likelihood of encounters with humans.

In addition to habitat loss, human activities have also led to changes in elephant behavior. Elephants in human-dominated landscapes are more likely to be active during the night, when they are less likely to encounter people. Furthermore, male elephants are more likely to band together in all-male groups to survive a high-risk production landscape. These changes in behavior are thought to be an adaptation to living in landscapes dominated by humans.

However, in many cases, these adaptations are not enough to prevent conflict. As human populations continue to grow, the demand for resources increases, leading to more encounters between elephants and people. These encounters can lead to significant economic losses for local communities, as elephants often feed on crops, destroy property, and even harm or kill people.

To address these challenges, several initiatives have been taken to reduce human-elephant conflict in human-dominated landscapes. One approach is to create a network of Protected Areas and wildlife corridors that allow elephants to move between different areas without coming into contact with people. These corridors provide the animals with access to resources and reduce their need to venture into areas occupied by people. In some cases, however, given the shape of the corridors, elephants have started suing these as refuge sites to feed from the crops grown in the surroundings. Similarly, the creation of elephant-friendly landscapes, such as the planting of elephant-resistant crops, can reduce the likelihood of conflict.

Other initiatives include the use of electric fences, loudspeakers, and firecrackers to deter elephants from entering human settlements only to a certain extent. Education and awareness programs have also been developed to help local communities understand elephant behavior and the importance of coexistence. In some cases, compensation schemes have been put in place to provide financial assistance to farmers who have suffered crop damage from elephants.

Despite these efforts, human-elephant conflict remains a significant conservation challenge in human-dominated landscapes. The success of conservation efforts depends on a range of factors, including political will, community involvement, and the scope to access resources.

On 4th January 2019, at around 0700 h, a group of four male elephants walked onto to the traffic laden Nandi Infrastructure Corridor Enterprises (NICE) ring road, a six lane expressway originally intended to connect the city of Bengaluru with Mysuru in the southern India state of Karnataka (*https://www.deccanherald.com/city/tuskers-crossing-nice-road-711470.html*), risking not only their own lives but also that of the numerous unsuspecting commuters. A number of pet theories, from ageold migratory routes being destroyed due to human activities to how humans are encroaching upon elephant inhabited forests thereby displacing elephants, started doing rounds. An understanding, however, of the actual set of events surrounding elephant sociality and larger landscape-level changes that may have resulted in, as drastic a measure by elephants, as coming onto the NICE road was lacking.

We have identified about 400 elephants individually (through direct observations) and track their movements regularly through direct observations and by using camera traps, which use the forested and the human dominated landscape close to the city of Bangalore in southern India. Of these, about 50 to 60 male elephants living close to human habitations interact with people, their crops and the infrastructure almost on a daily basis. Few of the individuals also make the long and arduous journey from Bannerghatta National Park towards the agricultural regions of Ramanagara and Tumakuru districts by crossing Bengaluru-Kanakapura, Bengaluru-Mysuru, Bengaluru-Mangaluru and Bengaluru-Shivamogga highways and railroads.

Data on elephant homerange, seasonality in movement, crops damaged, levels of human and livestock activity, conflict mitigation measures used, changes in landuse overtime and the demography of elephants using this landscape has been collected diligently over the last 10 years through primary and secondary sources. We would like to utilize this already available information to now assess the proximate factors, which influence decision-making in elephants and build predictive models of human-elephant conflict, which include future urbanization, in the peri-urban and urban areas of Bengaluru city to inform future developmental activities.

This project was aimed to highlight the potential impacts of land use change on the elephant, an icon of conservation efforts. We focus on human-elephant conflict in and around urban habitats, and provide guidelines for agriculture and infrastructure development and town planning in regions that are close to elephant habitats. Through this document, we also hope to make policy-makers more receptive towards the elephant use of this already fragile forest habitat of southern India.

The following are the **objectives** of the project:

1. To assess environmental and biological factors influencing the current foraging and ranging decisions by elephants in the peri-urban areas of Bengaluru city.
2. To assess current trends in elephant distribution and human-elephant conflict in the districts of Bengaluru, Ramanagara, Tumakuru and Krishnagiri and to identify human-elephant conflict hotspots.
3. To develop predictive models of human-elephant conflict, given future trends in landuse change in Bengaluru city, including Tumakuru, Ramanagara and Kanakapura towns based on the Master Plan 2031 of Government of Karnataka and the identification of Hosur as a special investment region by the Government of Tamilnadu.
4. To generate guidelines that can act as a policy document to help urban development in regions co-habited by elephants.

METHODS

Objective 1: To assess environmental and biological factors influencing the current foraging and ranging decisions by elephants in the peri-urban areas of Bengaluru city.

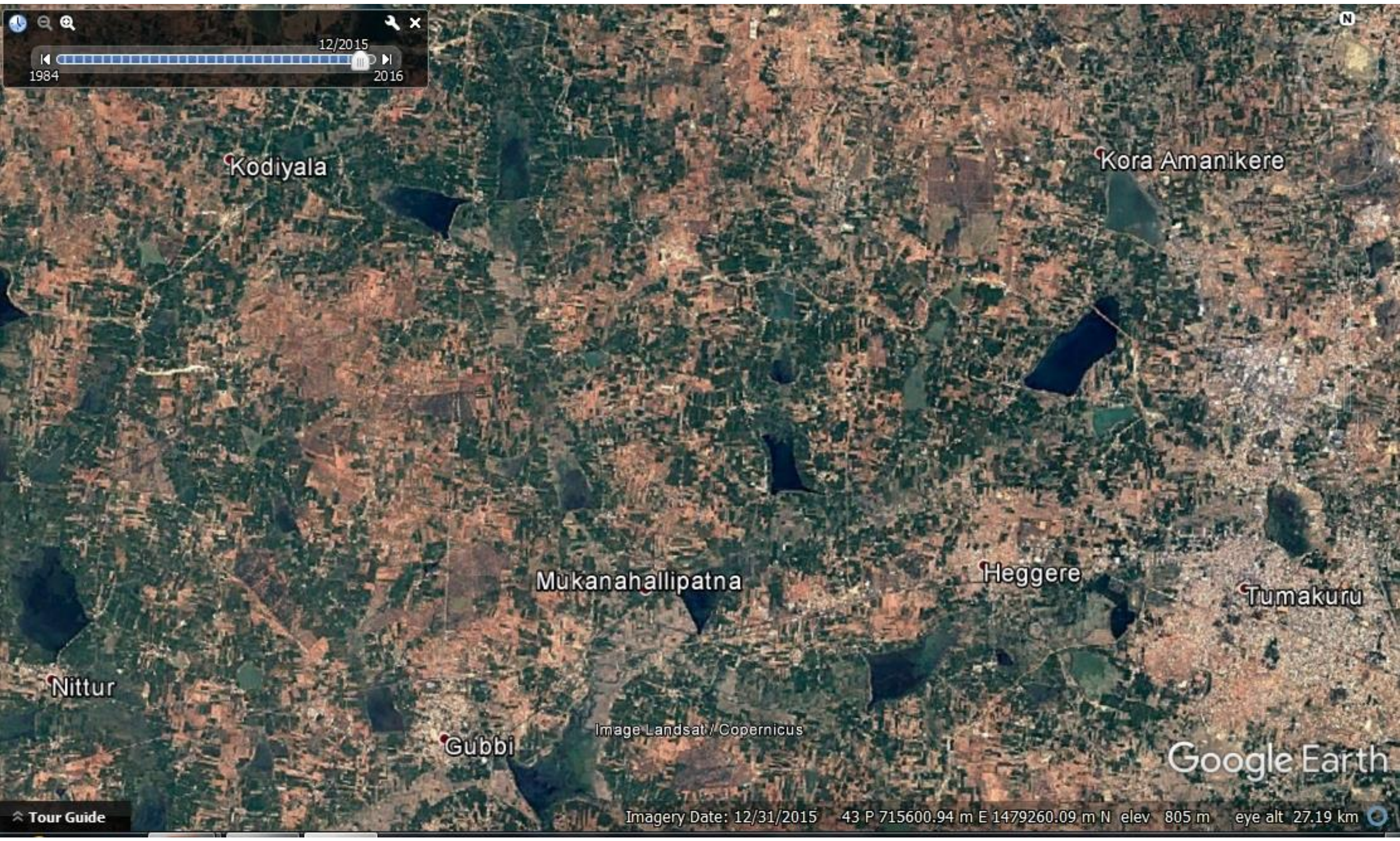
The following geospatial datasets will be used to identify the key environmental, biological and anthropogenic drivers of elephant-use of human-dominated landscape:

- Landuse types obtained from the National Remote Sensing Agency of the Government of India
- Human and livestock densities obtained from census data of Government of India
- Threats due to linear intrusions such as railroads and highways
- Age and sex classification of elephants through direct observations and photographic data
- Physiology and body condition of elephants assessed through direct observations and photographic data

We used data collected since 2009, on nearly 200 elephants ranging close to Bengaluru Urban and Rural districts. We analysed contiguity in the study area for 7 different land-use and land-cover (LULC) categories: built-up, agriculture, plantations, forest, scrubland, barren areas and waterbodies. We then associated individual elephant locations in the study area with the corresponding contiguity values. Using recursive partitioning classification trees, we used this combined data of elephant locations and contiguity, to assess environmental and biological factors influencing foraging and ranging patterns of Asian elephants, especially males, in peri-urban areas of Bengaluru.

To examine the influence of biological and environmental factors on decision-making by male elephants to associate in particular social group types, we constructed recursive partitioning classification trees in R, version 3.4.0 (Hothorn et al. 2006; Srinivasaiah et al. 2012). The ten input variables included two biological parameters, Maturity and Musth, and eight environmental parameters, namely Deciduous Forest, Degraded Forest, Wasteland, Crop, Plantation, Waterbody, Human Use Index (HUI) and Contiguity Index (CONTIG). The response variables measured were Group Size, Social Group Type, and Body Condition. Two of the landuse types, Built-Up Area and Current Fallow, were not used in the final analysis, as they did not offer any resource to the study elephants. We assessed the statistical significance of the differences in the propensity of occurrence of male Asian elephants in the three social group types, referred to above, as a response to varying levels of the above biological and environmental parameters using multiplicity-adjusted Monte-Carlo simulated (n=9999) p-values. The G-test of independence was used to assess differences in the occurrence of different classes of males in the population, the demographic composition of associations and also as a post-hoc procedure to test for the statistical significance of the recursive partitioning classification trees obtained above (McDonald 2014).

These baseline values were used as parameters in an agent-based model to simulate elephant movement in current and future land-use scenarios (Objectives 2 and 3). We extracted baseline values of 50 individuals of two different age classes rangning mostly in the human-use areas close to Bangalore city, representing the typical structure of the male elephant population in this region. We then finalized the LULC and infrastructure layers that will be used in the model.



Objective 2: To assess current trends in elephant distribution and human-elephant conflict in the districts of Bengaluru, Ramanagara, Tumakuru and Krishnagiri and to identify human-elephant conflict hotspots.

By assessing the information on elephant occurrence in this vast human-dominated landscape obtained through camera trapping in the human-use area, we aimed to understand the spatio-temporal distribution of elephants in the region but outside the forested habitats.

The current movement of elephants in the landscape was modeled under two different scenarios:
1) Elephants starting from a Protected Forest Area (PA) without any barrier to their movement, with partial barriers to their movement and with a completely barricaded boundary that does not allow for their movement outside the PA
2) Elephants starting from outside Protected Forest Areas (PA) without any barrier to their movement, with partial barriers to their movement and with a completely barricaded boundary that does not allow for their movement into the PA.

Generating Elephant Movement Models

We developed an individual-based model to simulate individual elephant movement using NetLogo 6.0.3 (Wilensky, 1999). The purpose of the model is to understand the movement patterns of individual elephants in response to land-use land-cover (LULC), infrastructure and conflict-management interventions such as linear barriers. In each of the scenarios mentioned under objectives b and c, the model captures potential movement of individual elephants, given their existing movement patterns in response to land-use land-cover.

We used nine LULC classes (built-up area, agriculture, plantation, forest, scrubland, littoral, grassland, barren and water body), four infrastructure layers (canals, mines, railways and roads) which are known to affect elephant movement due to barrier effects, edge effects, or by causing mortality (Laurance et al., 2009).

We downloaded a land-use land-cover layer for 2017-18 from the National Remote Sensing Agency of the Government of India (http://bhuvan3.nrsc.gov.in/cgi- 103 bin/LULC250K.exe), at a resolution of 55m. To incorporate a perception of contiguity of land-use classes, we calculated the Contiguity Index (CONTIG) in Fragstats (McGarigal, Cushman & Ene, 2012) in a 3 x 3 km moving window. Contiguity values vary from 0 to 1; values of 0 correspond to areas with no contiguity of the land-use class, while values of 1 correspond to areas with high contiguity of the land-use class, within a 3 x 3 km moving window.

For the rules of the movement model, we used 21 male elephants (6 socially and sexually mature individuals and 7) obtained through direct observations and camera trapping in the study landscape for a period of five years between 2013 to 2017. The median (min - max) number of observations per individual is 99 (60 - 1086). For each of the elephant locations, we extracted the corresponding contiguity index for each land-use class using Quantum Geographical Information System (QGIS; QGIS 3.10.1 Development Team).

To understand the likelihood of different individuals occurring in different land-use classes, we used location and landscape contiguity data in a classification and regression tree (CART) for each individual, using the 'partykit' package (Hothorn & Zeileis, 2015; Hothorn, Hornik & Zeileis, 2006) in RStudio (RStudio Team, 2020). We derived the probabilities of individuals choosing different land-use classes depending on landscape contiguity values, from the results generated by CART (Fig 1). Since roads were also classified as built-up area and we did not have sufficient data on road crossing in the study area, we did not use the CART-generated probability of occurring in builtup area. Instead, we applied separate probabilities of crossing roads (Supplementary Table), and used a probability of zero for all other built-up area.

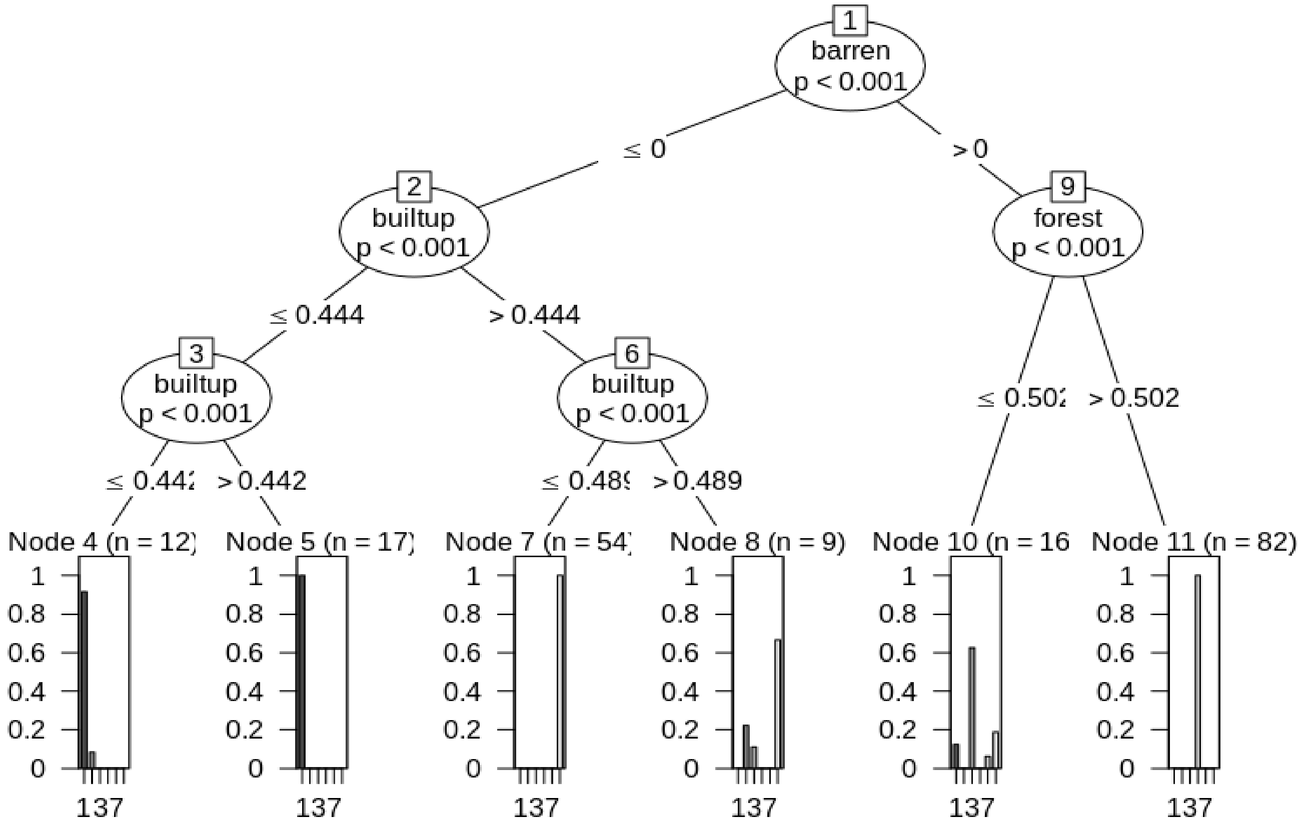


Figure 1: Classification and regression tree indicating probabilities of individual BB1 in different land-use classes.

Elephant movement in human-dominated areas differs between the night and day. Elephants take refuge in forests or waterbodies and generally move less during the day when human activity tends to be high (Gaynor et al 2018b). During the night, when human activity reduces, elephants are known to move long distances in high-risk crop fields and plantations. To capture this difference in movement, we ran another CART using a larger dataset of 53 male elephants, belonging to three different all-male groups, studied during the same period between 2013 to 2017 (total number of observations$_{day}$ = 2188; total number of observations$_{day}$ = 1769). This yielded probabilties of elephants occuring in different land-use classes during the day and night. These probabilities were not individual-specific, as most individuals were found to exhibit similar day-night movement patterns.

The movement model overlays input landscape layers in NetLogo in a virtual grid. Each cell in the grid has information on all overlapping landscape features. The model is run for 100 iterations, with each iteration representing 365 days, which captures typical movement of individuals from forests to crop fields. Each iteration in the model is independent and represents potential movement paths from the starting location.

Individual starting locations

For modelling movement of elephants outside the PA we used observed elephant locations as starting locations. For modelling movement inside the PA, we generated random starting points within the PA boundary.

Individual movement

In each iteration, individuals move a given distance during the day and night. We calculated these distances from the larger dataset of 53 male elephants (Table 1). To avoid autocorrelation of data, we randomly selected an observation for each day (6 am to 6 pm) and night for the analysis, based on the time of entry and exit of elephants from forest patches, obtained from camera trap data. In the movement model, the maximum distance an individual can move is calculated for each day and night, as a negative exponential function of the median distance (Table 1).

Table 1: Distance moved during the day and night

	Min (km)	Max (km)	Median (km)
Day	0.03	83.69	0.04
Night	0.04	52.8	6.08

Since elephants have a wide scale of perception of the landscape while moving, the model incorporates movement at two different scales: movement to a target cell a maximum of 500m away— which is typical of the distance elephants are able to detect scent, and movement to the neighbouring cell. Movement during the day or night thus involves locating for a target cell and moving towards this target cell by selecting suitable neighboring cells. This continues till the day-night distance is exhausted. The search angle for both target cells and intermediate cells are initially between 135-180 degrees to incorporate a directionality in movement, and expanded to 360 degrees only when a suitable cell cannot be found.

Target cells and intermediate neighboring cells are identified based on individual movement probabilties. These probabilties are a product of individual probabilties based on landscape contiguity, the probabilities of moving in different land-use classes during the day and night, and the probabilities of crossing infrastructure if present. The probabilities of crossing information were based on personal observations and communications with Forest Department staff (see table for probabilities of crossing infrastructure). Since built up-area corresponds to the presence of infrastructure, we used the product of the probability of crossing infrastructure and the probability of visiting the closest cell that is not classified as built-up.

Up to seven individuals that have spent more than 50 percent of time in crop fields are removed from the analysis, representing the mortality that is typical of the study elephants moving in the human-dominated landscape of our study area.

Model outputs

At the end of each iteration, the model stores a .CSV with information on the identity of each individual, and the X and Y coordinates of cells that it crossed. Using this, we derived a mosaicked raster containing the number of times individuals visited each cell in the landscape across 100 iterations in R.

Objective 3: To develop predictive models of human-elephant conflict, given future trends in landuse change in Bengaluru city, including Tumakuru, Ramanagara and Kanakapura towns based on agriculture and infrastructure plans.

Traditional LULC change models work on a time series of LULC maps and use roads and human population data as drivers of future change and most often do not include regional developmental plans. This might lead to biased or under representation of future change. In addition to the classical approach we incorporated regional development plans to simulate future change scenarios / landscapes. Future plans to increase perennial water storage for agricultural, especially for plantation purposes, could have potential long-term impact on the distribution of large mammals such as elephants in the landscape, which needs to be studied and understood. We also looked at plans that other line agencies might have, as implementation of these plans are linked to drivers of LULC change. The identified environmental, biological and anthropogenic drivers of decision-making in elephants and the range area of elephants that are currently in the human-use production landscape, close to urban centres, was used to develop rule-based models of human-elephant conflict, 10 years from now, using NetLogo. This will help us understand not only the spread of human-elephant conflict in the region but also the fate of many elephants in this high-risk landscape.

Similar to objective 2, the movement of elephants in the landscape in the future (2030) was modeled under different scenarios by incorporating the changes in LULC, which included increased area under agriculture and built-up and expansion of 4 lane highways to 10 lane highways for example.

We modeled the movement of elephants in the future landscape under two scenarios:

1) Elephants starting within a Protected Forest Area (PA) without any barrier to their movement, with partial barriers to their movement and with a completely barricaded boundary that does not allow for their movement outside the PA

2) Elephants starting from outside Protected Forest Areas (PA) without any barrier to their movement, with partial barriers to their movement and with a completely barricaded boundary that does not allow for their movement into the PA.

Objective 4: To generate guidelines that can act as a policy document to help urban development in regions co-habited by elephants.

Based on the results from the above three objectives a comprehensive set of guidelines informing decision-makers of the ways to plan urban development, agriculture intensification, infrastructure growth and town planning by keeping in mind 'the elephant in the room', has been attempted.

RESULTS

Objective 1: To assess environmental and biological factors influencing the current foraging and ranging decisions by male elephants in the peri-urban areas of Bengaluru city.

Biological and environmental influences on male elephant associations

Mixed-sex associations

Maturity was the first and the most significant factor determining the association of male elephants in mixed-sex groups (Figure 2; Node 1). With an increase in threshold of the proportion of Crop across the cells within the intensive study area (> 39.17%), the propensity of SIM males to occur in mixed-sex groups was halved, from nearly 80% to around 40% (Figure 2; Nodes 3 and 4 under Node 2; G-test of independence, $G = 5.27$, $df = 1$, $p = 0.02$). Male elephants in the SM and SSM class showed a relatively low propensity (13.3%, n= 13) to associate in mixed-sex groups in areas with low Contiguity Index or CONTIG (< 0.93, Node 5) and with a relatively lesser area under Plantation (≤ 0.27%). These males did not occur in areas with higher Plantation (> 0.27%; Figure 2; Nodes 6, 7 and 8; $G = 26.95$, $df = 1$, $p < 0.001$). In regions with higher Contiguity Index (> 0.93), however, a significant difference ($p < 0.001$) in the propensity of occurrence of SM and SSM males in mixed-sex groups was observed (Node 9). SM males occurred in mixed-sex groups in areas with Contiguity Index greater than 0.93 on 44.4% (n = 124) of all observations (Node 10). The propensity of SSM males to occur in mixed-sex groups was, however, low at 14.3% (n = 14) in areas with high Contiguity Index of > 0.93 but with low Plantation of ≤ 5.18% (Node 11). In regions with Plantation > 5.18%, there was a significant difference between males in musth and those not in musth in their propensity to occur in mixed-sex groups (Figure 2; Node 12). Males in musth associated with mixed-sex groups on 72.7 % of all occasions, reducing to 26.5% when not in musth (9 of 34 sightings, Node 13; $G = 26.95$, $df = 1$, $p < 0.001$).

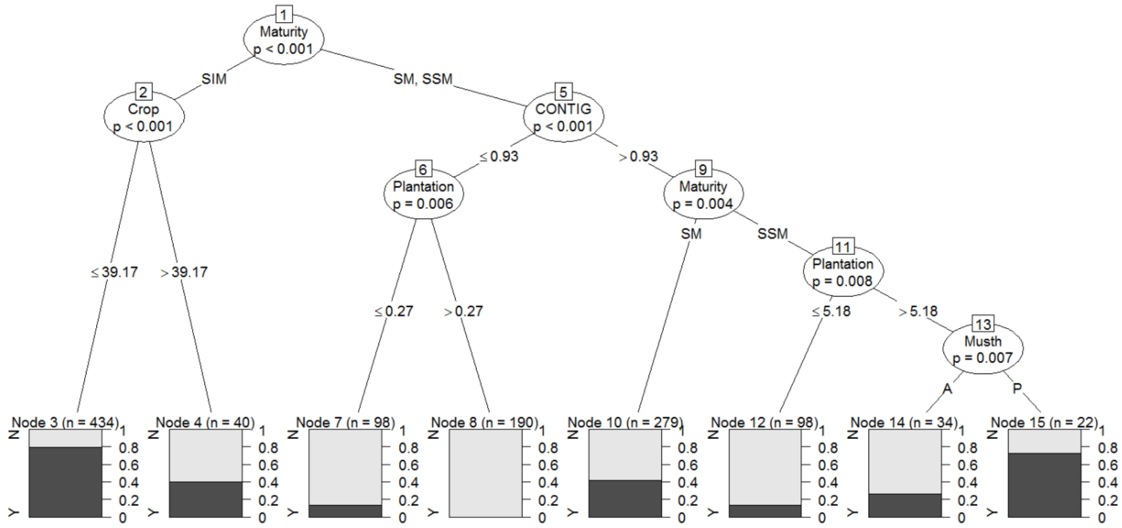


Figure 2: Classification tree showing the relative importance of the different biological and environmental attributes, with statistically significant branches at Nodes, in determining the propensity of male elephants to occur in mixed-sex groups. SIM: Sexually Immature, SM: Sexually Mature but Socially Immature, SSM: Sexually and Socially Mature, A: Musth absent, P: Musth present, Y: Associating in mixed-sex groups, N: Not associating in mixed-sex groups.

Solitary males

Maturity was again the primary determinant of the occurrence of male elephants as solitary individuals in the intensive study area (Figure 3; Node 1). SSM males were observed to be solitary at a relatively high proportion of 72% (Node 10) in areas with Deciduous Forest > 37.55%. Their propensity to occur as solitary, however, reduced to 42.2% (46 of 109 sightings) with a reduction in Deciduous Forest to ≤ 37.55% (Node 9; $G = 5.69$, $df = 1$, $p = 0.017$). SIM males primarily occurred as solitary individuals in 69.2% (9 of 13) of all sightings in cells with ≤ 1.02% Plantation and > 44.9% Crop (Figure 3; Nodes 3 and 5; $G = 6.88$, $df = 1$, $p < 0.01$). In SM males, the propensity to remain solitary was highest (53.7%) when Deciduous Forest was > 73.62% (Nodes 11 and 13), reducing to 30.2% (112 of 371 sightings, Nodes 11 and 12) when Deciduous Forest was < 73.6% ($G = 9.29$, $df = 1$, $p < 0.01$).

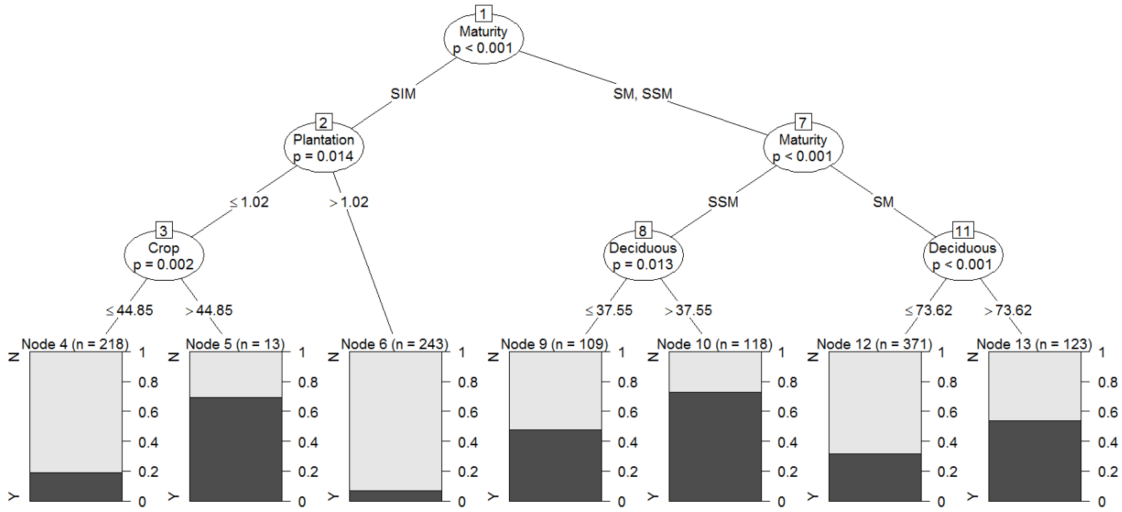


Figure 3: Classification tree showing the relative importance of the different biological and environmental attributes, with statistically significant branches at Nodes, in determining the propensity of male elephants to be solitary. SIM: Sexually Immature, SM: Sexually Mature but Socially Immature, SSM: Sexually and Socially Mature, Y: Solitary, N: Not solitary.

All-male groups

The primary factor determining the association of males in all-male groups was Deciduous Forest. Nearly 70% (176 of 252; Figure 4; Node 1) of our all-male group sightings were in areas with ≤ 20.3% Deciduous Forest. In areas with > 20.3% Deciduous Forests, in contrast, a significant difference was seen between SIM males and the other two maturity classes (Figure 4; Node 3; $G = 21.51$, $df = 1$, $p < 0.01$). Males in the SM and SSM categories associated in all-male groups at a relatively high level of 32.7% (17 of 52 occasions, Nodes 5 and 6) in areas with Deciduous Forest > 20.3% and Contiguity Index ≤ 0.93. In regions with Contiguity Index of > 0.93, however, it was the presence of musth that influenced the association of SM and SSM males in all-male groups. With Contiguity Index > 0.93 and in the absence of musth, the tendency of males to form all-male groups was at 14.5% (54 of 373 sightings, Nodes 7 and 8). SM and SSM males in musth rarely associated in all-male groups (1 of 60 occasions, Nodes 7 and 9; $G = 9.29$, $df = 1$, $p < 0.01$).

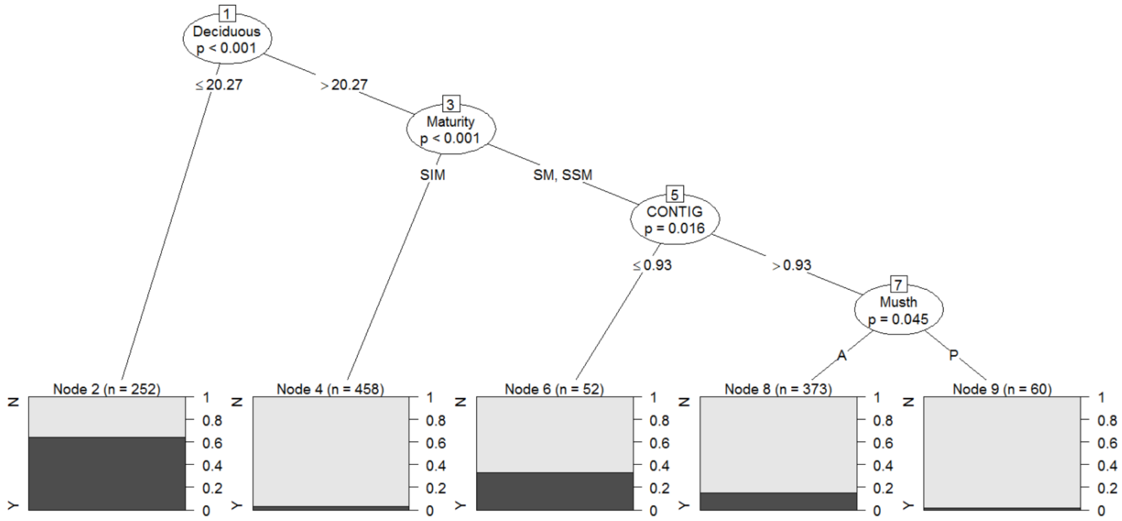


Figure 4: Classification tree showing the relative importance of the different biological and environmental attributes, with statistically significant branches at Nodes, in determining the propensity of male elephants to occur in all-male groups. SIM: Sexually Immature, SM: Sexually Mature but Socially Immature, SSM: Sexually and Socially Mature, A: Musth absent, P: Musth present, Y: Associating in all-male groups, N: Not associating in all-male groups.

There was significant variability in the size of all-male groups in the intensive study area (Figure 5). In cells with Crop > 40.8%, the group size was the highest, with a mean (± SE) of 4.64 (± 0.27, range 2 to 9, Node 5). In areas with < 40.8% Crop and ≤ 20.3% Deciduous Forest, group size reduced to a mean of 3.13 (± 0.12, range 2 to 6, Node 3). The size of all-male groups, however, was the least in areas with ≤ 40.8% Crop and > 20.3% Deciduous Forest, with a mean of 2.29 (±0.06, range 2 to 4, Node 4).

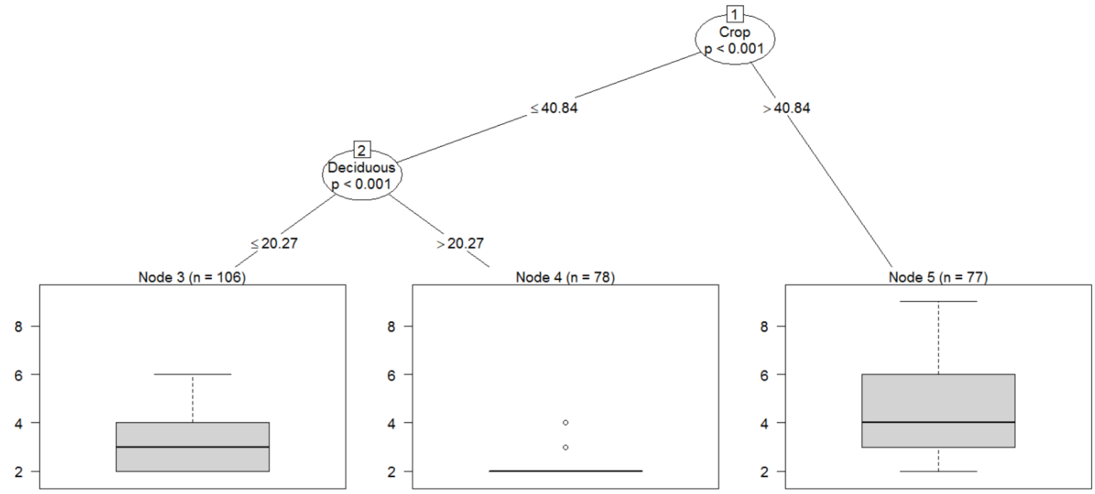


Figure 5: Classification tree showing the relative importance of the different biological and environmental attributes, with statistically significant branches at Nodes, in determining the size of all-male groups of elephants.

Biological and environmental influences on Body Condition

The Body Condition of SSM males differed significantly from that of individuals in the other two maturity categories in our study (Figure 6; Node 1); they had a Body Condition score of V on more than 80% of the sightings (Nodes 13 and 15). SIM males had a score of V on 25% of the sightings (4 of 16, Nodes 3 and 4) in areas with ≤ 14.31% Deciduous Forest and 20.1% in those with >14.31% Deciduous Forest (96 of 458, Nodes 6 and 7). In the case of SM males, we observed a significantly higher Body Condition score of V on 86.7% of all occasions in areas with > 31.3% Crop (Figure 6; Node 10; $G = 9.46$, $df = 1$, $p < 0.01$); this reduced to 32.7% in areas with ≤ 31.3% Crop. In addition, nearly 66% of all SM males sighted in all-male groups had assigned Body Condition score of V, which was significantly higher than the proportion of SM males with a Body Condition score of V seen either when solitary (45%) or in mixed-sex groups (27%, $G = 49.22$, $df = 2$, $p < 0.01$).

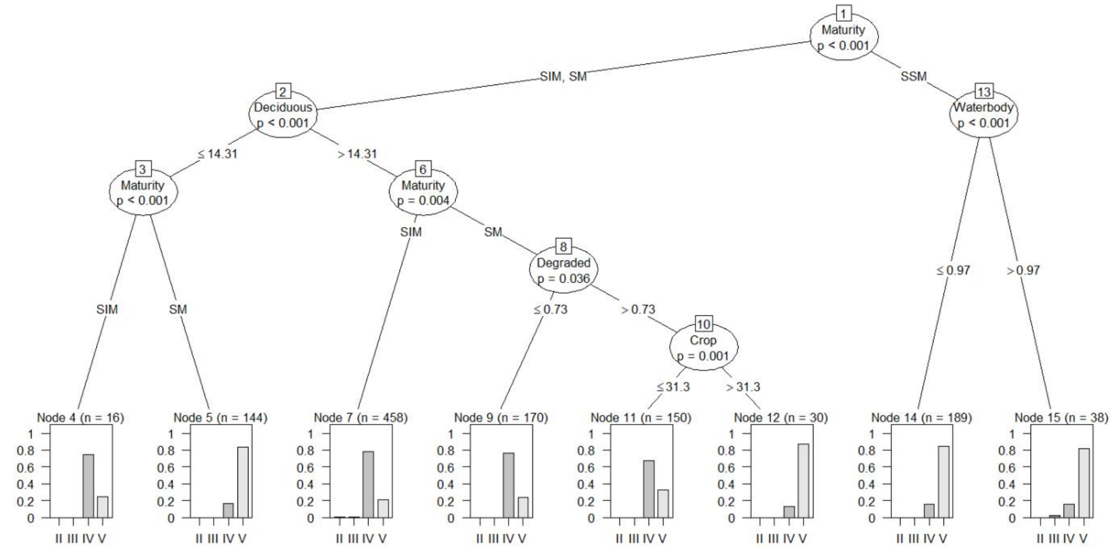


Figure 6: Classification tree showing the relative importance of the different biological and environmental attributes, with statistically significant branches at Nodes, in determining the Body Condition score, on a scale of I to V, of male elephants. SIM: Sexually Immature, SM: Sexually Mature but Socially Immature, SSM: Sexually and Socially Mature.

Kabbali, a solitary sexually and socially mature male elephant inside Bannerghatta

Bhim, a young adult sexually mature male, solitary in Sanamavu reserved forest

A small group of SM males interacting in an-all male group in Sanamavu

A large group of males of the SM and SSM class associating in an all-male group in Tumkur

An adult male elephant associating with a herd in Bannerghatta

A herd with two SIM males and one SSM male in Bannerghatta

Objective 2: To assess current trends in elephant distribution and human-elephant conflict in the districts of Bengaluru, Ramanagara, Tumakuru and Krishnagiri and to identify human-elephant conflict hotspots.

Under Objective 2, we first visualised the changing movement patterns and distribution of elephants, collected through direct observations and camera trapping, covering an area of nearly 10,000 km^2. Preliminary heat maps indicating elephant distributions are shown below (Figure 7).

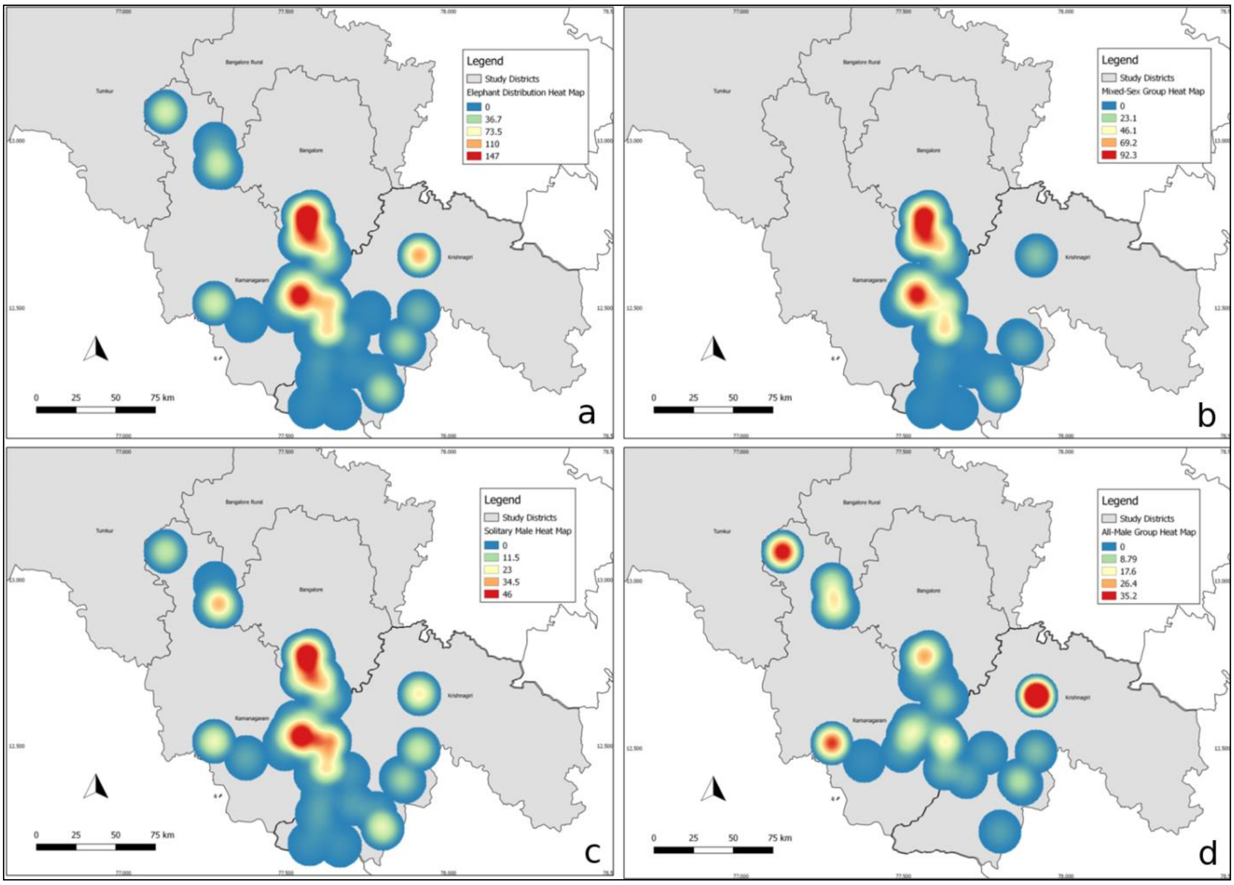


Figure 7: Heat maps showing the (a) distribution of elephants in the landscape and across three different social groups, (b) herds, (c) solitary and (d) all-male groups in the study site

A manuscript that assesses the change in habitat selection and daily activity patterns in elephants as they transition across a gradient of forest contiguity in peri-urban areas around Bengaluru has now been submitted to the journal iScience. One of the main results from our paper (Figure 8), suggests that when male elephants are in low contiguity areas with little available natural forest, they have modified their behaviour to select waterbodies as refuge sites, more than expected based on its availability. In contrast, when they are in high contiguity areas, elephants use forests more than expected based on availability, and adjoining crop fields and scrublands as per availability. This paper will provide an understanding of unique behavioural adaptations of elephants to navigate human-dominated and low forest-contiguity landscapes.

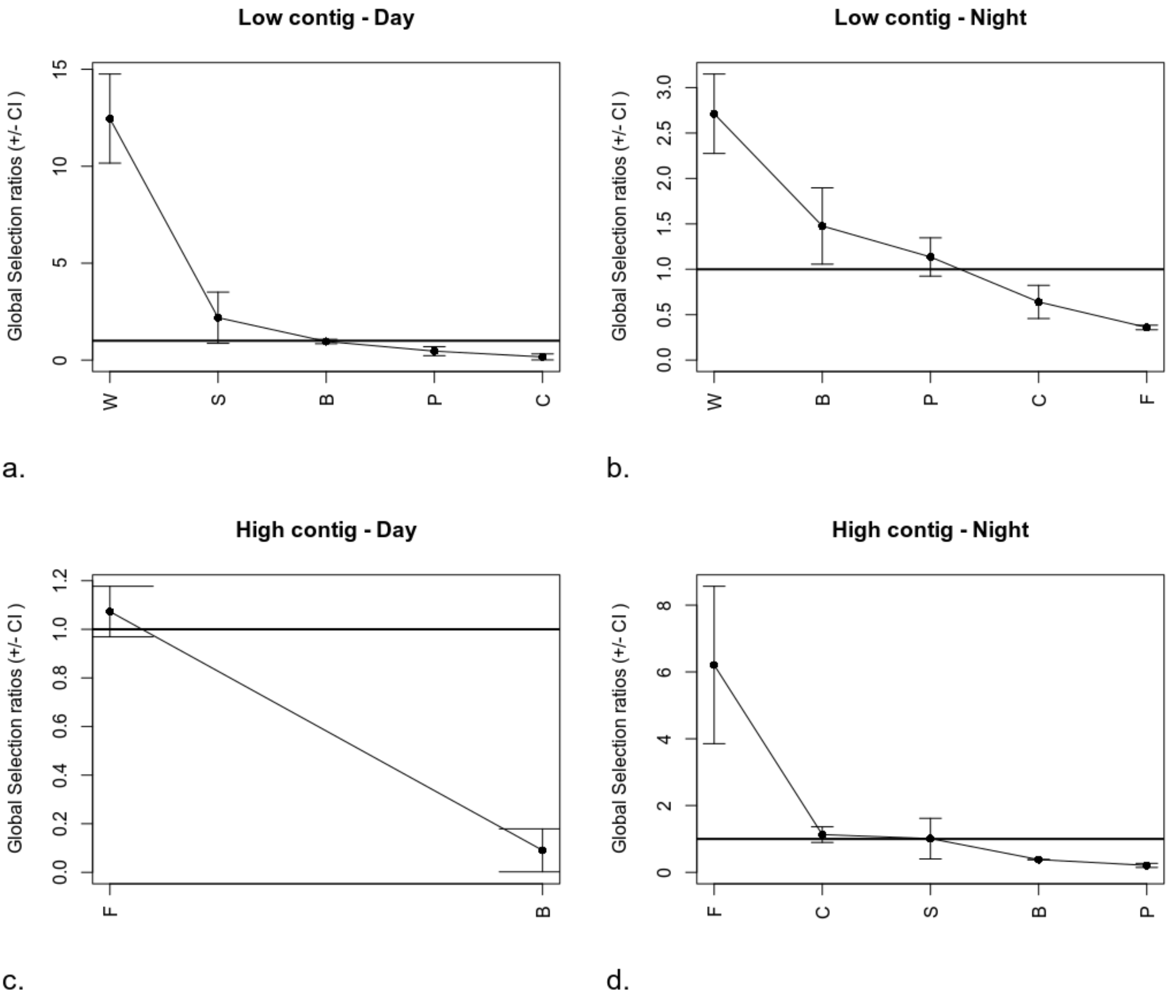


Figure 8: Habitat selection in (a) low contiguity areas during the day; (b) low contiguity areas during the night; (c) high contiguity areas during the day and (d) high contiguity areas during the night

Land Use Land Cover Change in the Landscape

A comparison of past (2005-06), current (2017-18) and projected (2030) Land use and land cover (LULC) maps suggested a major increase in area under agriculture in the study landscape (Figure 9). Agriculture area is expected to increase by 30% from the current extent of ~60,500 km^2 to 79,300 Km^2 by 2030. Similarly, nearly 22% increase in built-up area is expected by 2030 compared to the present extent of built-up area and settlements. A large decrease, ~87%, in current barren/fallow lands is expected by 2030, which is likely to be replaced by agriculture and builtup areas. The changes in forest areas is negligible, < 2%, which could be attributed mainly to the presence of Protected Areas in the landscape which are likely to remain constant under the current LULC modification projections. Grasslands, both in the plateau area and in high altitudes are likely to reduce by 58% from the current extent of 67 km^2 to 28 km^2. A reduction in plantation crops by 36% is expected by 2030, and they are likely to be replaced by agricultural crops in the study landscape (Figure 10). The increase in builtup areas could affect elephant movement while an increase in
agricultural area could facilitate the movement of elephants in the human-use areas of the landscape.

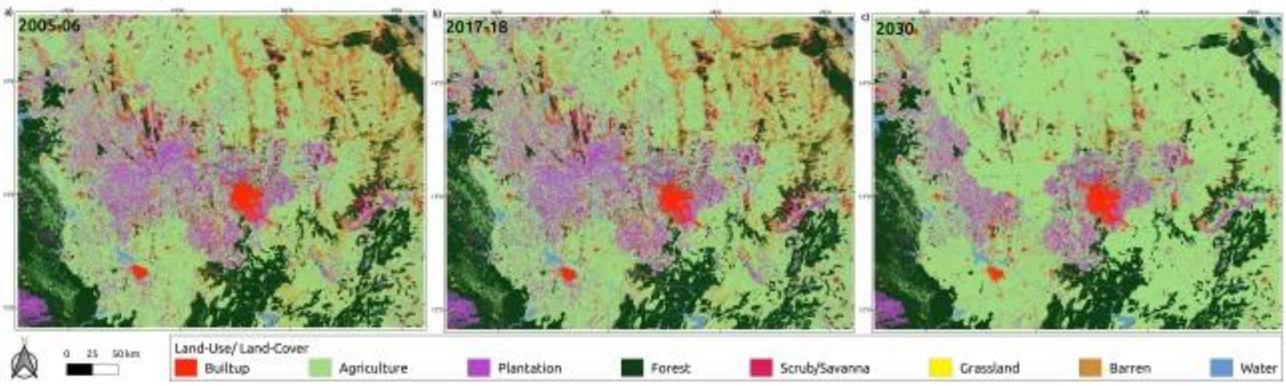


Figure 9: Land use land cover maps for the years 2005-06 and 2017-18, and the projected LULC change map for 2030.

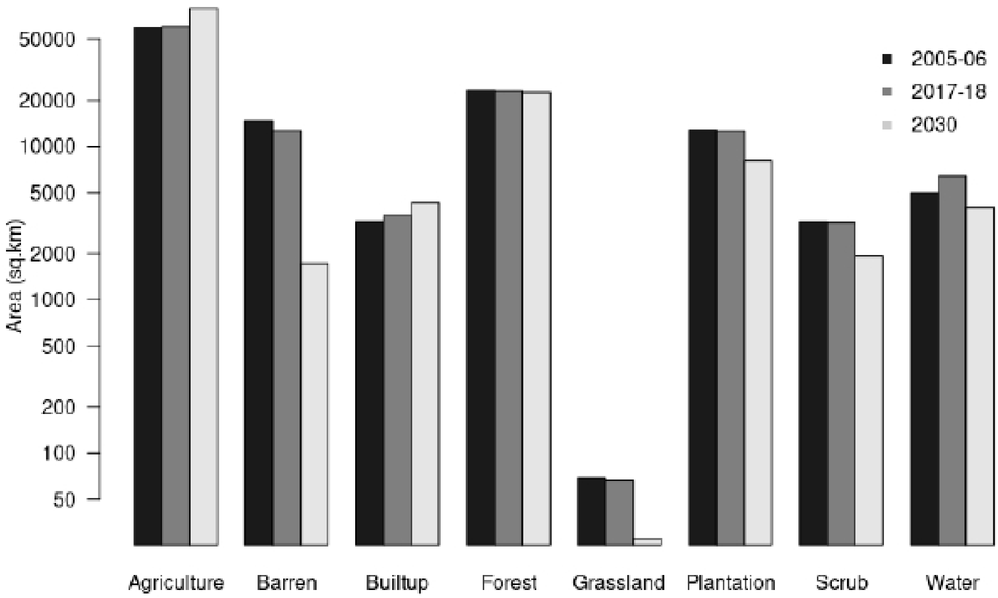


Figure 10: Area under different land use/land cover categories over three time periods 2005-06, 2017-18 and 2030.

Distribution Map of Elephants - Present

We classified the movement potential map into five categories in R (RStudio Team, 2022), based on the number of individuals in each cell. We defined Very Low movement areas as the 0-10^{th} quantile that represent cells with movement lower than expected; Low movement areas as the 10^{th} – 50^{th} quantile; Medium movement areas as the 50^{th} to 90^{th} quantile which represented cells with movement similar to those without LULC, infrastructure and human population; High movement areas as the 90^{th} to 95^{th} quantile and Very High movement areas as the 95^{th} – 100^{th} quantile which represented cells with movement higher than expected (Figure 11).

1. Starting points inside the Protected Forest Area

With starting points within the forested habitats of elephants, we modelled three further scenarios: a) Movement of elephants in the landscape with no barriers to movement; b) with partial barriers to movement and c) with complete barrier to movement outside the forested habitat. Since agriculture, barren and builtup areas were the major LULC layers that show change over time, we decided to assess the influence of these changes on the movement patterns of elephants at present. In addition, since forest is the primary habitat of an elephant and that is not expected to change, we analysed the influence of the barriers on its use by elephants under three scenarios listed above.

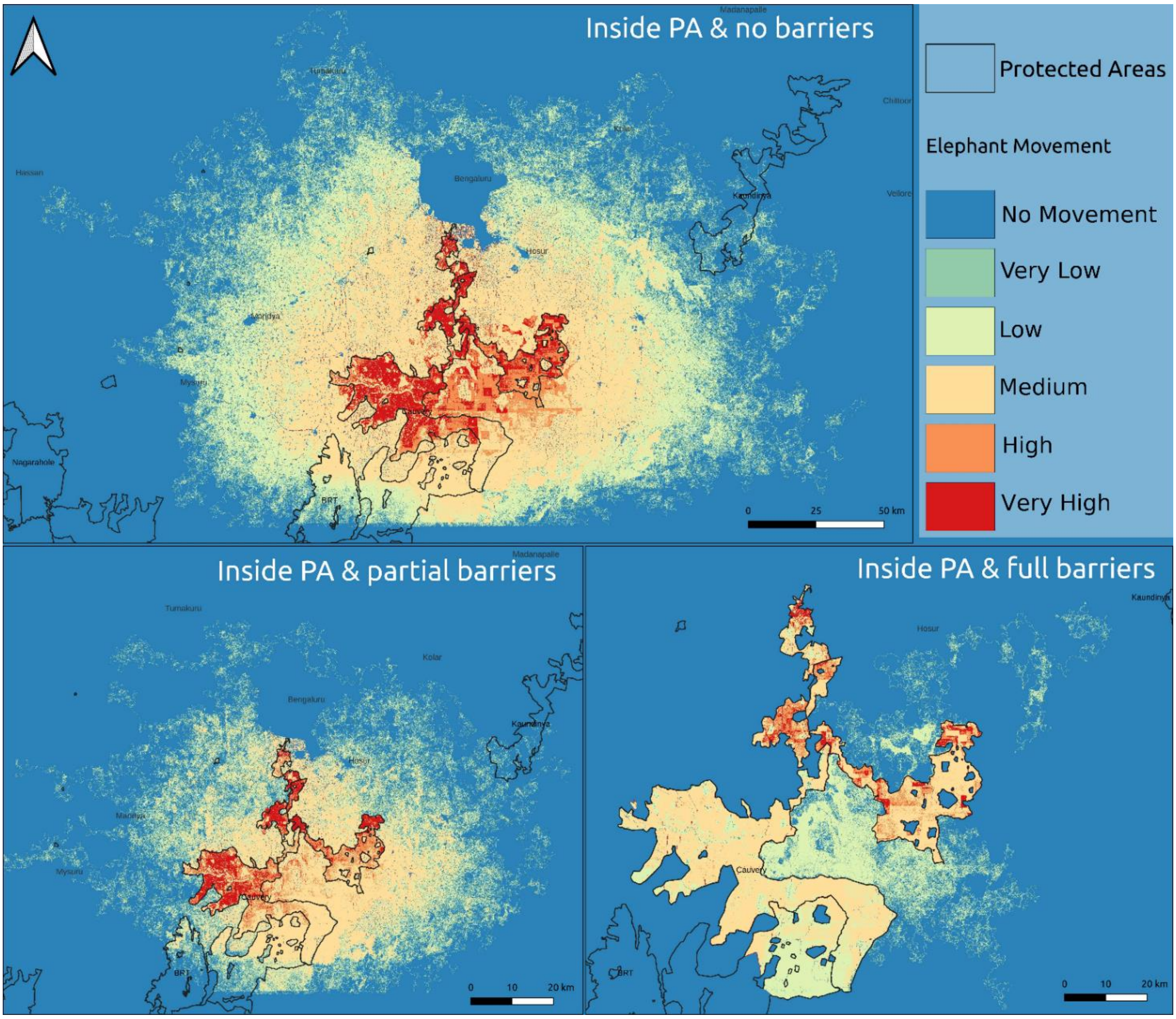


Figure 11: Movement patterns of elephants in the landscape no barrier, full barrier and partial barrier (clockwise)

a. Without barriers

There was a significant difference in the percent movement of elephants in the different LULC types (G = 81.03, $p < 0.001$, df = 35) in the landscape. As expected, No Movement of elephants was the highest in Builtup LULC type in the landscape with 85.47% of the area being unavailable. The lowest percent of No Movement of elephants in the landscape was recorded in the Forest LULC type at 50.22%. The Forest LULC type recorded the most movement in the two classes of High and Very High at 16.34% combined and the least (Very Low and Low categories) movement was recorded in LULC types Water at 21.88% and Agriculture at 23.26% (Table 2).

LULC	**Present (%area)**					
	No Movement	**Very Low**	**Low**	**Medium**	**High**	**Very High**
Agriculture	59.99	**7.49**	**15.77**	16.30	0.30	0.15
Barren	66.80	5.28	10.82	16.12	0.69	0.28
Builtup	**85.47**	2.85	5.69	5.18	0.33	0.49
Forest	**50.22**	5.23	10.79	17.41	**8.04**	**8.30**
Grassland	62.95	6.05	12.36	15.16	1.73	1.74
Plantation	68.93	6.81	11.15	12.41	0.41	0.29
Scrub	69.73	5.39	9.67	11.86	1.20	2.15
Water	69.81	**7.17**	**14.71**	8.18	0.07	0.05

Table 2: Intensity of movement across different LULC types in the landscape in percent

With no barriers along the forest boundary for movement of elephants with starting points within the Forest LULC type, we recorded both High and Very High Movement in the Forest LULC type at 0.83 and 0.86 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low and Low occurrence in the Agriculture LULC type at 0.54 and 0.57 respectively compared to all other LULC types (Table 3).

Movement	**Present (Proportion of Area)**							
	Agriculture	**Barren**	**Builtup**	**Forest**	**Grassland**	**Plantation**	**Scrub**	**Water**
No Movement	0.46	0.05	0.05	0.16	0.02	0.19	0.04	0.03
Very Low	**0.54**	0.04	0.01	0.16	0.02	0.18	0.03	0.03
Low	**0.57**	0.04	0.01	0.16	0.02	0.15	0.03	0.03
Medium	0.51	0.05	0.01	0.23	0.02	0.14	0.03	0.01
High	0.07	0.02	0.01	**0.83**	0.02	0.04	0.02	0.00
Very High	0.04	0.01	0.01	**0.86**	0.02	0.03	0.04	0.00

Table 3: Proportion of LULC types with different intensities of movement in the landscape

b. With partial barriers

There was a significant difference in the percent movement of elephants in the different LULC types (G = 110.27, p <0.001, df = 35) in the landscape. As expected, even with partial barriers No Movement of elephants was the highest in Builtup LULC type in the landscape with 93.40% of the area being unavailable. The lowest percent of No movement of elephants in the landscape was recorded in the Forest LULC type at 46.60%. The Forest LULC type recorded the most movement in the two classes of High and Very High at 12.90% combined and the least (Very Low and Low categories) movement was recorded in LULC types Barren at 20.10% and Agriculture at 16.87% (Table 4).

LULC	**Present (%area)**					
	No Movement	**Very Low**	**Low**	**Medium**	**High**	**Very High**
Agriculture	73.57	**9.31**	**7.56**	9.36	0.06	0.15
Barren	64.05	**9.40**	**10.70**	13.79	1.00	1.06
Builtup	**93.40**	2.59	1.68	2.08	0.08	0.17
Forest	**46.60**	7.26	6.76	26.48	**6.83**	**6.07**
Grassland	65.39	8.66	8.14	13.61	1.90	2.30
Plantation	78.50	7.58	6.15	7.33	0.17	0.28
Scrub	68.82	7.96	7.60	11.41	1.72	2.50
Water	81.92	8.75	5.86	3.39	0.03	0.05

Table 4: Intensity of movement across different LULC types in the landscape in percent

With the forest boundary partially barricaded for movement of elephants with starting points within the Forest LULC type, we recorded both High and Very High Movement in the Forest LULC type at 0.88 and 0.81 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low and Low occurrence in the Agriculture LULC type at 0.54 and 0.52 respectively compared to all other LULC types (Table 5).

Movement	**Present (Proportion of Area)**							
	Agriculture	**Barren**	**Builtup**	**Forest**	**Grassland**	**Plantation**	**Scrub**	**Water**
No Movement	0.51	0.03	0.06	0.13	0.02	0.20	0.03	0.03
Very Low	**0.54**	0.04	0.01	0.17	0.02	0.16	0.03	0.03
Low	**0.52**	0.05	0.01	0.19	0.02	0.15	0.03	0.02
Medium	0.37	0.04	0.01	0.43	0.02	0.10	0.03	0.01
High	0.02	0.02	0.00	**0.88**	0.02	0.02	0.04	0.00
Very High	0.05	0.03	0.00	**0.81**	0.03	0.03	0.05	0.00

Table 5: Proportion of LULC types with different intensities of movement in the landscape

c. With full barriers

There was a significant difference in the percent movement of elephants in the different LULC types (G = 176.59, p <0.001, df = 35) in the landscape. As expected, No Movement of elephants was the highest in Builtup LULC type in the landscape with 99.44% of the area being unavailable. But also No Movement in the Agriculture and Plantation LULC types were high at 92.95% and 92.66% respectively. The lowest percent of No Movement of elephants in the landscape was recorded in the Forest LULC type at 42.97%. The Forest LULC type recorded the most movement in the two classes of High and Very High at 6.10% combined and the least movement was recorded in LULC types Forest at 24.54% and Grassland at 11.94% (Table 6).

LULC	Present (%area)					
	No Movement	Very Low	Low	Medium	High	Very High
Agriculture	**92.95**	3.51	2.96	0.26	0.03	0.28
Barren	82.46	0.92	9.69	5.87	0.25	0.81
Builtup	**99.44**	0.21	0.28	0.04	0.00	0.03
Forest	**42.97**	**4.76**	**19.78**	26.39	**3.32**	**2.78**
Grassland	71.91	**1.55**	**10.39**	13.69	0.84	1.61
Plantation	**92.66**	1.93	3.66	1.01	0.16	0.59
Scrub	73.67	2.28	8.29	13.42	0.86	1.48
Water	91.20	1.08	5.75	0.83	0.12	1.03

Table 6: Intensity of movement across different LULC types in the landscape in percent

With the forest boundary fully barricaded for movement of elephants outside their forested habitats and with starting points within the Forest LULC type, we recorded both High and Very High Movement in the Forest LULC type at 0.93 and 0.75 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low occurrence in the Agriculture LULC type at 0.40 and then in Forest LULC type at 0.48 compared to all other LULC types (Table 7).

Movement	Present (Proportion of Area)							
	Agriculture	Barren	Builtup	Forest	Grassland	Plantation	Scrub	Water
No Movement	0.49	0.04	0.03	0.20	0.02	0.16	0.03	0.02
Very Low	**0.40**	0.01	0.00	**0.48**	0.01	0.07	0.02	0.00
Low	0.12	0.04	0.00	0.73	0.02	0.05	0.03	0.01
Medium	0.01	0.02	0.00	0.88	0.03	0.01	0.04	0.00
High	0.01	0.01	0.00	**0.93**	0.01	0.02	0.02	0.00
Very High	0.09	0.02	0.00	**0.75**	0.03	0.06	0.04	0.01

Table 7: Proportion of LULC types with different intensities of movement in the landscape

2. Starting points outside the Protected Forest Area

With starting points outside the forested habitats of elephants, we modelled three further scenarios: a) Movement of elephants in the landscape with no barriers to movement; b) with partial barriers to movement and c) with complete barrier to movement outside the forested habitat. Since agriculture, barren and builtup areas were the major LULC layers that show change over time, we decided to assess the influence of these changes on the movement patterns of elephants at present. In addition, since forest is the primary habitat of an elephant and that is not expected to change, we analysed the influence of the barriers on its use by elephants under three scenarios listed above.

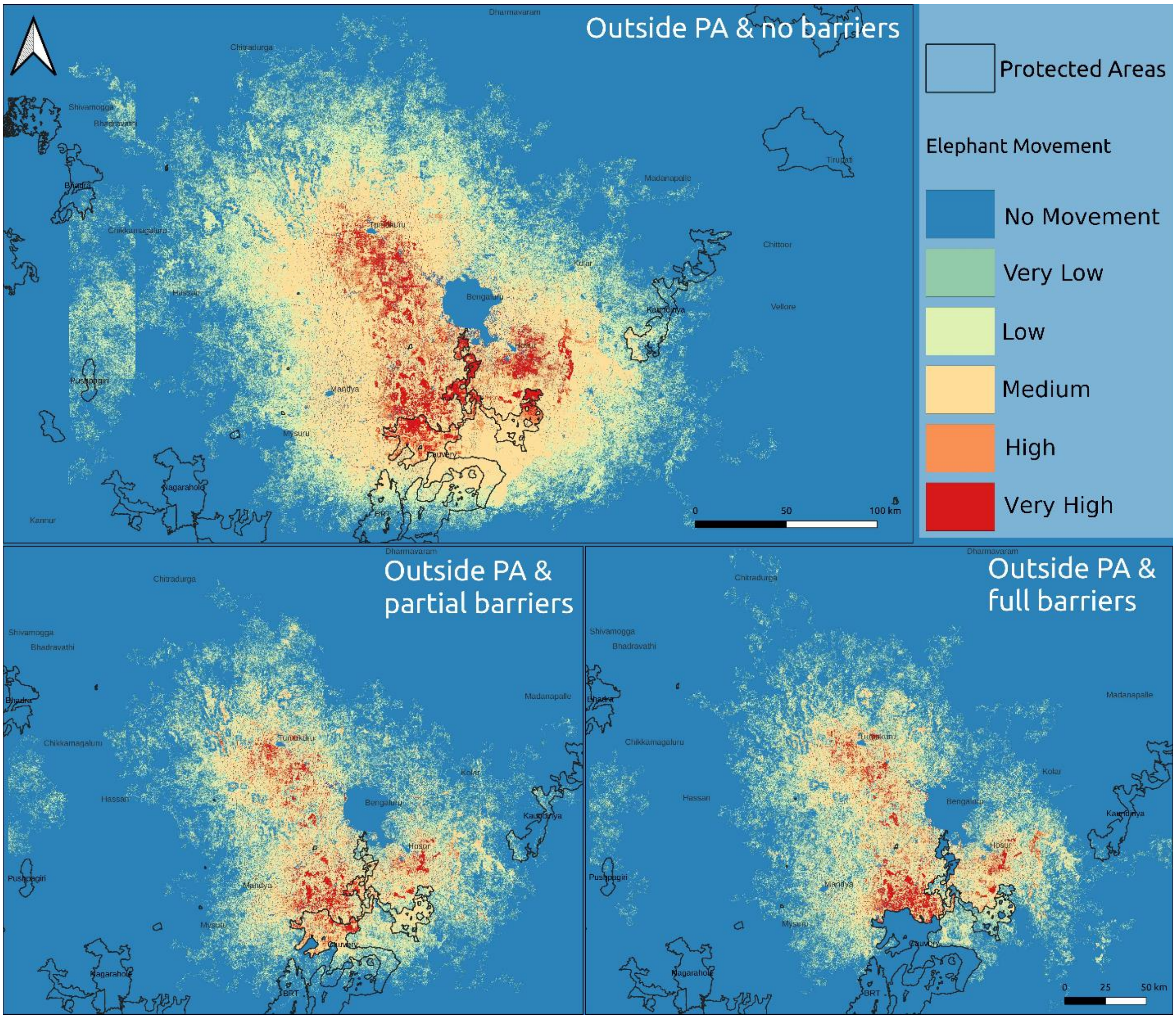


Figure 12: Movement patterns of elephants in the landscape no barrier, full barrier and partial barrier (clockwise)

a. Without barriers

There was no significant difference in the percent movement of elephants in the different LULC types (G = 49.84, p=0.05, df = 35) in the landscape. As expected, No Movement of elephants was the highest in Builtup LULC type in the landscape with 82.23% of the area being unavailable. The lowest percent of No Movement of elephants in the landscape was recorded in the Plantation LULC type at 47.37%. The Forest LULC type recorded the most movement in the two classes of High and Very High at 4.89% combined and the least (Very Low and Low categories) movement was recorded in LULC types Water at 21.50% and Plantation at 22.94% (Table 8).

LULC	**Present (%area)**					
	No Movement	**Very Low**	**Low**	**Medium**	**High**	**Very High**
Agriculture	60.65	8.45	12.32	15.28	1.84	1.46
Barren	**80.55**	5.18	6.19	5.18	1.09	1.81
Builtup	**82.23**	2.48	4.68	7.99	0.87	1.75
Forest	64.41	8.34	9.23	13.14	**2.10**	**2.79**
Grassland	68.37	7.01	9.95	10.38	**1.64**	**2.64**
Plantation	47.37	8.32	14.62	25.11	**2.59**	**1.99**
Scrub	72.13	7.34	9.22	8.56	1.15	1.61
Water	63.61	9.12	12.38	12.51	1.44	0.95

Table 8: Intensity of movement across different LULC types in the landscape in percent

With no barriers along the forest boundary for movement of elephants with starting points outside the Forest LULC type, we recorded both High and Very High Movement in the Agriculture LULC type at 0.46 and 0.36 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low and Low occurrence of 0.49 and 0.51 respectively compared to all other LULC types (Table 9).

Movement	**Present (Proportion of Area)**							
	Agriculture	**Barren**	**Builtup**	**Forest**	**Grassland**	**Plantation**	**Scrub**	**Water**
No Movement	0.45	0.10	0.03	0.21	0.02	0.10	0.05	0.03
Very Low	**0.49**	0.05	0.01	0.22	0.02	0.14	0.04	0.03
Low	**0.51**	0.04	0.01	0.17	0.02	0.18	0.04	0.03
Medium	0.48	0.03	0.01	0.18	0.02	0.24	0.03	0.02
High	**0.46**	0.04	0.01	0.23	0.02	0.19	0.03	0.02
Very High	**0.36**	0.07	0.02	0.31	0.03	0.15	0.04	0.01

Table 9: Proportion of LULC types with different intensities of movement in the landscape

b. With partial barriers

There was no significant difference in the percent movement of elephants in the different LULC types (G = 22.86, $p<0.05$, df = 35) in the landscape. As expected, even with partial barriers No Movement of elephants was the highest in Builtup LULC type in the landscape with 89.23% of the area being unavailable. The lowest percent of No movement of elephants in the landscape was recorded in the Plantation LULC type at 67.07%. The Grassland LULC type recorded the most movement in the two classes of High and Very High at 3.36% combined and the least (Very Low and Low categories) movement was recorded in LULC types Water at 14.02% and Plantation at 18.55% (Table 10).

LULC	Present (%area)					
	No Movement	**Very Low**	**Low**	**Medium**	**High**	**Very High**
Agriculture	77.14	7.77	6.35	6.79	1.05	0.90
Barren	**85.66**	4.50	3.21	3.98	**0.82**	**1.84**
Builtup	**89.23**	3.30	2.81	2.80	0.57	1.29
Forest	77.50	6.38	6.27	7.21	1.25	1.39
Grassland	78.71	6.51	5.23	6.19	**1.33**	**2.04**
Plantation	67.07	9.23	9.32	11.82	1.39	1.16
Scrub	82.22	6.33	4.53	4.82	0.91	1.19
Water	78.01	7.69	6.33	6.35	0.90	0.72

Table 10: Intensity of movement across different LULC types in the landscape in percent

With the forest boundary partially barricaded for movement of elephants with starting points outside the Forest LULC type, we recorded both High and Very High Movement in the Agriculture LULC type at 0.44 and 0.37 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low and Low occurrence of 0.50 and 0.46 respectively compared to all other LULC types (Table 11).

Movement	Present (Proportion of Area)							
	Agriculture	**Barren**	**Builtup**	**Forest**	**Grassland**	**Plantation**	**Scrub**	**Water**
No Movement	0.47	0.07	0.03	0.20	0.02	0.14	0.04	0.03
Very Low	**0.50**	0.04	0.01	0.17	0.02	0.20	0.04	0.03
Low	**0.46**	0.03	0.01	0.19	0.02	0.23	0.03	0.03
Medium	0.44	0.03	0.01	0.20	0.02	0.25	0.03	0.02
High	**0.44**	0.05	0.01	0.22	0.02	0.20	0.03	0.02
Very High	**0.37**	0.10	0.03	0.24	0.04	0.16	0.04	0.02

Table 11: Proportion of LULC types with different intensities of movement in the landscape

c. With full barriers

There was a significant difference in the percent movement of elephants in the different LULC types (G = 27.54, $p < 0.05$, df = 35) in the landscape. As expected, No Movement of elephants was the highest in Builtup LULC type in the landscape with 90.74% of the area being unavailable. But also No Movement in the Forest and Scrub LULC types were high at 87.00% and 87.96% respectively. The lowest percent of No Movement of elephants in the landscape was recorded in the Plantation LULC type at 70.00%. The Plantation LULC type recorded the most movement in the two classes of High and Very High at 2.57% combined and the least movement was recorded in LULC types Plantation at 16.60% and Agriculture at 11.27% (Table 12).

LULC	**Present (%area)**					
	No Movement	**Very Low**	**Low**	**Medium**	**High**	**Very High**
Agriculture	80.95	6.03	5.23	6.06	0.91	0.81
Barren	**90.89**	2.73	2.09	2.65	0.48	1.15
Builtup	**90.74**	2.77	2.34	2.58	0.53	1.03
Forest	87.00	4.88	3.51	3.15	0.58	0.87
Grassland	85.50	4.54	3.67	4.28	**0.71**	**1.30**
Plantation	70.00	8.36	8.24	10.83	**1.51**	**1.06**
Scrub	87.96	4.45	3.11	3.22	0.48	0.79
Water	81.82	6.21	5.01	5.62	0.78	0.56

Table 12: Intensity of movement across different LULC types in the landscape in percent

With the forest boundary fully barricaded for movement of elephants into their forested habitats and with starting points outside the Forest LULC type, we recorded both High and Very High Movement in the Agriculture LULC type at 0.50 and 0.43 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low occurrence of 0.50 compared to all other LULC types (Table 13).

Movement	**Present (Proportion of Area)**							
	Agriculture	**Barren**	**Builtup**	**Forest**	**Grassland**	**Plantation**	**Scrub**	**Water**
No Movement	0.47	0.08	0.03	0.21	0.02	0.12	0.05	0.03
Very Low	**0.50**	0.03	0.01	0.17	0.02	0.21	0.03	0.03
Low	**0.50**	0.03	0.01	0.14	0.02	0.25	0.03	0.03
Medium	0.50	0.03	0.01	0.11	0.02	0.28	0.02	0.03
High	**0.50**	0.04	0.02	0.13	0.02	0.25	0.02	0.02
Very High	**0.43**	0.09	0.03	0.19	0.03	0.17	0.04	0.02

Table 13: Proportion of LULC types with different intensities of movement in the landscape

Objective 3: To develop predictive models of human-elephant conflict, given future trends in landuse change in Bengaluru city, including Tumakuru, Ramanagara and Kanakapura towns based on agriculture and infrastructure plans.

Distribution Map of Elephants – Future (2030)

We classified the movement potential map into five categories in R (RStudio Team, 2022), based on the number of individuals in each cell. We defined Very Low movement areas as the 0-10th quantile that represent cells with movement lower than expected; Low movement areas as the 10th – 50th quantile; Medium movement areas as the 50th to 90th quantile which represented cells with movement similar to those without LULC, infrastructure and human population; High movement areas as the 90th to 95th quantile and Very High movement areas as the 95th – 100th quantile which represented cells with movement higher than expected (Figure 13).

1. Starting points inside the Protected Forest Area

With starting points within the forested habitats of elephants, we modelled three further scenarios: a) Movement of elephants in the landscape with no barriers to movement; b) with partial barriers to movement and c) with complete barrier to movement outside the forested habitat. Since agriculture, barren and builtup areas were the major LULC layers that show change over time, we decided to assess the influence of these changes on the movement patterns of elephants at present. In addition, since forest is the primary habitat of an elephant and that is not expected to change, we analysed the influence of the barriers on its use by elephants under three scenarios listed above.

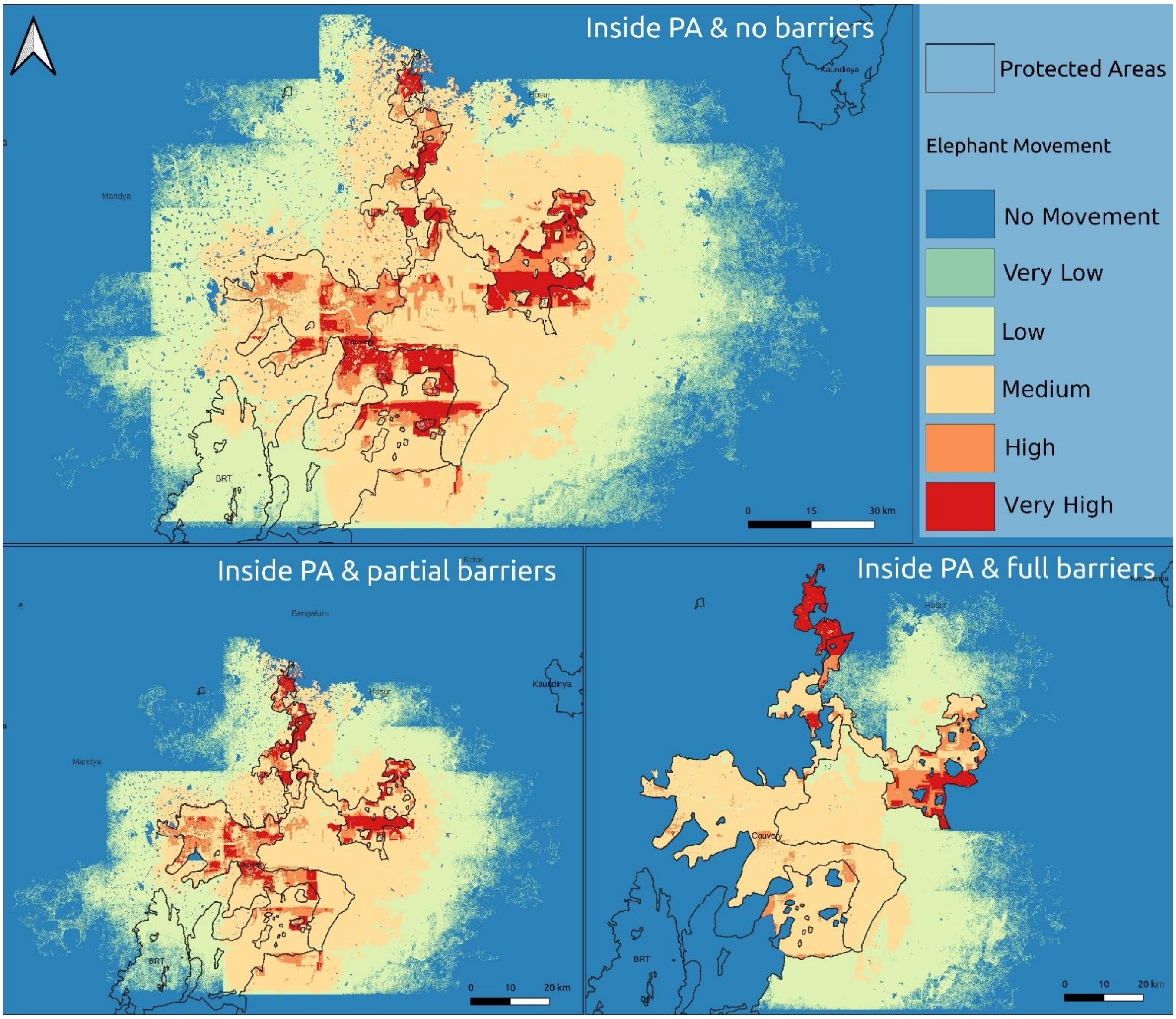


Figure 13: Movement patterns of elephants in the landscape no barrier, full barrier and partial barrier (clockwise)

a. Without barriers

There was a significant difference in the percent movement of elephants in the different LULC types (G = 250.29, p <0.001, df = 35) in the landscape. As expected, No Movement of elephants was the highest in Builtup LULC type in the landscape with 93.05% of the area being unavailable. The lowest percent of No Movement of elephants in the landscape was recorded in the Forest LULC type at 20.49%. The Forest LULC type recorded the most movement in the two classes of High and Very High at 22.48% combined and the least (Very Low and Low categories) movement was recorded in LULC types Water at 54.86% and Plantation at 37.00% (Table 14).

LULC	Future (%area)					
	No Movement	Very Low	Low	Medium	High	Very High
Agriculture	45.42	9.00	26.68	18.65	0.12	0.13
Barren	38.13	6.59	19.22	34.94	0.83	0.30
Builtup	**93.05**	0.73	3.13	2.56	0.13	0.40
Forest	20.49	3.11	14.04	39.87	**11.26**	**11.22**
Grassland	38.73	5.89	22.06	28.47	2.51	2.34
Plantation	36.80	6.94	30.06	24.91	0.65	0.64
Scrub	42.26	5.98	19.02	24.72	3.82	4.20
Water	32.41	11.63	43.23	12.67	0.03	0.02

Table 14: Intensity of movement across different LULC types in the landscape in percent

With no barriers along the forest boundary for movement of elephants with starting points within the Forest LULC type, we recorded both High and Very High Movement in the Agriculture LULC type at 0.93 and 0.93 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low and Low occurrence in the Agriculture LULC type at 0.75 and 0.67 respectively compared to all other LULC types (Table 15).

Movement	Future (Proportion of Area)							
	Agriculture	Barren	Builtup	Forest	Grassland	Plantation	Scrub	Water
No Movement	0.66	0.01	0.09	0.13	0.01	0.07	0.01	0.02
Very Low	**0.75**	0.01	0.00	0.11	0.01	0.08	0.01	0.03
Low	**0.67**	0.01	0.01	0.15	0.01	0.10	0.01	0.04
Medium	0.45	0.02	0.00	0.41	0.01	0.08	0.01	0.01
High	0.02	0.00	0.00	**0.93**	0.01	0.02	0.02	0.00
Very High	0.03	0.00	0.01	**0.93**	0.01	0.02	0.02	0.00

Table 15: Proportion of LULC types with different intensities of movement in the landscape

b. With partial barriers

There was a significant difference in the percent movement of elephants in the different LULC types (G = 232.17, $p < 0.001$, df = 35) in the landscape. As expected, even with partial barriers No Movement of elephants was the highest in Builtup LULC type in the landscape with 94.80% of the area being unavailable. The lowest percent of No movement of elephants in the landscape was recorded in the Forest LULC type at 21.25%. The Forest LULC type recorded the most movement in the two classes of High and Very High at 19.32% combined and the least (Very Low and Low categories) movement was recorded in LULC types Water at 45.04% and Agriculture at 30.77% (Table 16).

LULC	**Future (%area)**					
	No Movement	**Very Low**	**Low**	**Medium**	**High**	**Very High**
Agriculture	55.71	**8.03**	**22.75**	13.22	0.06	0.24
Barren	42.19	5.05	15.44	33.95	1.41	1.97
Builtup	94.80	0.66	2.38	1.86	0.05	0.24
Forest	21.25	4.56	11.42	43.46	**10.09**	**9.23**
Grassland	46.43	5.34	17.42	24.61	2.74	3.47
Plantation	54.84	6.40	21.53	15.79	0.36	1.08
Scrub	48.80	4.94	15.61	21.81	3.62	5.21
Water	43.71	**7.39**	**37.65**	11.03	0.05	0.17

Table 16: Intensity of movement across different LULC types in the landscape in percent

With the forest boundary partially barricaded for movement of elephants with starting points within the Forest LULC type, we recorded both High and Very High Movement in the Forest LULC type at 0.94 and 0.86 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low and Low occurrence in the Agriculture LULC type at 0.70 and 0.69 respectively compared to all other LULC types (Table 17).

Movement	**Future (Proportion of Area)**							
	Agriculture	**Barren**	**Builtup**	**Forest**	**Grassland**	**Plantation**	**Scrub**	**Water**
No Movement	0.67	0.01	0.08	0.11	0.01	0.09	0.01	0.02
Very Low	**0.70**	0.01	0.00	0.16	0.01	0.08	0.01	0.02
Low	**0.69**	0.01	0.01	0.14	0.01	0.09	0.01	0.04
Medium	0.37	0.02	0.00	0.51	0.01	0.06	0.01	0.01
High	0.01	0.01	0.00	**0.94**	0.01	0.01	0.02	0.00
Very High	0.05	0.01	0.00	**0.86**	0.01	0.03	0.03	0.00

Table 17: Proportion of LULC types with different intensities of movement in the landscape

c. With full barriers

There was a significant difference in the percent movement of elephants in the different LULC types (G = 353.75, p <0.001, df = 35) in the landscape. As expected, No Movement of elephants was the highest in Builtup LULC type in the landscape with 98.39% of the area being unavailable. But also No Movement in the Agriculture and Plantation LULC types were high at 69.75% and 88.78% respectively. The lowest percent of No Movement of elephants in the landscape was recorded in the Forest LULC type at 29.12%. The Forest LULC type recorded the most movement in the two classes of High and Very High at 10.50% combined and the least movement was recorded in LULC types Water at 51.29% and Agriculture at 27.97% (Table 18).

LULC	Future (%area)					
	No Movement	Very Low	Low	Medium	High	Very High
Agriculture	**69.75**	**9.55**	**18.42**	1.85	0.09	0.34
Barren	38.65	2.32	11.83	39.70	1.10	6.40
Builtup	**98.39**	0.40	0.94	0.17	0.01	0.09
Forest	29.12	1.60	16.56	42.22	**5.70**	**4.80**
Grassland	48.07	3.24	11.37	30.33	2.24	4.74
Plantation	**88.78**	1.30	5.03	3.48	0.28	1.14
Scrub	45.24	2.76	12.57	30.50	3.55	5.38
Water	44.68	**10.30**	**40.99**	3.27	0.21	0.55

Table 18: Intensity of movement across different LULC types in the landscape in percent

With the forest boundary fully barricaded for movement of elephants outside their forested habitats and with starting points within the Forest LULC type, we recorded both High and Very High Movement in the Forest LULC type at 0.93 and 0.78 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low occurrence in the Agriculture LULC type at 0.81 and 0.53 respectively (Table 19).

Movement	Future (Proportion of Area)							
	Agriculture	Barren	Builtup	Forest	Grassland	Plantation	Scrub	Water
No Movement	0.58	0.01	0.05	0.18	0.01	0.15	0.01	0.02
Very Low	**0.81**	0.01	0.00	0.10	0.01	0.02	0.01	0.04
Low	**0.53**	0.01	0.00	0.36	0.01	0.03	0.01	0.06
Medium	0.05	0.03	0.00	0.86	0.02	0.02	0.02	0.00
High	0.02	0.01	0.00	**0.93**	0.01	0.01	0.02	0.00
Very High	0.07	0.04	0.00	**0.78**	0.02	0.05	0.03	0.01

Table 19: Proportion of LULC types with different intensities of movement in the landscape

2. Starting points outside the Protected Forest Area

With starting points outside the forested habitats of elephants, we modelled three further scenarios: a) Movement of elephants in the landscape with no barriers to movement; b) with partial barriers to movement and c) with complete barrier to movement outside the forested habitat. Since agriculture, barren and builtup areas were the major LULC layers that show change over time, we decided to assess the influence of these changes on the movement patterns of elephants at present. In addition, since forest is the primary habitat of an elephant and that is not expected to change, we analysed the influence of the barriers on its use by elephants under three scenarios listed above.

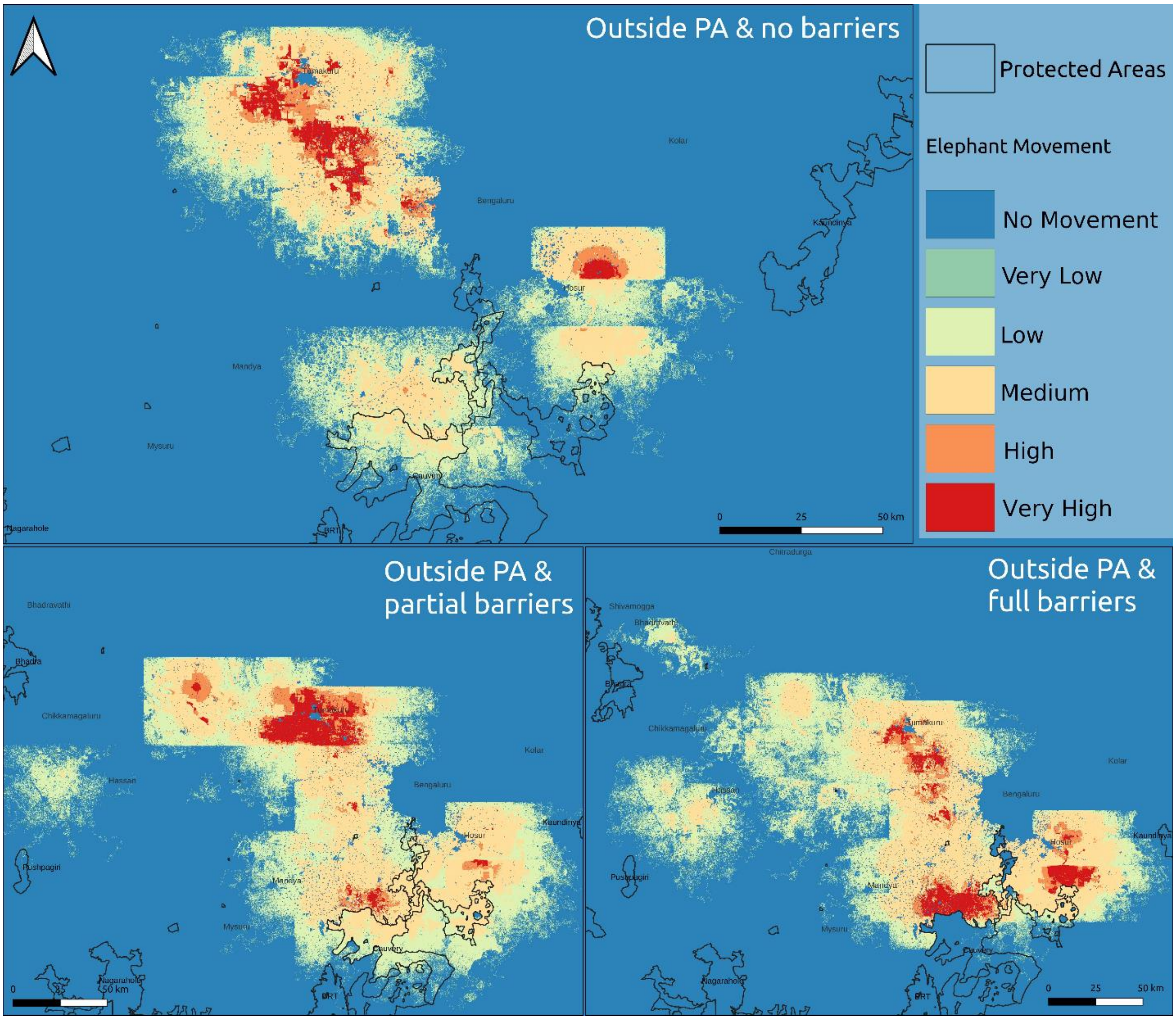


Figure 14: Movement patterns of elephants in the landscape no barrier, full barrier and partial barrier (clockwise)

a. Without barriers

There was a significant difference in the percent movement of elephants in the different LULC types (G = 68.94, p<0.01, df = 35) in the landscape. As expected, No Movement of elephants was the highest in Builtup LULC type in the landscape with 96.89% of the area being unavailable. The lowest percent of No Movement of elephants in the landscape was recorded in the Forest LULC type at 64.96%. The Plantation LULC type recorded the most movement in the two classes of High and Very High at 3.56% combined and the least (Very Low and Low categories) movement was recorded in LULC types Forest at 25.72% and Plantation at 15.81% (Table 20).

LULC	Future (%area)					
	No Movement	Very Low	Low	Medium	High	Very High
Agriculture	65.96	4.97	10.83	14.31	2.01	1.92
Barren	80.29	3.51	8.20	7.09	0.52	0.39
Builtup	**96.89**	0.28	0.69	1.53	0.22	0.39
Forest	64.96	**8.92**	**16.80**	8.27	0.36	0.69
Grassland	76.45	4.07	9.78	8.51	0.61	0.58
Plantation	67.25	**4.54**	**11.27**	13.38	**1.72**	**1.84**
Scrub	80.63	3.86	8.40	6.34	0.40	0.37
Water	81.30	3.21	6.78	7.34	0.94	0.43

Table 20: Intensity of movement across different LULC types in the landscape in percent

With no barriers along the forest boundary for movement of elephants with starting points outside the Forest LULC type, we recorded both High and Very High Movement in the Agriculture LULC type at 0.78 and 0.74 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low and Low occurrence of 0.59 and 0.60 respectively compared to all other LULC types (Table 21).

Movement	Future (% Area)							
	Agriculture	Barren	Builtup	Forest	Grassland	Plantation	Scrub	Water
No Movement	0.57	0.02	0.10	0.12	0.01	0.14	0.02	0.03
Very Low	**0.59**	0.01	0.00	0.23	0.01	0.13	0.01	0.01
Low	**0.60**	0.01	0.00	0.20	0.01	0.15	0.01	0.01
Medium	0.71	0.01	0.01	0.09	0.01	0.15	0.01	0.01
High	**0.78**	0.01	0.01	0.03	0.00	0.15	0.00	0.01
Very High	**0.74**	0.00	0.02	0.06	0.00	0.17	0.00	0.01

Table 21: Proportion of LULC types with different intensities of movement in the landscape

b. With partial barriers

There was a significant difference in the percent movement of elephants in the different LULC types (G = 55.18, p=0.01, df = 35) in the landscape. As expected, even with partial barriers No Movement of elephants was the highest in Builtup LULC type in the landscape with 95.15% of the area being unavailable. The lowest percent of No movement of elephants in the landscape was recorded in the Agriculture LULC type at 60.11%. The Agriculture LULC type recorded the most movement in the two classes of High and Very High at 5.16% combined and the least (Very Low and Low categories) movement was recorded in LULC types Forest at 19.49% and Scrub at 19.43% (Table 22).

LULC	Future (%area)					
	No Movement	Very Low	Low	Medium	High	Very High
Agriculture	60.11	3.81	14.50	16.42	**2.56**	**2.60**
Barren	72.36	3.32	13.84	9.19	0.69	0.59
Builtup	**95.15**	0.38	1.56	1.99	0.36	0.56
Forest	69.56	**4.59**	**14.90**	9.80	0.55	0.60
Grassland	70.57	3.23	13.35	11.29	0.81	0.76
Plantation	65.83	2.80	13.27	15.95	1.21	0.94
Scrub	69.99	**4.19**	**15.24**	9.31	0.68	0.59
Water	74.23	3.74	12.17	8.47	0.87	0.53

Table 22: Intensity of movement across different LULC types in the landscape in percent

With the forest boundary partially barricaded for movement of elephants with starting points outside the Forest LULC type, we recorded both High and Very High Movement in the Agriculture LULC type at 0.80 and 0.82 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Very Low and Low occurrence of 0.57 and 0.58 respectively compared to all other LULC types (Table 23).

Movement	Future (% Area)							
	Agriculture	Barren	Builtup	Forest	Grassland	Plantation	Scrub	Water
No Movement	0.51	0.01	0.06	0.23	0.01	0.13	0.02	0.02
Very Low	**0.57**	0.01	0.00	0.27	0.01	0.10	0.02	0.02
Low	**0.58**	0.01	0.01	0.23	0.01	0.13	0.02	0.02
Medium	0.65	0.01	0.01	0.15	0.01	0.15	0.01	0.01
High	**0.80**	0.01	0.01	0.07	0.00	0.09	0.01	0.01
Very High	**0.82**	0.00	0.01	0.07	0.00	0.07	0.01	0.01

Table 23: Proportion of LULC types with different intensities of movement in the landscape

c. With full barriers

There was a significant difference in the percent movement of elephants in the different LULC types (G = 69.83, p <0.01, df = 35) in the landscape. As expected, No Movement of elephants was the highest in Builtup LULC type in the landscape with 94.80% of the area being unavailable. But also No Movement in the Grassland and Scrub LULC types were high at 79.10% and 83.12% respectively. The lowest percent of No Movement of elephants in the landscape was recorded in the Plantation LULC type at 56.94%. The Plantation LULC type recorded the most movement in the two classes of High and Very High at 4.54% combined and the least movement also recorded Plantation LULC type at 20.54% (Table 24).

LULC	Future (%area)					
	No Movement	Very Low	Low	Medium	High	Very High
Agriculture	63.10	4.53	13.04	15.40	2.02	1.91
Barren	84.76	2.06	5.23	6.59	0.63	0.73
Builtup	94.80	0.45	1.51	2.26	0.34	0.63
Forest	76.56	5.04	11.26	5.71	0.45	0.98
Grassland	79.10	3.03	6.98	9.02	0.87	1.00
Plantation	56.94	**5.87**	**14.67**	17.98	**2.47**	**2.07**
Scrub	83.12	3.59	6.50	5.65	0.52	0.62
Water	70.03	4.26	11.85	11.61	1.06	1.20

Table 24: Intensity of movement across different LULC types in the landscape in percent

With the forest boundary fully barricaded for movement of elephants into their forested habitats and with starting points outside the Forest LULC type, we recorded both High and Very High Movement in the Agriculture LULC type at 0.72 and 0.68 respectively compared to all other LULC types. We also recorded less than expected movement in the Agriculture LULC type with Low and Very Low occurrence of 0.63 and 0.58 respectively (Table 25).

Movement	Future (% Area)							
	Agriculture	Barren	Builtup	Forest	Grassland	Plantation	Scrub	Water
No Movement	0.55	0.02	0.06	0.20	0.01	0.11	0.03	0.02
Very Low	0.58	0.01	0.00	0.20	0.01	0.16	0.02	0.02
Low	0.63	0.01	0.01	0.17	0.01	0.15	0.01	0.02
Medium	0.70	0.01	0.01	0.08	0.01	0.17	0.01	0.02
High	0.72	0.01	0.01	0.05	0.01	0.19	0.01	0.01
Very High	0.68	0.01	0.02	0.11	0.01	0.16	0.01	0.02

Table 25: Proportion of LULC types with different intensities of movement in the landscape

Objective 4: To generate guidelines that can act as a policy document to help urban development in regions co-habited by elephants.

The design and development of landscapes that are elephant-friendly and non-human centric is essential for promoting coexistence between humans and elephants. The strategies listed under this objective aim to promote coexistence between humans and elephants, reduce the negative impacts of human activities on elephant populations, and provide a framework for the sustainable management of elephant habitats. The conflict between humans and elephants is a growing issue in many parts of the world, particularly in areas where human-dominated landscapes and elephant habitats overlap. The conventional approach to landscape design and development often prioritizes human needs over the needs of elephants and other wildlife, which can exacerbate conflict and cause long-term harm to these species. To address this problem, the following guidelines propose a non-human centric approach to designing and developing landscapes with elephants close to human-dominated areas.

Guidelines and Policy Framework:

The following guidelines and policy framework outlines a range of strategies for designing and developing landscapes that are elephant-friendly and non-human centric. The framework is based on a combination of scientific research, best practices, and stakeholder input.

The first step in designing elephant-friendly landscapes is to ensure that elephant habitats are connected through various well-defined connectivity measures. Habitat connectivity is essential to the survival of elephant populations, as it allows them to move freely between different habitats without having to cross human settlements and other barriers. To achieve habitat connectivity, the following guidelines are recommended:

1. Protected Areas and wildlife corridors help to connect fragmented elephant habitats and reduce the likelihood of human-elephant conflict, especially since the range of the elephant is across multiple Protected Areas.

2. Degraded habitats could also be restored to provide elephants with a larger and more connected habitat range helping them spend more time within safe refuges such as forests.

3. Land-use policies should be developed to prioritize elephant habitat needs and ensure that human activities do not degrade or fragment elephant habitats. They should also consider basic but important needs of the elephants such as ranging and foraging.

4. Most linear infrastructure projects have the potential to alter or obstruct movement of elephants resulting in increased conflict with people or diminished capabilities of elephants to survive, socialise and reproduce.

5. In addition, increased availability of water to elephants in the human-use areas in large waterbodies could attract elephants to feed from the crops grown but also provide refuge for the elephants in the absence of forest patches thus increasing the length and intensity of conflicts with people.

6. Increased availability of palatable crops that are selected by elephants and are not elephant-resistant will increase the frequency of visitation by elephants and hence conflict with humans and loss of lives and livelihoods.

7. Promoting human-elephant coexistence is critical to reducing conflict and ensuring the long-term survival of both species. Education and awareness programs should be developed to help local communities understand elephant behavior, the importance of coexistence, and the benefits of conservation. These programs should be designed in collaboration with local communities and stakeholders and be tailored to their specific needs and interests.

8. Crop protection measures should be implemented to reduce the likelihood of elephants feeding on crops. This can be achieved through the use of elephant-

resistant crops, the provision of alternative food sources, and the installation of physical barriers such as community fences.

9. Alternative livelihoods should be promoted to reduce the dependence of local communities on agriculture and other activities that are vulnerable to human-elephant conflict, especially in the villages that are abutting elephant forests. This can be achieved through the promotion of ecotourism, sustainable forestry, and non-timber forest products.

10. Incorporating elephant habitat needs into land-use planning is essential. This involves the incorporation of elephant habitat needs into land-use planning, not only the designation of protected areas and wildlife corridors but also assessing the mitigating the impacts of planned development in the future.

11. Access and availability of food, water and refuge to elephants need to be planned in a way that it does not promote conflict with people but provides a safe feeding and ranging space for elephants.

12. The policy framework recommends the establishment of a comprehensive research and monitoring program to better understand the needs of elephants and the effectiveness of elephant-friendly landscape design.

13. Conducting research on elephant behavior, ecology, and habitat use. Monitoring elephant populations and habitat use are essential pre-requisites for any management plan.

14. Evaluating the effectiveness of landscape design measures: This involves the evaluation of the effectiveness of landscape design measures in promoting elephant habitat connectivity and reducing the negative impacts of human activities on elephants.

15. The policy framework recommends the engagement of a range of stakeholders in the design and development of elephant

The guidelines presented in this policy document provide a framework for designing and developing landscapes with elephants close to human-dominated areas that prioritize elephant needs and well-being. By adopting a non-human centric approach to landscape design, we can promote coexistence between humans and elephants, reduce the negative impacts of human activities that are not compatible with the elephant-use of the landscape.

Discussion

Behavioural Decision-Making in Elephants and Rules of Engagement in the Landscape

A change in the behavior of individuals is often considered the first sign of a species responding to human-induced changes in their environment (Dowding et al. 2010). As rapid alterations in the natural habitat of a nonhuman species, due to anthropogenic activities, do not necessarily provide adequate time for long-term genetic changes to facilitate the adaptations that could enable affected populations or individuals to survive (Chevin and Lande 2010), the phenotypic flexibility of individuals, rather than genetic evolution (Hendry et al. 2008), may play a crucial role in allowing such individuals to adapt and survive over the short-term.

Many studies have described the role of behavior in helping animals to adapt to increasingly anthropogenic landscapes (Sih et al. 2011; Wong and Candolin 2015). Several studies, especially on avian fauna, have specifically shown that birds have not only managed to survive but also thrive in such habitats, primarily driven by their phenotypic plasticity (Sol et al. 2013). For a few species, like northern cardinal *Cardinalis cardinalis*, for example, behavioral choices, such as selection of suboptimal or high-risk habitats, have, in contrast, proven to be maladaptive, as manifest in lowered survival and reproductive fitness (Schlaepfer et al. 2002; Rodewald et al. 2011; Robertson et al. 2013; Barrett et al. 2018).

Our study region, given its proximity to major towns and cities, such as Bangalore, also known as the Silicon Valley of India, has undergone major landuse changes, especially between the years 1973 and 1992, with rapid increase in agriculture and a concomitant burgeoning of the urban sprawl, human densities, and major and minor roads, all at the expense of forest cover and natural elephant habitats (Kumar 1994; Adhikari et al. 2015). Reforestation, in the form of monoculture of tree species such as *Acacia auriculiformis* and *Eucalyptus* spp., has ensued in the years between 1992 and 2007, following deforestation, mainly outside Protected Areas (PAs; Adhikari et al. 2015). Such reforestation has resulted in a concomitant reduction in the cultivation of subsistence crops bordering PAs, which may have increased tree cover for elephants, but may not have helped them nutritionally. More recently, quarrying activity in hillocks adjoining the PAs has resulted in the further loss of natural habitats and caused increased disturbance to elephants. These rapid and large-scale changes in landuse, within a life time of an individual, provide unique settings in which elephants may need to adapt in order to persist in these highly dynamic and potentially risky production landscapes, principally mediated through their behavioral plasticity.

Our previous studies in the study area have shown that ecological and anthropogenic factors have varied positive and negative influences on the distribution of and habitat use by individual elephants (Srinivasaiah et al. 2012; Srinivasaiah et al. in press). While individuals, in general, avoided high human-activity areas, females tended to range in patches that showed the least variation in forage availability and relatively low human activity (Srinivasaiah et al. 2012). Although the latter did visit human-use areas such as cropfields during the crop-growing season, extensive foraging on crops by male elephants, especially for long periods in highly fragmented areas, had been observed in specific sites within the study landscape since 2005 (Srinivasaiah et al. 2017). Male elephants, in contrast, preferentially used patches with relatively high resource availability, such as cropfields and plantations, even though these areas may have had relatively high levels of human activity (Sukumar and Gadgil 1988a; Chiyo et al. 2012; Srinivasaiah et al. 2012). It is noteworthy that Kumar (1994), in his study on elephants in the Hosur Forest Division, an integral part of our study area, more than two decades ago, categorically mentions that all crop raids by male elephants were by solitary males alone. He does not mention the occurrence of these large all-male groups, suggesting that this type of association of elephants in the landscape may be of a rather recent origin. In this study, we show, for the first time, that male elephants reside in high-risk areas in these all-male groups almost throughout the year.

In our study area, we have been observing males associating in large bull groups almost exclusively in human-modified production landscapes, with croplands forming the major landuse but interspersed by highly fragmented and isolated forest patches, for over five years now (Srinivasaiah et al. 2019). In contrast, smaller bull groups have been mainly seen in areas close to well-connected and large forest patches; such associations primarily consist of groups of Sexually Mature but Socially Immature (SM) males, of Sexually and Socially

Mature (SSM) bulls in musth associating with their natal herds or of SM and SSM males while raiding crops (Sukumar 1992). SM males often occur close to natal herds but at a distance; they could be either avoiding musth bulls actively or may have been chased away by a musth bull. These, we suggest, may be important social triggers for dispersal in the life of a young individual male elephant. It should be noted here that the relatively high intraspecific variability in social organization displayed by SM males and their increased propensity to associate with other males of the same or older age classes is reminiscent of what has been observed in African elephant populations as well (Evans and Harris 2008).

We have rarely observed SSM males when in musth, to associate with all-male groups; they either tended to move solitarily in search of females in estrus or associate with mixed-sex groups, possibly to increase their chances of mating. In fact, the statistically significantly higher percentage of photo-captures of individually identified SSM males that we obtained during our study could potentially be attributed to this roving nature of these males. Support for this proposition was obtained when we excluded the sightings of bulls in musth from our analysis; the proportion of SSM males, individually identified and sighted were not statistically different from that obtained through camera trap captures.

In Asian elephant society, it is well established that male elephants in musth and with larger body size have higher mating opportunities and hence, likely to have, higher reproductive success as well (Chelliah and Sukumar 2015). We found that male elephants in our study population, especially the SM males that used production landscapes, had significantly better Body Condition than those inhabiting areas with relatively more deciduous forest. Foraging on crops may, therefore, be an effective strategy for these young dispersing males to increase their body size relatively rapidly. For SSM males, in turn, this strategy may serve to maintain good Body Condition and enable them to stay in musth for longer periods of time (Srinivasaiah et al. in prep). Foraging on crops and ranging in human-use areas, however, have their own associated costs (Barrett et al. 2018). Conflict-related injuries and mortality were recorded in the study area with eight SM and two SSM males succumbing to such injuries or captures in 15 months within the study period.

The mortality of elephants, due to conflict with local human communities and the various resultant interventions, is an enormous conservation challenge (Goswami et al. 2014), especially for males in an already female-biased population (Sukumar 1991). A disproportionately large number of tusked male elephants have historically been poached for their ivory in south and southeast Asia, often rendering these populations distinctly female-biased (Sukumar 2003); in one southern India population, for example, an adult male to female sex ratio of about 1:100 was reported two decades ago (Sukumar et al. 1998). The lack of mature adult males in such populations may lead to reduced population growth rates (Arivazhagan and Sukumar 2005) and may have behavioral implications for younger individuals who then grow up in an environment without role models to learn from (Slotow et al. 2000). This may often result in “unruly” or aggressive behaviors, displayed by such adolescent males towards both conspecific and non-conspecific individuals in the area (Slotow et al. 2000). Under these circumstances, losing even more males through captures, accidents or retaliatory killing could have a further negative effect on populations, in a manner like to that of poaching. Elephant movement patterns may also change, resulting in additional conflict in novel areas, while the absence of mature bulls may lead to uninformed decisions by young and inexperienced males, resulting in enhanced human-elephant conflict, with a rise in both human and elephant deaths.

Given such environmental adversity, associating in all-male groups may be an effective, even essential, strategy for young male elephants to reduce mortality risks and learn behaviors that are adaptive and could potentially aid their survival and successful reproduction. Individually conducted trial-and-error methods of exploring new habitats or resources may occasionally be maladaptive and too costly, especially if elephants choose high-risk landscapes of those with low productivity (Silk 2007). Hence, the association of young and naïve individuals with experienced males living in high-risk areas, mediated by their phenotypic social flexibility at the dispersal stage and leading to long-term benefits of improved body condition and eventually higher mating success, may have emerged as a behavioral necessity for elephants in high-risk, high-resource landscapes, especially in recent years (Stamps 2001; Ims and Hjermann 2001; Doligez et al. 2002). Our hypothesis seems to be supported by the observation that, in the study area, a majority of the all-male groups comprised mainly SM males in the dispersal stage, accompanying at least one SSM male.

The elephant population in the study region may also be highly physiologically and nutritionally stressed, primarily due to anthropogenic activities such as deforestation, livestock grazing, quarrying and increasing human densities in the natural elephant habitat (Kumar 1994; Adhikari et al. 2015). More recently, studies on the stress physiology of free-ranging Asian elephants have found that individuals in poorer Body Condition and when actively disturbed by interactions with humans exhibit increased chronic and acute stress respectively (Pokharel et al. 2017; Vijayakrishnan et al. 2018) although a superior-quality diet from agricultural areas may significantly reduce physiological stress (Pokharel, Seshagiri and Sukumar, submitted). While acute stress could potentially also be offset by social buffering (Vijayakrishnan et al. 2018) or by resting, chronic stress may have long-term negative impacts on individual elephants, including lowered fertility or changes in physiology, affecting processes such as musth. Male elephants in the study region that occurred in patches of dry deciduous, scrub or woodland forests, often infested with the weed *Lantana*, appeared to be nutritionally stressed, as evidenced by their poor Body Condition. In addition, such areas were usually under high human use, thus creating conditions for acute stress as well. The male elephants in our study population could also, therefore, be associating with conspecific individuals, in this case, other males, to reduce acute stress through social buffering, while offsetting their potential nutritional stress by feeding on better-quality forage, such as crops. The older bulls, on the other hand, maybe benefiting by distributing the risks that they face among the other members of the all-male groups and also by controlling musth in younger bulls within these associations, thus reducing potential competition and increasing their own fitness. These functional aspects of the newly emergent, stable all-male groups and the associated costs and benefits experienced by individuals of different age categories within these associations, however, require further investigations and analyses.

While the variation in group size in mixed-sex groups of elephants have been well established in the study area (Srinivasaiah et al. in press), our observations on intraspecific variation in social organization of male elephants and the emergence of large, stable all-male groups in response to extrinsic environmental factors is rather novel in the Asian elephant literature. We have thus now shown that male Asian elephants display great social flexibility by associating in different group types, depending on their age and sexual maturity, especially at the dispersal stage (see also Wiens 2001). Elephants, like several other mammalian species, thus appear to cope with increasing anthropogenic pressures in their changing environments by displaying significant phenotypic plasticity (reviewed in Schradin 2013 and Wong and Candolin 2015). Such phenotypic plasticity, primarily shown by young male elephants in the dispersal stage and manifest through the formation of all-male groups and adoption of novel foraging strategies, leading to improved body condition, may constitute an example of how even large mammals such as elephants can develop behavioral strategies to increase their survival and reproductive fitness (Wong and Candolin 2015; Silk 2017). On a more applied note, it is imperative that future attention focuses on the management and conservation of young dispersing males of this highly endangered species, as the often-flexible decisions made by these individuals appear to directly influence the utilization of production landscapes by the species, thus bringing them into direct conflict with local agricultural communities.

Present and Future Movement Patterns of Elephants and its Implications to Human and Elephant Conflict

With an expected overall increase in the area under Agriculture, Builtup and Barren LULC types in the future, the movement of elephants inside the Forest LULC type reduced with the arrival of barriers both in the present and in the future scenarios, although not significantly. The results also show a marginal decrease in the No Movement area of the elephants which could mean that the elephants will start moving more uniformly within the forested habitats in the future. The No Movement area of elephants in Agriculture LULC type reduced with the progression of the fence along the forest boundary and there is an observed concomitant reduction in the High and Very High areas of movement in the Agriculture LULC type. These were only trends observed and no statistically significant results were obtained. No significant results were obtained with regards to the movement patterns of elephants in the Forest or Agriculture LULC types at present when the starting points of the elephants were outside the Forest either.

A significant difference was observed, however, in the movement pattern of elephants across the LULC types between the present and the future scenarios with starting points inside the forest ($G = 19.91$, $df = 7$, $p < 0.01$) and in the absence of any barriers to movement. This difference may largely be due to the reduction in the No Movement areas across the LULC types in the future as compared to the present, thus indicating an increase in elephant ranging area in the landscape and probably with it the conflict too. A similar pattern was observed in the presence of a full barrier too with a significant result.

A significant reduction in the movement intensities of elephants across the LULC types was observed (points starting from inside the Forest LULC) between the present and future ($G = 33.32$, $df = 7$, $p < 0.01$) with elephants showing higher levels of reduced and impeded movement in the Water and Agriculture LULC types in the absence of barriers to movement in the future.

A significant difference in the movement pattern of elephants across the LULC types (points inside the forest) between no barrier and full barrier ($G = 22.79$, $df = 7$, $p < 0.01$) was observed with higher levels of reduced or impeded movement of elephants in the area under Forest LULC and lowered levels of reduced or impeded movement of elephants in the area under Agriculture LULC type under the full barrier scenario. This would mean that the elephant movement within the Forest is reduced or impeded with the fencing of the forest boundary, as there may be elephants outside the forest that may not be able to utilize their entire range area. An overall reduction in the intensities of elephant movement across LULC types is observed including that of Agriculture in the presence of a full barrier at present. A similar pattern is observed in the future scenario with the staring points being inside the forest ($G = 20.10$, $df = 7$, $p < 0.01$).

The two important takeaways from the movement analysis for the landscape include:

1. It is expected that the overall intensity of movement of elephants across the LULC types will be reduced in the future although not its spread.
2. The construction of the fence along the forest boundary although can help in the mitigation of human and elephant conflict, could also impede the utilization of the forest habitat by many elephants that use habitats both within and outside the forested habitats.

Specific Guidelines and Policy Framework for the Landscape:

The following guidelines and policy framework outlines a range of strategies for designing and developing landscapes that are elephant-friendly and non-human centric. The framework is based on a combination of scientific research, best practices, and stakeholder input.

1. Protected Areas and wildlife corridors in the region especially the ones connecting Bannerghatta National Park, Cauvery Wildlife Sanctuary and the North Cauvery Wildlife Sanctuary should help to connect fragmented elephant habitats and reduce the likelihood of human-elephant conflict, especially since the range of the elephant is across multiple Protected Areas.

2. Degraded habitats, especially with the larger Wildlife Sanctuaries could also be restored to provide elephants with a larger and more connected habitat range helping them spend more time within safe refuges such as forests.

3. Land-use policies should be developed to prioritize elephant habitat needs and ensure that human activities do not degrade or fragment elephant habitats. They should also consider basic but important needs of the elephants such as ranging and foraging outside the Protected Areas.

4. Most linear infrastructure projects have the potential to alter or obstruct movement of elephants resulting in increased conflict with people or diminished capabilities of elephants to survive, socialise and reproduce. This will be the case in this landscape if fences and other linear infrastructure is built with upto about 150 elephants ranging outside the Protected Areas.

5. Increased availability of palatable crops that are selected by elephants and are not elephant-resistant will increase the frequency of visitation by elephants and hence conflict with humans and loss of lives and livelihoods, as the expected area under Agriculture is going to increase in the future.

6. Crop protection measures should be implemented to reduce the likelihood of elephants feeding on crops. This can be achieved through the use of elephant-resistant crops, the provision of alternative food sources, and the installation of physical barriers such as community fences, which is being carried out in the landscape.

7. Incorporating elephant habitat needs into land-use planning is essential. This involves the incorporation of elephant habitat needs into land-use planning, not only the designation of protected areas and wildlife corridors but also assessing the mitigating the impacts of planned development in the future, which has been accomplished through this project.

8. The policy framework recommends the establishment of a comprehensive research and monitoring program to better understand the needs of elephants and the effectiveness of elephant-friendly landscape design, which is currently being conducted.

9. Conducting research on elephant behavior, ecology, and habitat use. Monitoring elephant populations and habitat use are essential pre-requisites for any management plan, which are also being conducted.

10. Evaluating the effectiveness of landscape design measures: This involves the evaluation of the effectiveness of landscape design measures in promoting elephant habitat connectivity and reducing the negative impacts of human activities on elephants, which is being conducted periodically.

11. The policy framework recommends the engagement of a range of stakeholders in the design and development of the landscape under question. This would be the next step of the project where we plan to reach out to the policy and decision makers of the government.

References

1. Gaynor, K. M., Branco, P. S., Long, R. A., Gonçalves, D. D., Granli, P. K., & Poole, J. H. (2018). Effects of human settlement and roads on diel activity patterns of elephants (Loxodonta africana). *African Journal of Ecology*, *56*(4), 872-881.

2. FRAGSTATS v4: Spatial pattern analysis program for categorical and continuous maps. University of Massachusetts, Amherst, MA, USA

3. Hothorn T, Zeileis A (2015). "partykit: A Modular Toolkit for Recursive Partytioning in R." *Journal of Machine Learning Research*, **16**, 3905-3909. https://jmlr.org/papers/v16/hothorn15a.html.

4. Hothorn T, Zeileis A (2015). "partykit: A Modular Toolkit for Recursive Partytioning in R." Journal of Machine Learning Research, 16, 3905-3909. https://jmlr.org/papers/v16/hothorn15a.html.

5. Laurance, W. F., Goosem, M., & Laurance, S. G. (2009). Impacts of roads and linear clearings on tropical forests. *Trends in ecology & evolution*, *24*(12), 659-669.

6. RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.

7. Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL

8. Adhikari S, Southworth J, Nagendra H (2015). Understanding forest loss and recovery: a spatiotemporal analysis of land change in and around Bannerghatta National Park, India. J Land Use Sci. 10:402–424.

9. Arivazhagan C and Sukumar R (2005). Comparative demography of Asian elephant populations (Elephas maximus) in southern India. Technical Report No. 106. Indian Institute of Science, Bangalore, India: Centre for Ecological Sciences.

10. Barrett LP, Stanton L, Benson-Amram S (2018). The cognition of 'nuisance' species. Anim Behav. doi:10.1016/j.anbehav.2018.05.005.

11. Baskaran N, Venkatesh P (2009). Human Elephant Conflict in Hosur Forest Division, Tamilnadu, India. An Interim Report to Hosur Forest Division, Tamil Nadu Forest Department. Bengaluru, India: Asian Nature Conservation Foundation. p. 1–30.

12. Bridges AS, Noss AJ (2011). Behaviour and Activity Patterns. In. O'Connell AF, Nichols JD, Karanth KU, editors. Camera Traps in Animal Ecology: Methods and Analyses. New York, USA: Springer New York. p. 57–69.

13. Caravaggi A, Banks PB, Burton AC, Finlay CMV, Haswell PM, Hayward MW, Rowcliffe MJ, Wood MD (2017). A review of camera trapping for conservation behaviour research. Remote Sens Ecol Conserv. 3:109–122.

14. Caro TM, Bateson P (1986). Organization and ontogeny of alternative tactics. Anim Behav. 34:1483–1499.

15. Census (2011). District Census Handbook Karnataka and Tamilnadu. Ministry of Home Affairs. Government of India, New Delhi: Office of the Registrar General and Census Commissioner. http://www.censusindia.gov.in/2011census/dchb/DCHB.html

16. Chelliah K, Sukumar R (2013). The role of tusks, musth and body size in male-male competition among Asian elephants, Elephas maximus. Anim Behav. 86:1207–1214.

17. Chelliah K, Sukumar R (2015). Interplay of male traits, male mating strategies and female mate choice in the Asian elephant, Elephas maximus. Behaviour. 152:1113–1144.

18. Chevin LM, Lande R (2010). When do adaptive plasticity and genetic evolution prevent extinction of a density-regulated population? Evolution. 64:1143–1150.

19. Chiyo PI, Cochrane EP (2005). Population structure and behaviour of crop-raiding elephants in Kibale National Park, Uganda. Afr J Ecol. 43:233–241.

20. Chiyo PI, Lee PC, Moss CJ, Archie E a., Hollister-Smith J a., Alberts SC (2011). No risk, no gain: effects of crop raiding and genetic diversity on body size in male elephants. Behav Ecol. 22:552–558.

21. Chiyo PI, Moss CJ, Alberts SC (2012). The influence of life history milestones and association networks on crop-raiding behavior in male african elephants. PLoS One. 7:e31382

22. Chiyo PI, Wilson JW, Archie EA, Lee PC, Moss CJ, Alberts SC (2014). The influence of forage, protected areas, and mating prospects on grouping patterns of male elephants. Behav Ecol. 25:1494–1504.

23. Crook JH (1970). Social organization and the environment: Aspects of contemporary social ethology. Anim Behav. 18:197–209.

24. Doligez B, Danchin E, Clobert J (2002). Public information and breeding habitat selection in a wild bird population. Science. 297:1168–1170.

25. Dowding C V, Harris S, Poulton S, Baker PJ (2010). Nocturnal ranging behaviour of urban hedgehogs, Erinaceus europaeus, in relation to risk and reward. Anim Behav. 80:13–21.

26. Evans KE, Harris S (2008). Adolescence in male African elephants, Loxodonta africana, and the importance of sociality. Anim Behav. 76:779–787.

27. Gale UT (1974). Burmese Timber Elephant. Rangoon, Burma: Trade Corporation.

28. Ghosal R, Ganswindt A, Seshagiri PB, Sukumar R (2013). Endocrine correlates of musth in free-ranging Asian elephants (Elephas maximus) determined by non-invasive faecal steroid hormone metabolite measurements. PLoS One. 8:4–8.

29. Goswami VR, Vasudev D, Oli MK (2014). The importance of conflict-induced mortality for conservation planning in areas of human-elephant co-occurrence. Biol Conserv. 176:191–198.

30. Hendry AP, Farrugia TJ, Kinnison MT (2008). Human influences on rates of phenotypic change in wild animal populations. Mol Ecol. 17:20–29.

31. Hothorn T, Hornik K, Zeileis A (2006). Unbiased recursive partitioning: A conditional inference framework. J Comput Graph Stat. 15:651–674.

32. Ims RA, Hjermann DO (2001). Condition-dependent dispersal. In: Clobert J, Danchin E, Dhondt AA, Nichols JD, editors. Dispersal. Oxford, UK: Oxford University Press. p. 203–216.

33. Jainudeen MR, McKay GM, Eisenberg JF (1972). Observations on musth in the domesticated asiatic elephant (Elephas maximus). Mammalia. 36:247–261.

34. Joshi R, Singh R, Pushola R, Negi MS (2009). Reproductive behaviour of wild Asian elephants Elephas maximus in the Rajaji National Park, north-west India. Researcher. 1:77–84.

35. Kappeler PM, Barrett L, Blumstein DT, Clutton-Brock TH (2013). Constraints and flexibility in mammalian social behaviour: introduction and synthesis. Philos Trans R Soc B. 368 1618: 20120337.

36. Kumar SR (1994). Ecology of Asian Elephants, their Habitats and Interactions with People in Hosur and Dharmapuri Forest Division, Tamil Nadu, South Indian. Ph.D. thesis. Bharathidasan University, Trichirapally, Tamil Nadu, India.

37. LaGro J (1991). Assessing patch shape in landscape mosaics. Photogramm Eng Remote Sensing. 57:285–293.

38. McDonald JH (2014). Handbook of Biological Statistics (3rd ed.). Baltimore, Maryland, USA: Sparky House Publishing.

39. McGarigal K, Cushman SA, Ene E (2015). FRAGSTATS v4. 2. FRAGSTATS Help.

40. National Remote Sensing Agency (2006). Manual of national land use land cover mapping using multi-temporal satellite data. Hyderabad, India: Department of Space.

41. Pokharel SS, Seshagiri PB, Sukumar R (2017). Assessment of season-dependent body condition scores in relation to faecal glucocorticoid metabolites in free-ranging Asian Elephants. Conserv Physiol. 5:191–206.

42. Poole JH (1987). Rutting behaviour in African elephants: the phenomenon of musth. Behaviour. 102:283–316.

43. Poole JH (1989). Mate guarding, reproductive success and female choice in African elephants. Anim Behav. 37:842–849.

44. Project Elephant (2017). Synchronized elephant population estimation India 2017. New Delhi, India: Ministry of Environment, Forest and Climate Change, Government of India.

45. QGIS Development Team (2015). QGIS Geographic Information System. Open Source Geospatial Found Proj. doi:http://www.qgis.org/.

46. R core team (2017). R: A language and environment for statistical computing. R Found Stat Comput Vienna, Austria. doi:http://www.R-project.org/.

47. Ranjeewa ADG, Tharanga YJS, Sandanayake GHNA, Perera BV, Fernando P (2015). Camera traps unveil enigmatic crop raiders in Udawalawe, Sri Lanka. Gajah. 42:7–14.

48. Rasmussen HB, Ganswindt A, Douglas-Hamilton I, Vollrath F (2008). Endocrine and behavioral changes in male African elephants: Linking hormone changes to sexual state and reproductive tactics. Horm Behav. 54:539–548.

49. Rasmussen HB, Okello JB a., Wittemyer G, Siegismund HR, Arctander P, Vollrath F, Douglas-Hamilton I (2007). Age- and tactic-related paternity success in male African elephants. Behav Ecol. 19:9–15.

50. Robertson BA, Rehage JS, Sih A (2013). Ecological novelty and the emergence of evolutionary traps. Trends Ecol Evol. 28:552–560.

51. Rodewald AD, Shustack DP, Jones TM (2011). Dynamic selective environments and evolutionary traps in human-dominated landscapes. Ecology. 92:1781–1788.

52. Schlaepfer MA, Runge MC, Sherman PW (2002). Ecological and evolutionary traps. Trends Ecol Evol. 17:474–480.

53. Schradin C (2013). Intraspecific variation in social organization by genetic variation, developmental plasticity, social flexibility or entirely extrinsic factors. Philos Trans R Soc B Biol Sci. 368 1618:20120346.

54. Shoshani J, Eisenberg JF (1982). *Elephas maximus*. Mamm Species. 182:1–8.

55. Sih A, Ferrari MCO, Harris DJ (2011). Evolution and behavioural responses to human-induced rapid environmental change. Evol Appl. 4:367–387.

56. Silk JB (2007). The adaptive value of sociality in mammalian groups. Philos Trans R Soc B Biol Sci. 362:539–559.

57. de Silva S, Wittemyer G (2012). A comparison of social organization in Asian Elephants and African savannah elephants. Int J Primatol. 33:1125–1141.

58. Sinha A (2005). Not in their genes: Phenotypic flexibility, behavioural traditions and cultural evolution in wild bonnet macaques. In: Journal of Biosciences. 30:51–64.

59. Slotow R, van Dyk G, Poole J, Page B, Klocke A (2000). Older bull elephants control young males. Nature. 408:425–426.

60. Smit J, Pozo RA, Cusack JJ, Nowak K, Jones T (2017). Using camera traps to study the age–sex structure and behaviour of crop-using elephants *Loxodonta africana* in Udzungwa Mountains National Park, Tanzania (Forthcoming/Available Online). Oryx. 1–9. doi:10.1017/S0030605317000345

61. Sol D, Lapiedra O, González-Lagos C (2013). Behavioural adjustments for a life in the city. Anim Behav. 85:1101–1112.

62. Srinivasaiah NM, Anand VD, Vaidyanathan S, Sinha A (2012). Usual populations, unusual individuals: Insights into the behavior and management of Asian elephants in fragmented landscapes. PLoS One. 7.e42571.

63. Srinivasaiah NM, Vaidyanathan S, Sukumar R and Sinha A (2016). Landscape-level management of the Asian elephant through population and individual level monitoring in human-dominated landscapes of the Eastern Ghats: A report to the Karnataka Forest Department. Bengaluru, India: National Institute of Advanced Studies.

64. Srinivasaiah NM, Vaidyanathan S, Sinha A and Sukumar R (2017). Landscape-level management of the Asian elephant through population and individual level monitoring in human-dominated landscapes of the Eastern Ghats: A report to the Tamil Nadu Forest Department. Bengaluru, India: Asian Nature Conservation Foundation.

65. Srinivasaiah NM, Vaidyanathan S and Sinha A. *Elephas flexibilis*: Behavioural plasticity in Asian elephants in a human-dominated landscape in southern India. In: Kumar A and Vasudev D, editors. Ecological and Anthropological Studies in India: The Science of Conserving Wildlife. New Delhi, India: Springer India. In press.

66. Srinivasaiah NM, Vaidyanathan S, Sukumar R and Sinha A. Inter- and intra-group dynamics of all-male groups in Asian elephants in a human-modified landscape. In prep.

67. Stamps JA (2001). Habitat selection by dispersers: Integrating proximate and ultimate approaches. In: Clobert J, Danchin E, Dhondt AA, Nichols JD, editors. Dispersal. Oxford, UK: Oxford University Press. p. 230–242.

68. Sukumar R, Gadgil M (1988a). Male-female differences in foraging on crops by Asian elephants. Anim Behav. 36:1233–1235.

69. Sukumar R, Joshi N V., Krishnamurthy V (1988b). Growth in the Asian elephant. Proc Anim Sci. 97:561–571.

70. Sukumar R (1991). The management of large mammals in relation to male strategies and conflict with people. Biol Conserv. 55:93–102.

71. Sukumar R (1992). The Asian Elephant: Ecology and Management. Cambridge, UK: Cambridge University Press.

72. Sukumar R (1995). Elephant raiders and rogues. Natural History. 104:52–61

73. Sukumar R, Ramakrishnan U, Santosh JA (1998). Impact of poaching on an Asian elephant population in Periyar, southern India: A model of demography and tusk harvest. Anim Conserv. 1:281–291.

74. Sukumar R (2003). The Living Elephants: Evolutionary Ecology, Behavior and Conservation. New York, USA: Oxford University Press.

75. Vijayakrishnan S, Kumar MA, Umapathy G, Kumar V, Sinha A (2018). Physiological stress responses in wild Asian elephants Elephas maximus in a human-dominated landscape in the Western Ghats, southern India. Gen Comp Endocrinol. doi:10.1016/j.ygcen.2018.05.009.

76. Wiens JA (2001). The landscape context of dispersal. In: Clobert J, Danchin E, Dhondt AA, Nichols JD, editors. Dispersal. Oxford, UK: Oxford University Press. p. 96–109.

77. Wong BBM, Candolin U (2015). Behavioral responses to changing environments. Behav Ecol. 26:665–673.