Effects of landscape change on mammals in Eastern Ghats, India

Final report

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Overall aim of project: To study effect of landscape change on mammals in Eastern Ghats, India

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Section 1

Background:

The northern Eastern Ghats landscape of southern India has extensive tropical forests harboring several endangered species of flora and fauna. The region acts as an important forest corridor between the Western Ghats and northeast Indian biodiversity hotspots, with floristic and faunal charecteristics shared between both. No studies on mammal diversity patterns have been previously conducted in this ecologically important region. Large scale infrastructure projects and development pressures have resulted in extensive landscape change and forest degradation over the past few decades in the region, with no information on how mammal species are impacted. The aim of our project was to analyse landscape change and habitat degradation in the region over the past three decades and to study its impact on terrestrial, forest dwelling, non-volant mammals in the Papikonda NP and its buffers.

Summary:

The objectives of our project were to study the land cover change in the northern Eastern Ghats over the past 3 decades, to estimate diversity patterns and relative abundance of mammals in Papikonda National Park (NP) and adjacent contiguous forests, and understand stakeholders' views on land cover change. We quantified land cover change in Papikonda NP and adjacent contiguous forests (buffers) through time series analysis of change in forest cover between 1991 and 2014 using satellite imagery and Geographic Information System/Remote Sensing software. We stratified Papikonda NP and its contiguous buffer along elevation/habitat strata divided into equal-area sampling grids of 2 km^2. We conducted intensive field surveys in 58 grids (= 62 km^2) stratified across three different habitat types/elevation zones, through 271 camera trap stations and sign surveys. We analysed the results through an occupancy approach and obtained presence and relative abundance estimates of mammals. We recorded a total of 25 mammal species through over 400 total camera trap captures (336 in sampling period), and combining this with sign survey and a comprehensive literature review resulted in the enumeration of a total of 58 species of mammals from 47 genera, belonging to 24 families.

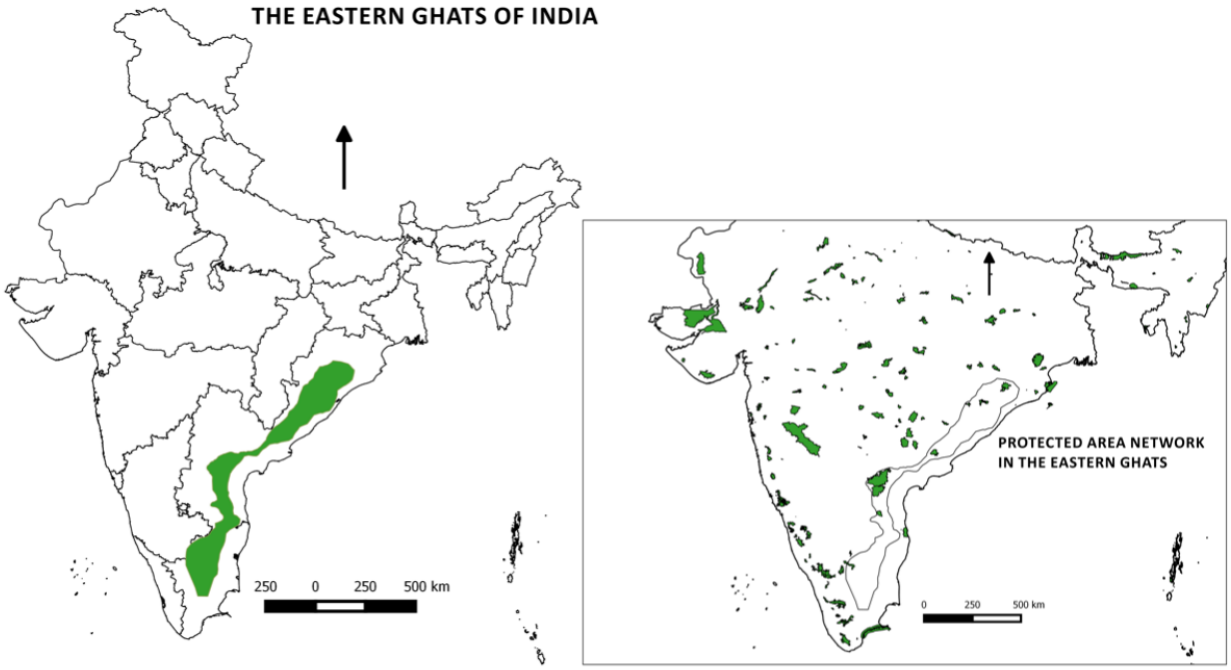
There was a high diversity of carnivores with 15 species, followed by chiropterans (bats) with 13 species and rodents with 12. We collected data on habitat and disturbance factors in the camera trap plots. We correlated mammal diversity across the habitats with land cover change, habitat factors and disturbance inidcators using landscape ecological tools. We found that the majority of mammal species in Papikonda NP prefer well vegetated and dense forest patches away from human dominated areas, with mammal diversity being closely associated with closed canopy moist forests in mid and high elevations. Species richness and diversity patterns differed significantly between habitats. However there was no significant difference in occupancy levels between habitats or preferential habitat selection. The biggest threat to mammals in Papikonda NP is forest conversion, especially in accessible dry deciduous forests in low elevation due to intrusion of roads, higher density of villages and inadequate patrolling. We also conducted community meetings and detailed interviews with 138 respondents from 33 indigenous communities across Papikonda NP to understand their observations of land cover change, its causes, affects on their livelihoods and on the forest. We also interviewed other stakeholders such as government officials and local NGO representatives. We studied the effect of villages and roads in driving forest conversion. We used this information along with our land cover and mammal diversity analysis to develop a conservation plan for Papikonda NP. The plan is being disseminated to all stakeholders concerned with the conservation of the landscape.

Our CLP project revealed the first records of the Smooth Coated Otter *Lutrogale perspicillata, Prionailurus* cats (Aditya and Ganesh 2016) and camera trap records of the Indian porcupine Hystrix *indica* from the region (Aditya and Ganesh 2015). Our CLP project also resulted in the assessment and declaration of Papikonda NP and the northern Eastern Ghats landscape as an Important Bird Area (IBA) after an intensive bird survey we conducted in 2015, and the launch of a newsletter (*Manyam*) that is also being widely disseminated across various stakeholders in the landscape, and two peer reviewed articles, for the first time, from Papikonda NP.

Introduction:

The Eastern Ghats hills, stretching 1,600 km from north to south along the India's eastern coast and spread over 1,50,000 km^2 contain expansive stretches of tropical deciduous forests and natural vegetation (Figure 1). The landscape is a treasure trove of biodiversity. However, rapid land cover changes have been occurring in recent decades through deforestation, agricultural encroachments and infrastructure development in the form of dams, roads and mines, resulting in forest conversion and degradation. Several studies have looked at land cover change and the impact of habitat modification on various taxa in other natural forested landscapes of India (Raman and Mudappa 2003; Umapathy and Kumar 2000; Kumar et al. 2002, Sridhar et al. 2008; Jha et al. 2000). In contrast, few studies have assessed land cover change and habitat degradation patterns in the Eastern Ghats, and their impacts on biodiversity (Nagulu et al. 2001, Srinivasulu and Nagulu 2002, Srinivasulu 2001).

Figure 1: The Eastern Ghats of India



A comparison of the difference in NDVI (Normalized Difference Vegetation Index - a remotely derived indicator of vegetation density observed on satellite imagery) pixel values of LANDSAT 5 images (LANDSAT/LT5_L1T_32DAY_NDVI) for the entire Eastern Ghats between 1991 to 2011 on Google Earth Engine reveals large areas of forest which have experienced a significant drop

in NDVI in the two decades, indicating deforestation and forest loss throughout the Eastern Ghats (Figure 2). This forest conversion is especially pronounced in the northern Eastern Ghats in Odisha and Andhra Pradesh states, which incidentally also contain extensive moist deciduous and semi-evergreen forests that harbour high biodiversity and several endangered species (Rao et al. 1999, Javed et al. 2007, Seetharamaraju et al. 2009), is resulting in rapid habitat fragmentation and change in forest structure (Reddy et al. 2013). These rapid forest cover changes are also degrading forests and affecting biodiversity. However, the spatial dynamics of land cover change and forest conversion in the northern Eastern Ghats has not been adequately quantified (Reddy et al. 2013, Reddy et al. 2011). This information is important to identify areas which have undergone forest degradation for restoration. Also, there is no baseline data on the mammalian community to understand how landscape change affects them (Aditya and Ganesh, 2016). Enumerating community diversity is necessary for estimating animal population density, detecting changes and planning future conservation action (Yoccoz et al. 2001, Robinson et al. 1992). There is hence an urgent need to document the mammalian diversity of the region to understand how mammals are responding to forest changes.

Figure 2: Forest conversion indicated by drop in NDVI values (red areas) of LANDSAT 5 composite images over large parts of Eastern Ghats (Google Earth Engine image) between 1991 and 2011

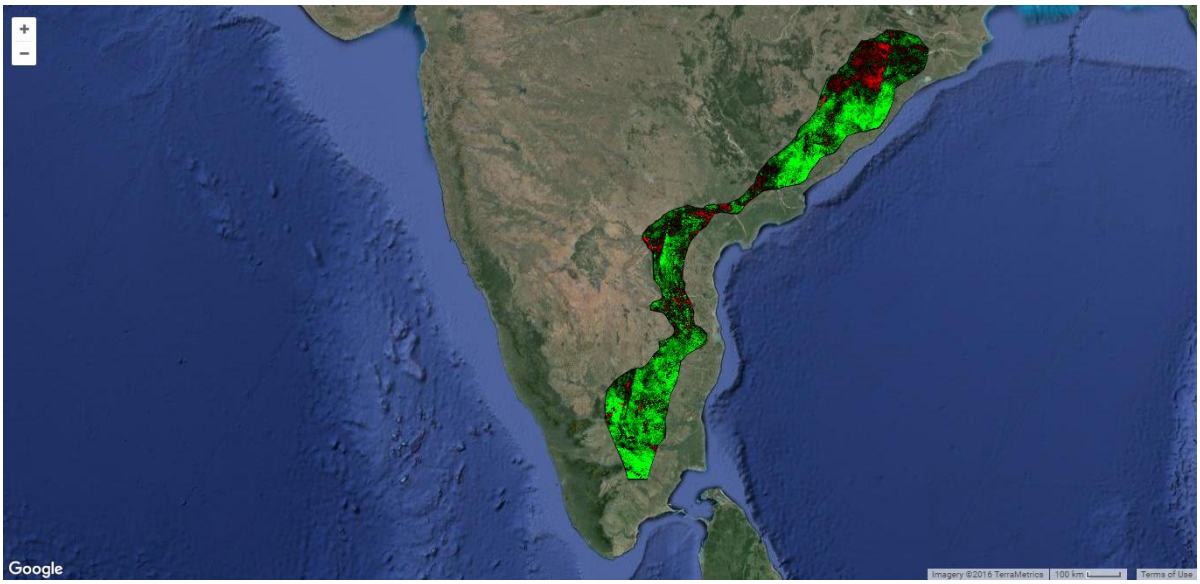


Figure 2: Forest conversion indicated by drop in NDVI values (red areas) of LANDSAT 5 composite images over large parts of Eastern Ghats (Google Earth Engine image) image between 1999 and 2014

Papikonda National Park (NP) (Figure 3), located in the northern Eastern Ghats of Andhra Pradesh between 18°29'31"N - 19°10'53" N Latitude and 79°32' 28" - 83°14'0" E Longitude spread over 1,012 km^2, is an important protected area in the landscape, where it is the only NP. Straddling the Godavari River, an important biogeographic divide, Papikonda NP contains habitats typical of the northern Eastern Ghats. The topography is hilly with steep slopes and elevation ranging from 20 to 850 masl. The dominant forest type is southern tropical mixed moist deciduous, with some semi-evergreen patches in the higher elevation and dry deciduous forests in lower areas. Few studies on mammals have been published from Papikonda NP or the northern Eastern Ghats previously.

Papikonda NP has experienced varying levels of protection in the past, beginning with core areas being notified as Reserve Forests (RFs) under the Andhra Pradesh Forest Act, 1967 Later it was declared as a Wildlife Sanctuary in 1978, one of the first in the state, covering 590.68 km^2, and then upgraded as a National Park in 2008 (Papikonda NP Management Plan, 2008). The long history of protection in Papikonda NP beginning from a cluster of Reserve Forests in 1967 to culminating in a National Park in 2008, has afforded the region better protection than other parts of the northern Eastern Ghats. Consequently, Papikonda NP contains some of the last contiguous forests in the landscape supporting viable populations of mammals, and provides an opportunity to analyze land cover changes and their affects on mammals. Large sections of Papikonda NP are also currently facing the threat of submergence from the Indira Sagar Multi Purpose (Polavaram) project which is being constructed across the Godavari River immediately adjacent to the NP, for hydropower generation and irrigation in the downstream plains to the east and south of the Ghats. Dam building and the resulting fragmentation of riverine ecosystems, and its effects on native riverine diversity has been documented worldwide (Magilligan and Nislow 2005, Kingsford 2000, Power et al. 1996, Collier et al. 1996, Briggs 1992) especially in places where baseline information exists. This project also provides baseline

information on mammal diversity patterns in the submergence areas of Papikonda NP that would be useful for conservation actions.

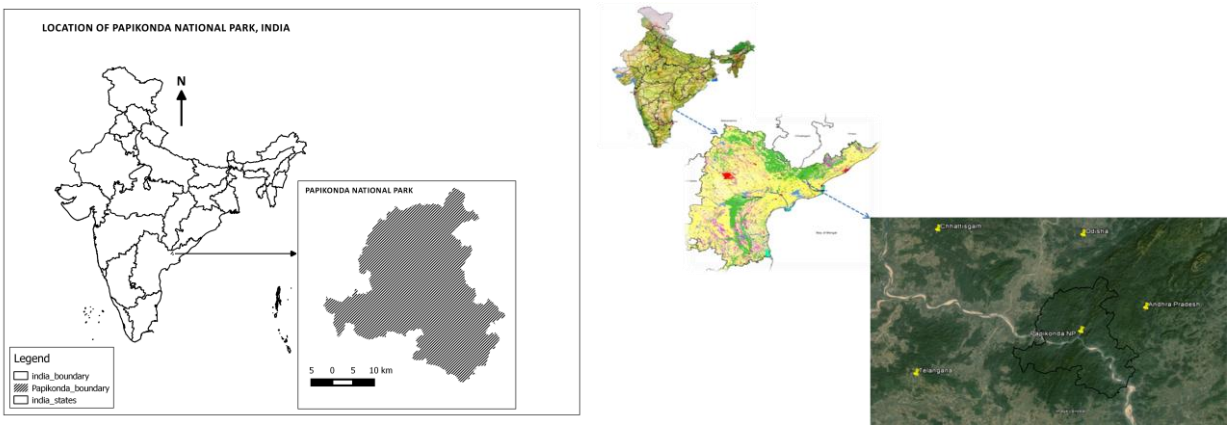


Figure 3: The location of Papikonda National Park in Andhra Pradesh, India

The overall goal of our project is to contribute to better informed management and conservation of the northern Eastern Ghats by analysing land cover changes and their impact on terrestrial non-volant mammals in and around Papikonda NP. We use primary field data on mammal diversity and distribution patterns across Papikonda NP and its buffer forests obtained through camera trapping, and GIS based land cover change analysis, combined with stakekholder observations to study how land cover changes are affecting mammals and to document a conservation acton plan for Papikonda NP and its contiguous forests. The plan will be disseminated to all stakeholders involved and will provide an additional tool for the conservation and sustainble management of the region.

Key partners and collaborators:

Ashoka Trust for Research in Ecology and the Environment: ATREE was the host institution that was involved in managing finances, supplying equipment from the Bangalore head office to field, providing spaces for team meetings, providing lab services from the Eco-informatics for GIS and Remote Sensing work and change analysis. The project advisor and faculty advisory members who were involved in supervising the project were also based at ATREE.

Agriculture and Social Development Society: Mr. Gandhi Babu, Director of ASDS was very helpful in providing resources, local contacts and accommodation for the researchers near Rekhapalli, during the implementation of the project and for sharing his insights.

ASHA, Chinturu: Mr. Subhani, Director of ASHA was instrumental in providing useful local insights, transportation and local support for the researchers during the project.

Field assistants and local communities: Some members of the local indigenous communities were involved as field assistants in the project namely Mr. Prasad, Mr. Babu Rao, Mr. Rattaiah, Mr. Rama Krishna and Mr. Kunda Rajulu. They were also involved in facilitating community meetings, interviews and focus group discussions.

Andhra Pradesh Forest Department: Andhra Pradesh Forest Department provided the research permission which made this project possible. They also provided the boundary maps of Papikonda NP through which we were able to perform our land cover change analysis.

Project members:

List the project members, giving brief details of their relevant qualifications, experience, current occupation and employer, and their main roles in the project. Where relevant give an indication of the age group.

1. Vikram Aditya – Project Leader – Currently a PhD student in conservation science at the ATREE, completed M.Sc in Zoology in 2006 from Kuvempu University, India and B.Sc in Geology and Geography in 2004 from Osmania University, India. Vikram previously worked as an intern with the UNEP Regional Resource Center for Asia Pacific in, Thailand in 2005, and as a Research Associate at the World Wide Fund for Nature – India from April 2006 to 2010. He was a National Geographic Young Explorer Grantee in 2010. Vikram was the project leader in this project. He is currently aged 32.

2. Mr. Giridhar Malla – Project Member – Currently a PhD student and Research Fellow at the Wildlife Institute of India, Dehradun, India and formerly employed with ATREE. Giridhar acquired a Masters degree in Environmental Science from Andhra University, Visakhapatnam, Andhra Pradesh, India in 2006. He previously worked with ATREE as a Research Associate in

2013 and with the Environment Protection Training and Research Institute (EPTRI) Hyderabad as a Research Associate. Helped in designing and implementing the project. Aged 32.

3. Mr. Krishna Mohan Rao Adiraju - Project Member – Currently invoved in social development work in Hyderabad, acquired Masters degree in Social Work (MSW) from Osmania University, Hyderabad, Andhra Pradesh in 2006. Previously worked as Lecturer in Social Work at Roda Mistry College of Social Work, Hyderabad, India and also worked at Human Action for Rural Empowerment (HARD), and NGO working on social issues in Andhra Pradesh as well as in the Eastern Ghats area. Krishna was involved with the project in designing and advising in community interview component. Currently aged 32.

4. Dr. T. Ganesh – Project Advisor – Currently working as Senior Fellow at the Ashoka Trust for Research in Ecology and the Environment. Involved with providing technical and methodological advise and cooridnation of the project, also acted as the liason between the host institution and the project team.

Section 2

Aim and objectives:

The overall goal of the project is to study the effects of landscape change and habitat degradation on terrestrial, forest dwelling, non-volant mammals in the northern Eastern Ghats of India, and use this information to develop a conservation plan that would contribute to more effective conservation of the region.

Objective 1: Estimate diversity and relative abundances of mammals in the Papikonda National Park and adjacent non PA reserve forest areas of the northern Eastern Ghats

Objective 2: Estimate the landscape change in the northern Eastern Ghats region over the last 3 decades and identify present connectivity between large forest patches in Papikonda National Park and adjacent non-PA areas for mammals

Objective 3: Collect stakeholders' views on landscape change and its effect on mammals and use this information to develop a conservation action plan for the region

Methodology:

Objective 1 : Papikonda NP and a 5 km contiguous forest buffer was gridded into 2 km^2 grids using LANDSAT 8 ETM+ images from 2014 from USGS (Table 1), cross-referenced and stratified according to habitats/elevation identified using classified vegetation maps (Buckland et al. 2005). Grids were selected randomly within each stratum, corresponding to their proportion of total area. Camera trap plots were setup at suitable locations in 58 grids selected using stratified random sampling, to record mammal presence (Ahumada et al. 2011, O'Connell et al. 2011, Tobler et al. 2008, Karanth and Nichols 1998). 5 camera traps were placed in each grid, fixed to trees betweeen 50 to 100 cm, with minimum distance of 300 m seperating each camera for 3 nights (72 hours =19,512 camera trap hours), after which they were rotated to another grid (Figure 4 and 5). We also conducted sign surveys in selected grids for secondary evidence using pugmarks, hoofprints, scat, pellets, scrape and rake. We collected data on habitat variables and disturbance indicators (cattle/human presence, tree cutting, fire, distance to nearest village, evidence of fire and grazing, NTFP collection, human and domestic animal presence) at camera trap stations through 5 m^2 circular plots (Table 2). We also extracted the landscape variable data from GIS analysis, Global Forest Watch and Google Earth Engine, and bioclimatic/environmental data from the WorldClim database (Table 2). Species occupancy was estimated through an occupancy modeling framework to arrive at presence estimates of all species using the software PRESENCE (MacKenzie et al 2002; Royle and Nichols 2003; Karanth and Nichols 1998). Mapping of landscape and habitat types was done on GIS. Data on mammal presence, richness and captures across plots was overlaid on GIS layers of landscape features to analyse mammal occupancy and variation in diversity patterns between habitats. Multivariate statistical analysis was performed on R to identify habitat, disturbance factors landscape and environmental variables significant for mammal occurrence. Species diversity patterns across camera trap plots and habitat types across the landscape were highlighted and assessed using diversity estimators (Shannon H, Simpson 1-D, Evenness, and Fisher's Alpha), diversity models and rank abundance curves. Baseline information was also collected on village locations, administrative boundaries, flora and fauna, and recent mammal census estimates and an exhaustive literature review was conducted to arrive at a comphrensive enumeration of

mammals in Papikonda NP. A conservation action plan was prepared based on the findings of the project, for which Forest Department officials, NGOs and community organizations working in the area were consulted and interviewed.

Objective 2 : Satellite imagery of the study area (of 30 m resolution) was collected from LANDSAT 4-5 TM and 7 ETM+ from 1988 to 2014 and from the Global Forest Watch, to study change in forest cover between 1991 (1988-1990 images unusable) and 2014 using IDRISI Selva, Quantum GIS and Google Earth Engine softwares. A Digital Elevation Model (CGIAR SRTM) was procured for elevation information. We also procured topographical maps (1:50000 cm RF) from the Survey of India (65G8, 65G9, 65G10, 65G11) of the northern Eastern Ghats, and the Papikonda NP boundary from the Andhra Pradesh Forest Department. All images were geo-referenced to the WGS 84 datum on UTM (Zone 44N) and EPSG: 4326 (latitude, longitude) Coordinate Reference Systems. We mapped all human settlements and roads in and around Papikonda NP, different habitat types in Papikonda NP and contiguous forests using classified satellite imagery (Andhra Pradesh State Forest Report 2011, MODIS International Geosphere Biosphere Programme, MERIS GlobCover 2009 global land cover imagery). We calculated NDVI (Normalised Difference Vegetation Index) of the images from 1991-2014 for analysing change (Figure 9). NDVI is an indicator of vegetation greenness showing reflectance on a scale from -1 to +1. Forests have high NDVI values above +0.5. NDVI is defined as:

$$\text{NDVI} = (\text{NEAR INFRARED} - \text{RED}) / (\text{NEAR INFRARED} + \text{RED})$$

We analysed land cover change through time series analysis and change detection between 1991 and 2014 using NDVI values (Figure 13-15) for supervised landscape classification (Jha et al. 2000; Vaidyanathan et al 2010, Sudhakar et al. 2011) by assigning pixels with NDVI>0.6 to forest and pixels with NDVI<0.6 to non-forest classes (Figure 10-12). We further classified land cover over Papikonda NP and its buffer using supervised classification using Google Earth Engine using global land cover classified imagery (Figure 16 to 18) and looked at change between 1991 and 2014. To understand effect of villages and roads on forest conversion, we identified all settlements in Papikonda NP and its buffer, and obtained their population data,

tribal group and % of tribal population from the 2011 Census of India[3]. We included 33 villages (18 inside NP, 15 outside) and 20 roads identified around Papikonda NP. We overlaid the villages and roads layer on change images and examined effect of villages and roads on forest change in a 1000 m buffer around them, using elevation and slope as covariates. We studied the effect of village population, location inside or outside the PA, predominant tribal group, distance to forest edge and access to villages (road or river) on forest conversion between 1991 and 2014. We compared our land cover change analysis with the Global Forest Watch global forest loss analysis available from the Global Forest Watch (Hansen et al. 2013) (Figure 19).

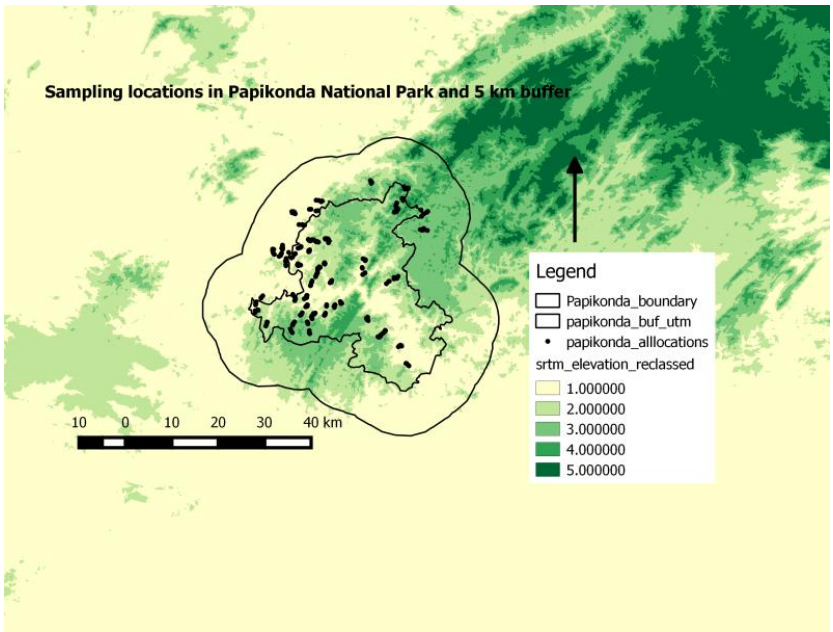
Objective 3 : We identified 212 villages in and around Papikonda NP and selected 33 villages distributed across the region representing different indigenous groups, located within and outside the NP and at varying distances from the forest for in-depth consultations. In the selected villages, we conducted community interactions and detailed semi-structured interviews with 138 randomly selected respondents, belonging to 3 indigenous groups (Konda Reddy, Koya and Nayakpod) and 2 other communities (Vaada Balija, OC). The discussion questions ranged from observations of forest changes over the past 3 decades, perceived causes for changes, dependence on forests, presence of tree species and changes, sightings of animals, hunting practises, livestock depradation, livelihood occupations, knowledge of the presence of the NP, presence of plantations in the forest around the village, etc. We also identified other stakeholders including the Forest Department staff of Papikonda NP and NGO workers and conducted detailed interviews with them.

Outputs and Results:

Objective 1: Through our field surveys on mammal presence and distribution patterns across the landscape, we recorded presence of 25 species, including the Tiger and first records of Leopard Cat and the Rusty Spotted Cat for Papikonda NP, through more than 400 camera trap captures. In addition, we also combined our camera trap and sign survey data with a literature review to arrive at the first comprehensive checklist of mammals in Papikonda NP (Table 3). A total of 58 species from 47 genera belonging to 24 families were enumerated, including 25

species captured for the first time on camera trap images. There was a high diversity of carnivores with 15 species, followed by chiropterans with 13 species and rodents with 12.

Figure 4 and 4a: Sampling locations across different elevation zones representing different habitat types in Papikonda NP and its buffer



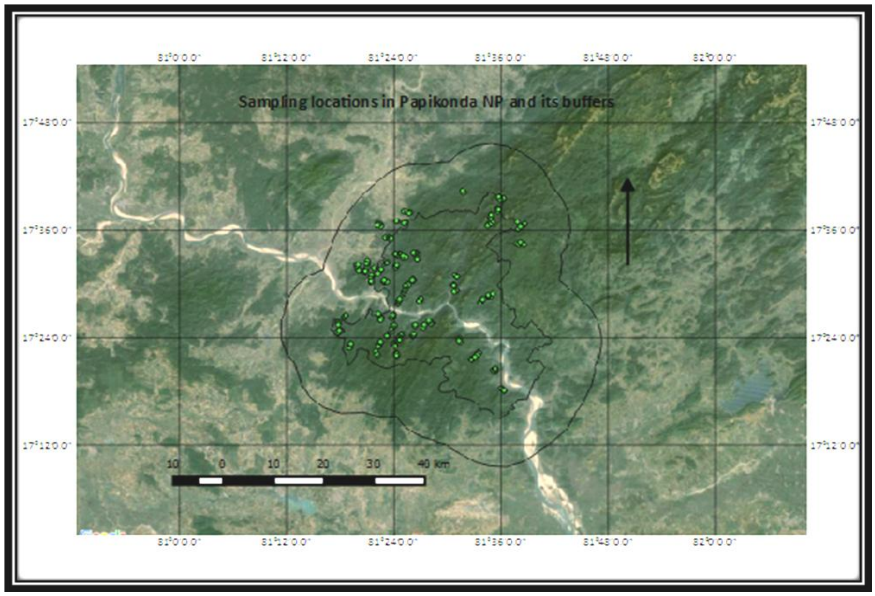


Figure 5: Installing camera traps and gathering habitat variable data from camera trap plots

Diversity patterns and relative abundance of species:

A total of 61.8 km^2 of forest area in Papikonda NP was intensively surveyed, with 36.4 km^2 in low elevation, 16 km^2 in mid and 6.4 km^2 in high and 3 km^2 in the top elevation zone. We recorded a total of 15 species in the high and mid elevation and 10 species in the low elevation from camera trap data (Figure 6 and 6a). Barking Deer had highest captures (125) followed by Rhesus Macaque (47) and Wild Boar (45) (Figure 7 and 8). A total of 20 species were captured within the sampling period (and 25 overall), including rare species such as the Leopard Cat, Pangolin and Mouse Deer. There were 202 captures in low elevation, 56 in mid and 78 in the third with a mean capture rate of 1.28, 0.88 and 1.73 respectively indicating that highest capture frequency was in high elevation moist forests (Figure 8) (Table 4). There were no captures in the survey period in the top elevation. Comparing guild wise and habitat wise species accumulation, we found that carnivores were the dominant guild across all habitat

types (303) followed by herbivores (226) and omnivores (76) (Figure 8) (Table 5). The Tiger *Panthera tigris* Wild Dog *Cuon alpinus* and Indian Pangolin *Manis crassicaudata* were listed as Endangered (EN) by the IUCN. In addition, six species (Leopard *Panthera pardus*, Sloth bear *Melursus ursinus*, Smooth coated otter *Lutrogale perspicillata*, Sambar *Rusa unicolor*, Gaur *Bos gaurus* and Four horned antelope *Tetraceros quadricornis*) were categorized as Vulnerable (VU) and one, the Rusty spotted cat *Prionailurus rubiginosus* as Near Threatened (NT). Overall, 10 species were listed as threatened. The order Carnivora had the highest number of threatened species with 7 of the 17 being Endangered, Vulnerable or Near Threatened, whereas orders Rodentia, Chiroptera, Scandentia and Insectivora had no species listed as Threatened. We published the first records of the *Prionailurus* cats (Aditya and Ganesh 2016) and the first camera trap records of the Indian porcupine (Aditya and Ganesh 2015) from Papikonda NP.

We studied the community diversity patterns and niche occupancy by plotting rank abundance distributions of mammal diversity using Poisson and Gaussian error distributions for abundance data throughout, and habitat wise (Whittaker 1965, Tokeshi 1990). We found that the Poisson Lognormal abundance distribution best explained the mammal community diversity in the Papikonda NP (AIC = 87.42, BIC = 89.41), indicating dominance by a few species (Barking Deer, Rhesus Macaque, Wild Boar) with abundance of other species dropping sharply thereafter. Mammal diversity in the low elevation habitat was best explained by Geometric abundance model (dominance pre-emption model, Takeshi 1990), indicating high dominance by Barking Deer (AIC =70.06, BIC = 70.77). The mid elevation forests had the most evenly distributed community, with the Broken Stick model best fitting data (AIC = 47.88, BIC = 47.88), as well as the top elevation forests, where the Zipf Mandelbrot model best explained the community diversity (AIC = 39.31, BIC = 39.91) (Figure 9). The highest Alpha diversity (Shannon-Weiner H and Simpson D) values (H = 2.455, D = 0.899) were recorded in mid elevation (Table 4). A two sample T-test of differences in the Alpha diversity of habitats showed that Shannon-Weiner H (Low and mid elevation T = -4.357, df = 128.77, p = <0.00001; Mid and high elevation T = 5.144, df = 132.21, p = <0.0000) and Simpson 1-D diversity of the three habitats was significantly

different (Low and mid elevation T = 4.6168, df = 232.01, p = <0.0000; Mid and high elevation T = -4.0609, df = 90.018, p = 0.0001).

The habitat compositional similarity (Beta Diversity) of species between the three habitats using the Bray Curtis dissimilarity coefficient showed differences in mammal community between habitats (Table 6). Low values indicate high similarity and high values indicate low similarity. There was high similarity between low and mid elevation forests with a value of 32.55, low and high elevation forests were more dissimilar with a value of 51.42, whereas mid and higher elevation forests share a moderate degree of similarity at a value of 41.79.

Bray Curtis habitat dissimilarity table			
Habitats	**Low**	**Mid**	**High**
Low	0	32.55814	51.42857
Mid	32.55814	0	41.79104
High	51.42857	41.79104	0

Table 6: A Bray Curtis dissimilarity table of dissimilarity values (Beta diversity) between habitats

We performed a compositional analysis of habitat selection to compare habitat availabillity vs. habitat use by analysing proportion of area surveyed in each habitat with capture abundance to test if certain habitats were being significantly selected by species over others (Garshelis 2000, Thomas and Taylor 2006). We observed that high elevation moist deciduous and semi-evergreen forests were being preferentially selected by mammals. We performed a Pearson's chi-squared test (Table 7) of habitat use vs. availability. There was no statistically significant selection (Table 4, Pearson's X squared = 3.8215, df = 3, p = 0.2). However the presence of threatened mammalian species such as the Gaur *Bos gaurus*, Smooth coated otter *Lutrogale perspicillata* and Sloth bear *Melursus ursinus* in the highest and lowest elevation zones highlights their unique habitat requirements. The high species richness in the low elevation dry deciduous forests indicates their importance in sustaining viable mammal populations.

Habitat availability vs. habitat use of species in Papikonda NP				
Habitat type	**Total area (sq km)**	**Prop. of total area**	**Tot. abundance**	**Tot. proportion**
Low	36.4	58.3	202	60.11904762
Mid	16	23.6	56	16.66666667
High	6.4	16.6	78	23.21428571
Highest	3	1.5	0	0
Total	61.8	100	336	100

Table 7: Compositional analysis of habitat availability and use by mammal species

We compared habitat variables across habitat types and found significant differences betweeen habitats (Figure 8a). We tested the effect of 41 habitat, disturbance and landscape level variables (including bioclimatic variables) to assess their relative importance for mammal presence and richness using a Generalised Linear Model with Logistic and Poisson distributions. We found that NDVI in 2014 and 1991, EVI (Enhanced Vegetation Index) in 2014 and herbaceous stem density were most important in determining mammal occupancy (Table 6 and 6a), whereas NDVI in 1991 and 2014 and herbaceous stem density were most important in determining mammal richness (Table 7 and 7a). This suggests that mammals prefer dense forests with high vegetation cover, away from human dominated areas. We also performed a multivariate canonical correlation between variables and species captures to analyse effect of these variables on diversity patterns. The correlation was highly significant (Pallai's trace F statistic = <0.000008). The correlation table between variables and captures shows that NDVI, vegetation density, canopy cover and distance to NP edge are amongst the most significant predictors of mammal presence (Figure 9a and 9b). Otter and Pangolin occupy the most unique microhabitats resulting in significant niche seperation from other species, whereas large herbivores such as the Sambar and Gaur occupy similar niches. However, most species were observed to have a similar requirement of well forested habitat (Figure 10).

Objective 2: The mean LANDSAT NDVI of Papikonda NP in 1991 was 0.776, this decreased to 0.628 in 2014 representing a decrease by 0.148. For the buffer, mean NDVI in 1991 was 0.717 which decreased to 0.561 by 2014, indicating significantly faster rates of forest loss in the buffer

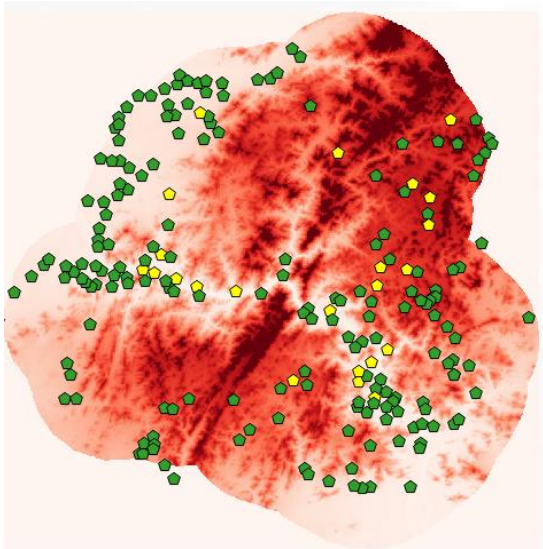
compared to NP (Figure 11-13). In terms of area, there was 856.35 km^2 of forest in Papikonda NP in 1991, which had reduced to 754.21 km^2 in 2014 indicating that 102.14 km^2 of forest was converted to non-forest representing 11.9% of forest cover decrease in Papikonda NP (Table 8, Figure 11-13). Computed separately for the buffer, there was 1499.23 km^2 of forest in the buffer in 1991, which had reduced to 1009 by 2014 (Figure 5b). This represented a reduction of 490 km^2 of forest in the buffer alone, representing a 32.68% decrease in forest cover in the buffer (Figure 13, Table 8). Combining results for the NP and buffer, total forest area in 1991 was 2448.08 km^2. This reduced to 1798.7 km^2 in 2014, representing a loss of 649.38 km^2 (Figure 11) or 26.5% conversion of forest to non-forest. This indicates a significant reduction in overall forest area in the northern Eastern Ghats. A noticeable change in forest cover over Papikonda NP and its buffer was also seen using the GlobCover and IGBP global classified imagery (Figure 16 to 18). We compared our results with the forest loss over Papikonda NP using the GFW platform between 2000 -2014 (Figure 19 and 19b) and there was a high degree of spatial correlation of areas which experienced forest conversion.

We studied impact of villages and roads on forest conversion and found that there was a significant decrease in forest cover between 1991 and 2014 in the 1000 m buffer around villages and roads indicating that they were major drivers of forest conversion in Papikonda (Figure 20). The decrease was strongly correlated with log of elevation, with lower elevation forests around villages experiencing greater change than higher elevation areas (Figure 21). Village population and their location inside or outside the NP were also significant drivers in determining forest conversion (Figure 22 and 23). Villages with higher population and those located inside the NP experienced a greater decrease in forest NDVI. We also found that forests around villages only connected by the river experienced a greater reduction (Figure 24).

Objective 3: A total of 33 villages were selected from the 212 human settlements scattered around Papikonda NP and its buffers (Figure 27). The selected villages had a total population of 12,460 individuals, with indigenous groups constituting 10,101 or 81% of the population. A total of 95 interviews were conducted inside the NP and 43 in the buffer villages, with the largest group (81) of respondents being Konda Reddis followed by Koyas (35). The chief occupations of

communities were farming and farm labour, *podu* cultivation (a traditional system of swidden or shifting cultivation practiced along forested hills by tribal communities in the Eastern Ghats), collection of forest produce, work in Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS, a public employment guarantee scheme), toddy tapping etc. A majority of respondents (93) reported that forest cover had noticeably decreased around their villages. 60 respondents said that forest had decreased significantly and 33 said that forest had decreased marginally. 32 respondents said that there was no noticeable change in forests. However, 13 individuals argued that forest cover had increased in the same time period (Figure 12). Averaging responses per village, 25 villages said that forest extent had decreased around their habitation, 7 reported no noticeable change and 1 reported growth. We plotted the village responses on forest change over the NDVI analysis of forest change between 1991 and 2014, and found that there was a high degree of conformity between village responses and NDVI change of forests, i.e., villages which had mentioned that forest cover had reduced noticeably had experienced high forest conversion (Figure 25). The principal drivers for forest cover change in Papikonda NP observed by communities were *podu* shifting cultivation, logging, over extraction of forest produce, forest based plantations by Forest Department, bamboo cutting, population growth, timber smuggling by outsiders, natural reasons (storms, floods and drought), cultivation, forest fires and livestock grazing in the forest (Figure 26).

Figure 27: Human habitations in Papikonda NP and its 5 km buffer, yellow indicating habitations selected for in depth interviews and meetings



Communication of results:

1. We have so far published **three peer reviewed articles** in journals and one popular article based on the CLP project thus far. Two more papers from the project are under submission.

2. We have started a newsletter on the Eastern Ghats, *Manyam,* focusing particularly on conservation challenges in the northern Eastern Ghats that we have identified during our CLP project in the region. *Manyam* has completed two issues and is being disseminated to a wide network of individuals, researchers groups working in the Eastern Ghats.

3. We have presented the project findings in three national and international conferences (Student Conference on Conservation Science, Bangalore 2015, National Conference on the Conservation of the Eastern Ghats, 2016 and Manipal University Research Colloquium, 2016).

4. We are also communicating the results of the project for the EPTRI (Environment Protection Training and Research Institute), the government designated center for the Eastern Ghats.

5. We have created a conservation action plan from the findings of the project where we identified mammal distribution and diversity patterns in the landscape, habitats that have undergone highest degree of conversion, threats to habitats, and patches supporting high mammal diversity for conservation. The findings have been reported to the Forest Department. They will also be disseminated in a meeting in Maredumilli, Papikonda NP on August 27th and at a workshop at the Ashoka Trust for Research in Ecology and the Environment, Bangalore.

Monitoring and evaluation:

The field component of the project was implemented in 2014 and 2015 and data analysis, reporting and dissemination were done in 2016. Thereafter, we are continuing to work in the region through bird and butterfly surveys conducted in 2014 and 2015 and planned in December 2016. Evaluation will be carried out continuously over the next two years through field visits, interactions with the Forest Department to assess if the recommendations of the reports are being considered, as well as discussions with NGOs and local communities to elicit their feedback. We will also be undertaking another land cover change assessment next year using similar methods to analyze if the rate of forest conversion in and around Papikonda NP has reduced perceptibly, particularly in areas which we have identified as conservation priority

zones. This will indicate if the overall aim of the project has been successful in the longer term. In addition, we are planning a long term monitoring project for birds and bats using acoustic monitoring equipment using song meters in the Papikonda NP and will be partly using the same grids and plots where we will have opportunities for monitoring habitat use by mammals. We will also be using the *Manyam* Eastern Ghats newsletter to elicit the views of local communities on the project and to assess its success.

Achievements and Impacts:

1. We conducted the first comprehensive mammal surveys in the northern Eastern Ghats across 271 individual camera trap stations covering 61.8 km^2 in Papikonda NP and a range of habitats.
2. We recorded the presence of 25 mammal species through field surveys, including the Tiger and **first records** of Leopard Cat and the Rusty Spotted Cat, as well as the Smooth coated otter through more than 400 total camera trap captures.
3. We conducted the first enumeratation of the mammal diversity of the Papikonda National Park combining our field surveys with stakeholder interviews and a literature review.
4. We produced **three peer reviewed articles** on the **first records** of the Leopard Cat and the Rusty Spotted Cat, the first photographic evidence of the Indian Porcupine from Papikonda NP, the impacts of hunting on biodviersrity in the Papikonda NP and the northern Eastern Ghats (Aditya and Ganesh 2015, Aditya and Ganesh 2016, Ganesh et al. 2015). We have also published two general articles.
5. Three more peer reviewed articles, on the extent and nature of land cover change in Papikonda NP, the dynamics of shifting cultivation in the landscape and a checklist of the butterfly diversity of the region are under submission.
6. We interviewed 138 respondents from 3 different tribal groups belonging to 33 villages spread across the study area to study some of the drivers of forest conversion in the Eastern Ghats. The respondents identified tree felling, *podu* shifting cultivation, forest plantations and population pressure as the main drivers of forest conversion in the region.
7. We identified extent of forest conversion between 1991-2014 inside Papikonda NP and its 5 km buffer. We identified areas where conversion was occurring rapidly, in low-lying areas

below 200 m, along roads and villages, and along the Godavari. Our GIS land cover analysis showed that pressure from villages and roads combined with topography and protection levels (NP and outside) had significant impact in forest conversion in and around Papikonda NP.

8. Our project demonstrated that although the National Park was not successful in arresting deforestation, although rate of conversion was significantly lower in the NP than outside.

9. The findings of our project were reported to the Forest Department as well as the local field level Departmental staff who took cognizance of our findings.

10. The preliminary findings of the project were also presented in various fora, including the Manipal University Research Symposium and National Conference on the Conservation of the Eastern Ghats in April, 2016; and the Students Conference on Conservation Science at Bangalore, India in September 2015.

11. We received the **Second prize** for our project at the Manipal University Research Symposium and the **Third prize** for our presentation at the National Conference on the Conservation of the Eastern Ghats

12. During the course of our project, we condcuted a one week long intensive bird survey across Papikonda NP and the northern Eastern Ghats in December 2014. From this we were able to provide a site assessment of Papikonda NP resulting in its upcoming declaration as an IBA. The survey involved local students and NGOs and was widely covered by local media.

13. We organized a two week long field course on ecology and conservation science in Papikonda National park in July 2015. The course involved 15 students from the northern Eastern Ghats and other parts of India.

14. We have started a newsletter on the Eastern Ghats titled *Manyam* highlighting the biodiversity, ecology and conservation challenges of the landscape, which is widely disseminated to individuals, NGOs, researchers and others interested in the landscape. Manyam is available online through the following link (http://www.atree.org/policy_role/ar_nl)

Capacity Development and Leadership capabilities:

The team members acquired a great deal of new skills and capacities during the course of the CLP project. We were able to attend a number of seminars and courses in 2014 and 2015 on

various aspects related to ecology, implementing conservation projects, GIS and landscape ecological tools. In particular, we attended a workshop held by Google Inc. in Bangalore, India on using Google Earth Engine which enabled us to compute and analyze trends in land cover changes at a much faster rate. We also attended a course on using Open Data Kit, a web application for gathering field data which we attempted in the field. We also attended several seminars on study design and field survey methods for mammals during the Conservation Science course that ATREE organized in Papikonda National Park in 2015. We were also able to put these into all of these into practice during the project.

Section 3

Conclusion:

The project identified the extent, nature and spatial patterns in landscape change in the Papikonda NP and its contiguous forest buffers in the northern Eastern Ghats over the past three decades, and the drivers of the change using GIS landscape analysis, intensive field surveys during 2014 and 2015 and meetings and discussions with local communities, NGOS and government departments about their observations and experiences of these changes. We find that there has been a significant degree of forest conversion in the landscape over the past three decades. We conclude that while the causes and nature of forest change in the northern Eastern Ghats remains highly complicated with multiple factors, the primary drivers of change appear to be *podu* cultivation, encroachments for agriculture, tree felling, over-extraction of forest produce, forest fires and infrastructure development mainly through roads, although forest loss in the low elevation will be exacerbated manifold over the next decade through the ongoing construction of the Polavaram project across the Godavari in the buffer of Papikonda NP. Villages and roads have had a high influence on forest conversion, especially in accessible lower elevation forests. Papikonda NP experienced a much lower rate of forest conversion than its buffers, demonstrating its pivotal role in minimizing forest conversion in the landscape, despite the fact that it was ineffective in altogether preventing deforestation.

Our project inventoried the mammal community assemblage in the landscape for the first time, and produced the first established records of three mammal species for the landscape. We studied the diversity patterns of the mammalian community across the Papikonda NP, their habitat relationships, their preference of particular habitats and which habitat factors were important in determining their presence. The moist deciduous and semi evergreen habitats are most critical in maintaining a high diversity and large population of mammals in Papikonda NP. However, the lowest elevation dry forests which are under threat of submergence from the Polavaram dam which presently face extirpation also support high mammal diversity. Our project also led to the site assessment and declaration of the Papikonda NP as an IBA (likely to be announced shortly in the next IBA assessment). The findings of the project and the status of the IBA are being highlighted in the conservation action plan.

Problems encountered and lessons learnt:

The project was a success overall due to support from ATREE and CLP. Our land cover analysis was supported by ATREE's Geomatics Lab using the latest GIS techniques and was finished earliest, despite some problems acquiring imagery, license registration of raster software and performing analyses. The community interactions and discussions also progressed well due to the presence of competent field support staff in different parts of the northern Eastern Ghats. However, we faced some challenges mainly during mammal surveys which delayed our work. There are persistent rains causing occasional floods through August and September of 2014, due to which our field work has been delayed by several months. We encountered delays in procuring our first set of camera traps, compounded when an additional set of camera traps were detained by the Indian Customs for 4 months. Some field assistants often failed to arrive. We overcame these by spending additional days conducting field surveys. One camera trap was also stolen in the field, but we had two camera traps ready as backup so we could immediately deploy another one. Another challenge was the lack of a permanent field base, because of which we were forced to constantly move around. This made project management and administration difficult logistically because of the lack of regular internet access and constant travelling. However, ATREE's excellent support ensured funds release even on short notice whenever required.

The project methodologies were guided by the specific objectives – Remote Sensing and GIS based imagery analysis for assessing landscape change, field surveys across Papikonda NP for studying mammals and their response to land cover change and informal community interactions and discussions for eliciting their responses on forest change. These methodologies were fixed after an intensive literature review of other studies on land cover change and mammals as well as standard field techniques for mammal surveys and they were found to be suitable for this project. One important lesson learnt was to always budget more time than necessary in order to compensate for unexpected delays, and to have additional critical field equipment such as camera traps as backup in case of loss.

In the future:

We are going to continue our work in the landscape in the long term by building on our work supported by the CLP. Firstly, we are planning to start with a long term monitoring study for birds and bats using acoustic monitoring equipment in the Papikonda NP this year for which we have submitted a propsal to Wildlife Acoustics. Secondly, we have also applied for funding from the Ministry of Environment and Forests, Government of India for a long term multi-taxa study to assess species richness and conduct threat assessment in forest habitats across the larger Eastern Ghats landscape, including Papikonda NP and the Satkosia Gorge Tiger Reserve in the north, Nagarjunasagar-Srisailam Tiger Reserve in the central region and Seshachalam Biosphere Reserve and Kolli Hills in the south. Thirdly, we plan to establish permanent vegetation monitoring plots in Papikonda National Park and surrounding forests of the northern Eastern Ghats across a gradient of disturbance and forest types. This would provide important information on species composition, recruitment and population dynamics of various species of flora and fauna, as well as the long term changes in the forest structure essential for forest management. We also aim to use these plots for studies on ecosystem dynamcis and the affects of various disturbances such as deforestation, fire, grazing etc on forest diversity. We plan to identify potential sites for establishing plots using the Global Forest Watch GLAD and FORMA deforestation alerts. This would be crucial in generating further information on the ecosystem changes in the Eastern Ghats.

Financial Report

Please copy and paste the summary sheet from your financial report here

Itemized expenses	Total CLP Requested (USD)*	Total CLP Spent (USD)	% Difference	Details & Justification (Justification must be provided if figure in column D is +/- 25%)
PHASE I - PROJECT PREPARATION				
Communications (telephone/internet/postage)	350.00	340.79	-3%	
Field guide books, maps, journal articles and other printed materials	450.00	450.00	0%	We purchased most of the books and maps required, will be buying some more during data analyses and report writing
Insurance	100.00		-100%	
Visas and permits				
Team training	100.00	65.59	-34%	Team training was organized at ATREE so most expenses were avoided
Reconnaissance	100.00	29.41	-71%	Most of the reconnaissance work was completed before the project began and hence these expenses were not spent during that period
Other (Phase 1)				
EQUIPMENT				
Scientific/field equipment and supplies	6,827.00	5508	-19%	We didn't need to purchase satellite imagery as we downloaded all of it free, so saved that amount for running expenses like accommodation, travel and food
Photographic equipment	431.00	983.39	128%	Running expenses including batteries for camera traps cost a lot (8 batteries for each camera trap lasting only two weeks)
Camping equipment	255.00	255.00	0%	
Boat/engine/truck (including car hire)	1,000.00	1000.00	0%	We hired a bike for field travel and thus saved on more expenses
Other (Equipment)	150.00	165.27	10%	

PHASE II - IMPLEMENTATION				
Accommodation for team members and local guides	637.00	731.00	15%	We could not find a permanent accommodation in field, so had to change base several times over the past two years
Food for team members and local guides	1,147.00	1147.00	0%	
Travel and local transportation (including fuel)	764.00	1635.97	113%	Project was extended by 6 months for field work and this involved more field travel expenses
Customs and/or port duties				
Workshops	640	640.00	0%	
Outreach/Education activities and materials (brochures, posters, video, t-shirts, etc.)	399.00	399.00	0%	
Other (Phase 2)	1,147.00	1147.00	0%	
PHASE III - POST-PROJECT EXPENSES				
Administration	250.00	250.00	0%	ATREE administrative expenses during project
Report production and results dissemination	250.00	250.00	0%	Used during analysis and report writing
Other (Phase 3)				
Total	14,997.00	14,997.00		

Appendices:

Output	Number	Additional Information
Number of CLP Partner Staff involved in mentoring the Project		
Number of species assessments contributed to (E.g. IUCN assessments)		
Number of site assessments contributed to (E.g. IBA assessments)	1	Site assessment for the Papikonda NP contributed in 2015
Number of NGOs established		
Amount of extra funding leveraged ($)	1,000	Received an Idea Wild grant for camera traps and GPS unit. Two more proposals submitted for continued research on different taxa in the northern Eastern Ghats (Ministry of Environment and Forests, Government of India; Wildlife Acoustics Limited)
Number of species discovered/rediscovered	2	Rusty spotted cat and Leopard cat presence established with camera trap records. Presence of Smooth coated otter also reported for the first time (paper under preparation)
Number of sites designated as important for biodiversity (e.g. IBA/Ramsar designation)	1	Likely to be announced in the upcoming IBA assessment
Number of species/sites legally protected for biodiversity		
Number of stakeholders actively engaged in species/site conservation management	3	Ashoka Trust for Research in Ecology and the Environment, Bangalore; ASHA, Chinturu Agriculture and Social Development Society, Rekhapalli
Number of species/site management plans/strategies developed	1	Conservation action plan for the Papikonda NP
Number of stakeholders reached	3	Local communities, NGOs and students (part of a conservation science course held in the landscape in 2015)
Examples of stakeholder behavior change brought about by the project.		The grassroots NGOs that we collaborated with during the project, ASHA, Chinturu

		Agriculture and Social Development Society, Rekhapalli, are now more closely involved in conservation and sustainable development related work than earlier
Examples of policy change brought about by the project		
Number of jobs created		
Number of academic papers published	3	Papers shared earlier with CLP (published in Small Mammal Mail, Journal of Threatened Taxa and Current Science)
Number of conferences where project results have been presented	3	Student Conference on Eastern Ghats, Eastern Ghats conference, Manipal University conference

We are in the process of submitting two papers from our CLP project in the next two weeks. We will be sharing the submitted manuscripts once they are accepted and under review.

Selected camera trap photos:

Photo 1 and 2: A Barking Deer *Muntiacus muntjac* and Spotted Deer *Axis axis*

Photo 3 and 4: A pair of Ruddy Mongoose *Herpestes smithii* and a Northern Plains Grey Langur *Semnopithecus entellus*

Photo 5 and 6: Leopard Cat *Prionailurus bengalensis* and Small Indian civet *Viverricula indica*

Tables and graphs:

Figure 6: Summary of sampling effort, captures, species richness and diversity across the study area

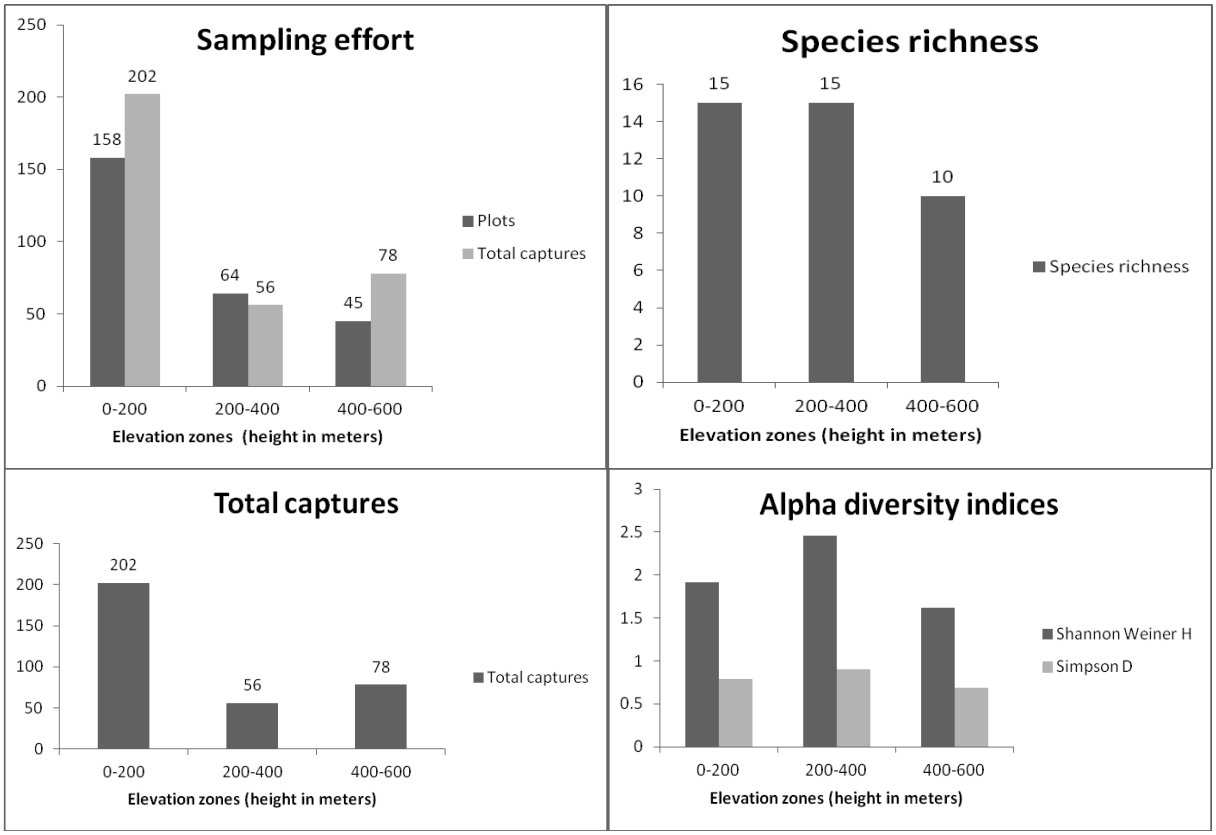


Figure 6a: Map of the study area showing grids for sampling across Papikonda NP and species richness encountered in each sampling location (richness increasing from white to red)

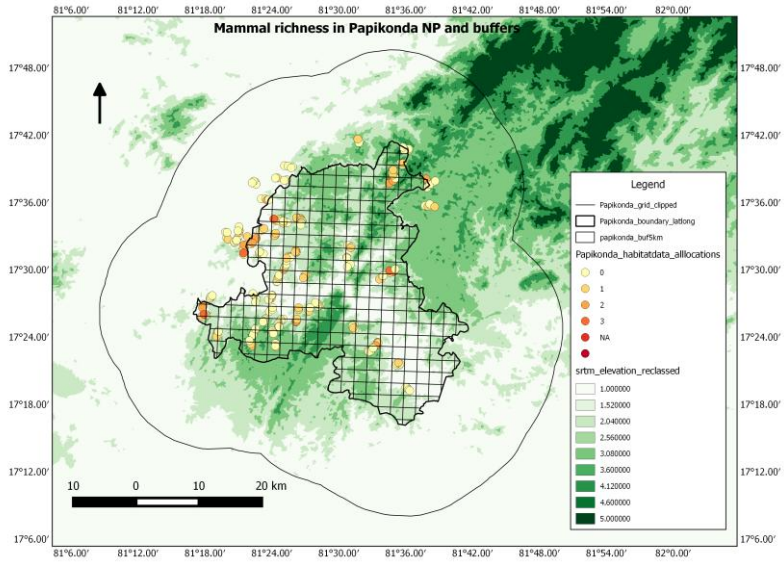
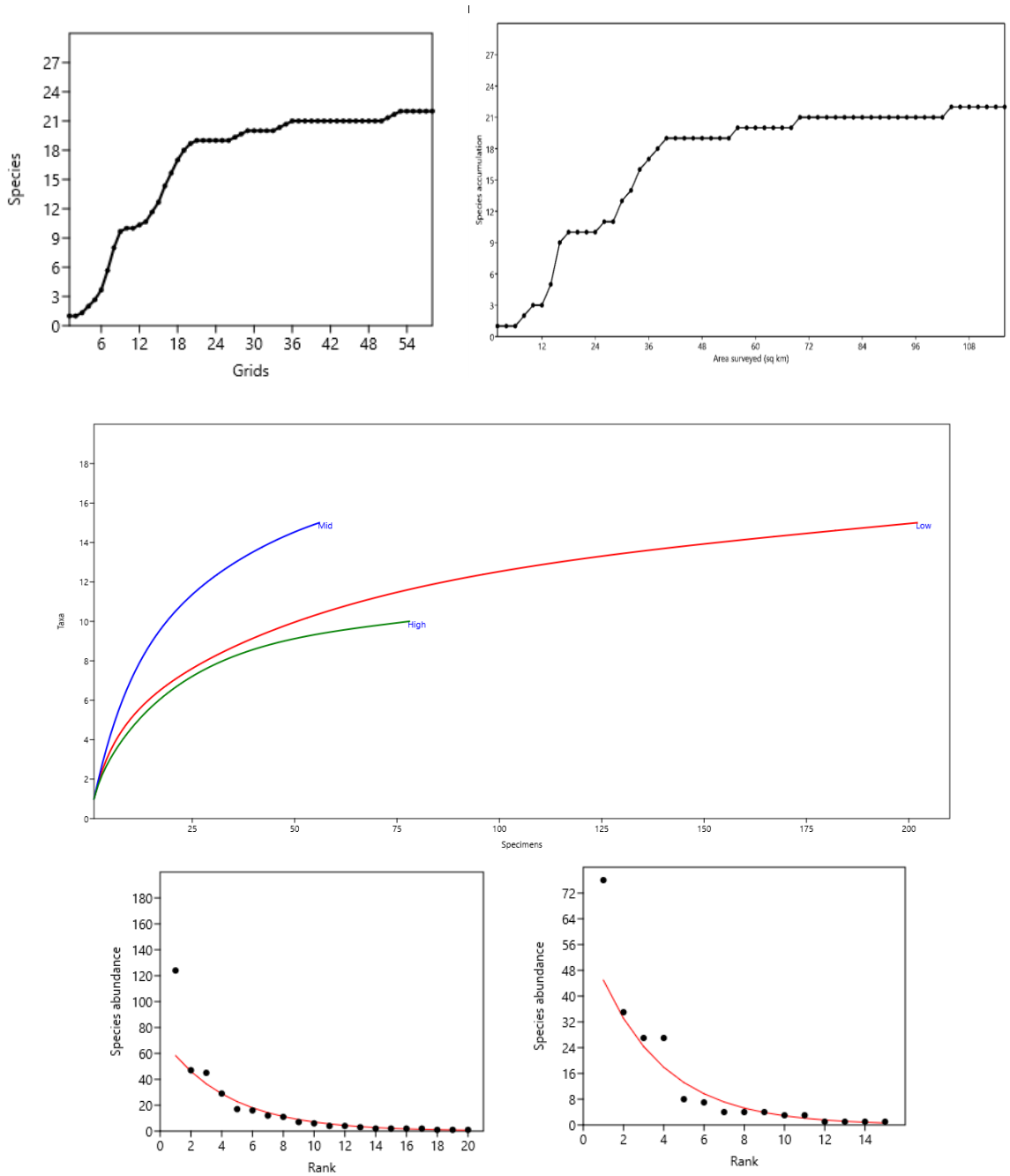


Figure 7a: Species accumulation and species area curves, followed by species rarefaction curves clockwise starting with cumulative, and across the low, mid and high elevation habitats



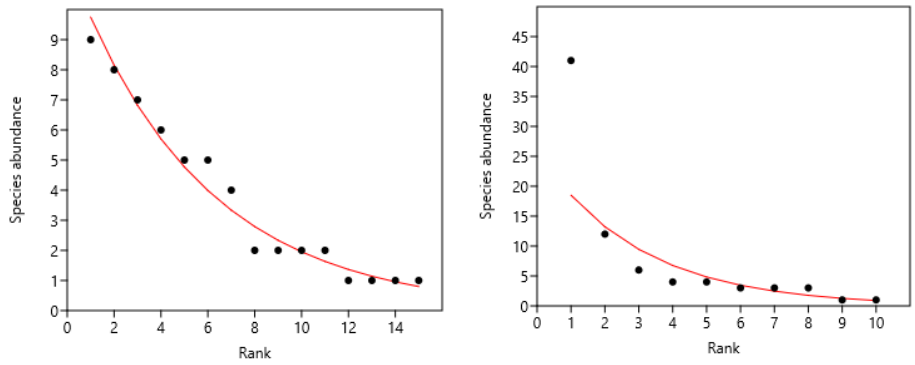


Figure 7b and 7c: Capture estimates (rank abundance histograms) of species from camera traps and species density per km^2

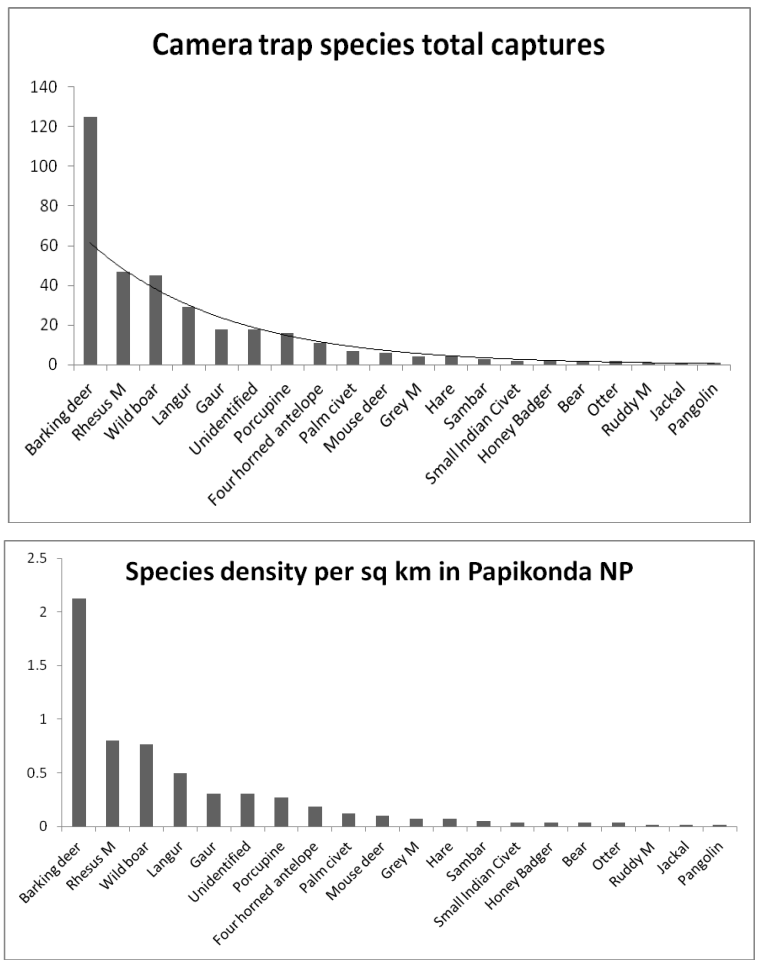


Figure 8: Mammalian guild wise patterns across the habitat types

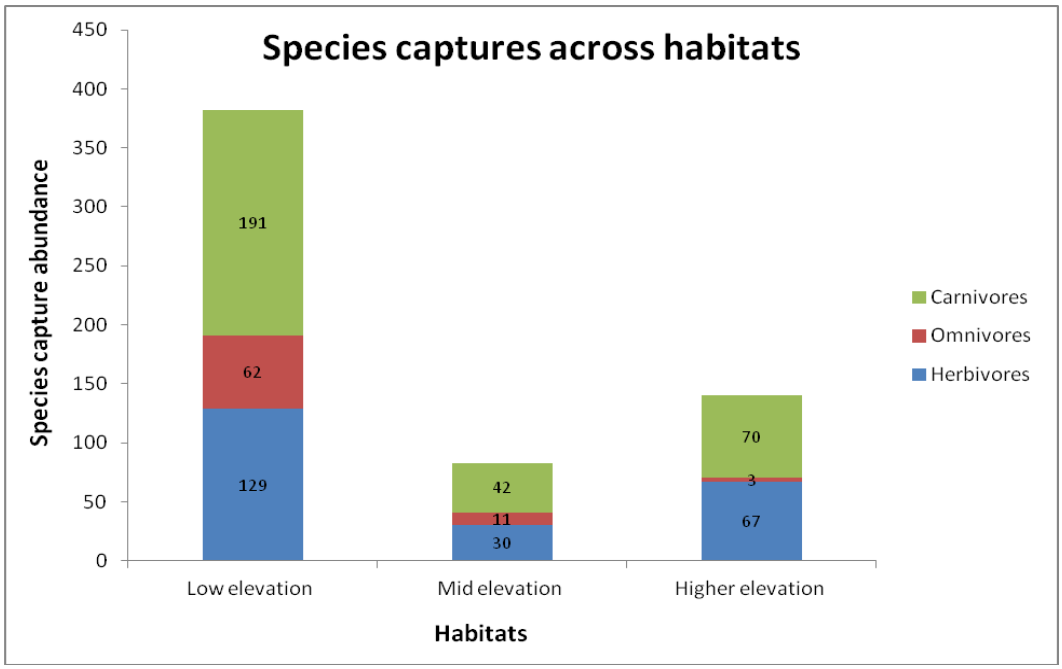
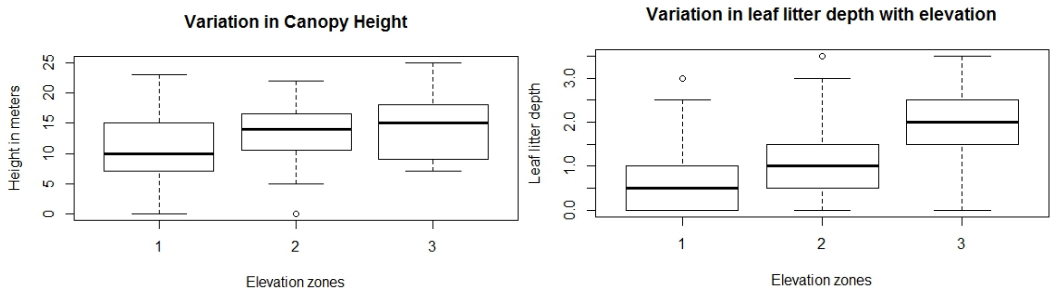
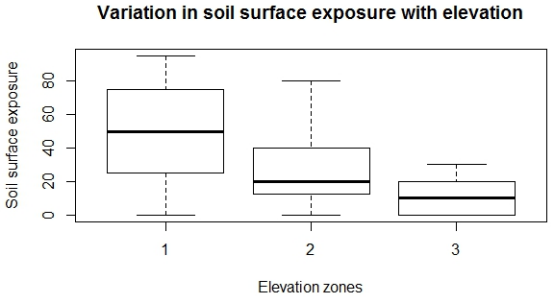


Figure 8a: Variation in habitat variables across the three habitats from sampling data subset

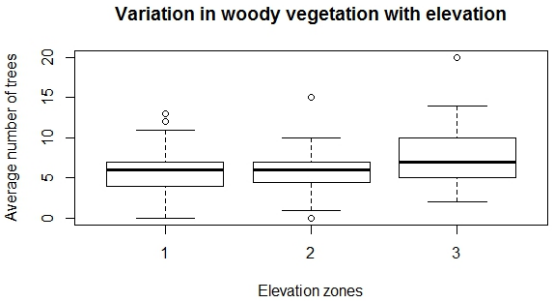


n = 162, ANOVA F = 6.938, p = 0.00129**

n = 162, ANOVA F = 13.38, p = 0.000**

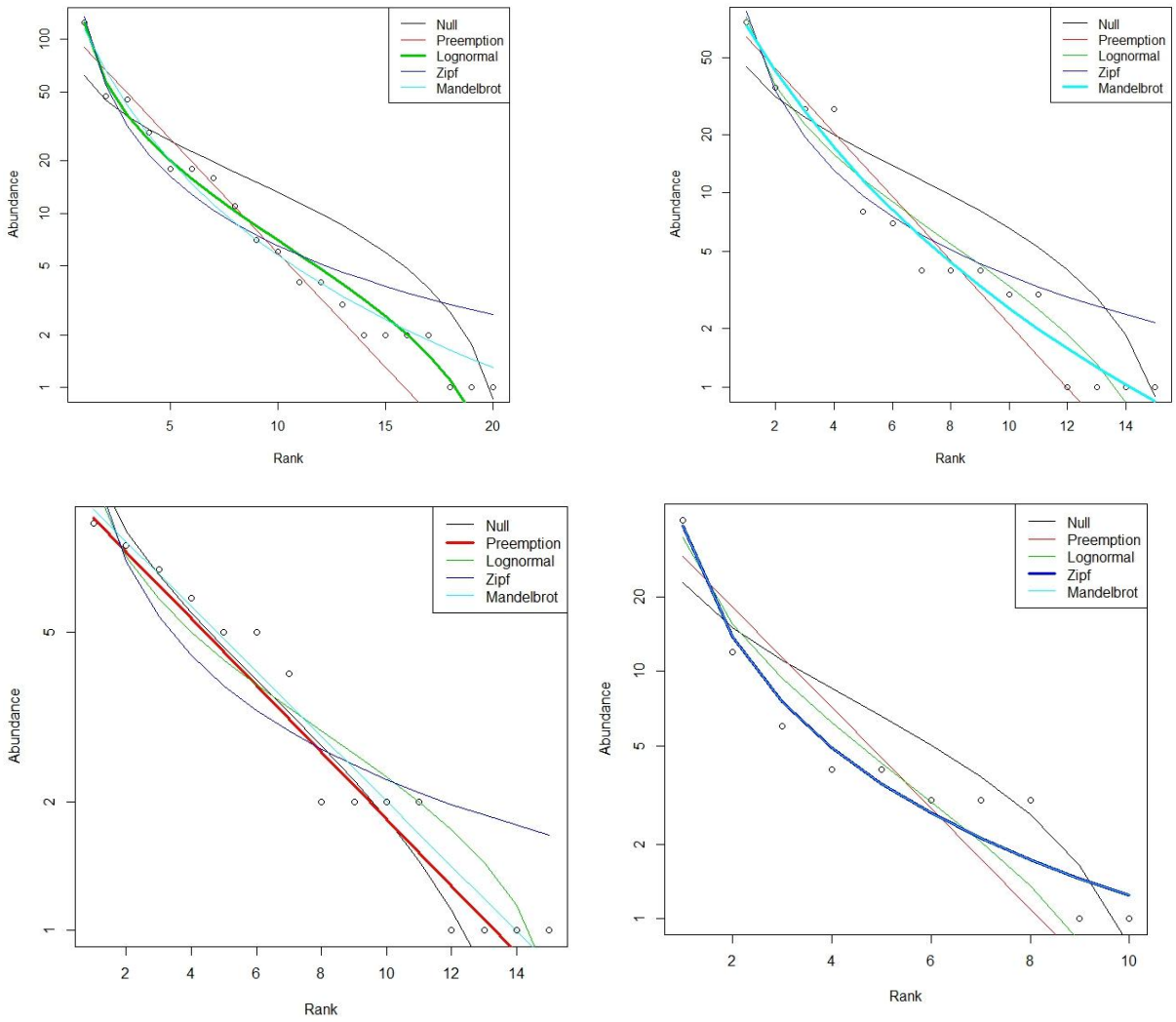


n = 162, ANOVA F = 3.873, p = 0.0228**



n = 162, ANOVA F 23.23, p = 0.000**

Figure 9: Species diversity (rank abundance) models fitted for the mammal community in Papikonda NP. The Lognormal distribution best fits the data, indicating that the community is highly unevenly represented, with high dominance by one species



Figures 9a and 9b: Multivariate canonical correlation of predictors (environmental and habitat variables; left side plots) and responses (species captures; right side plots)

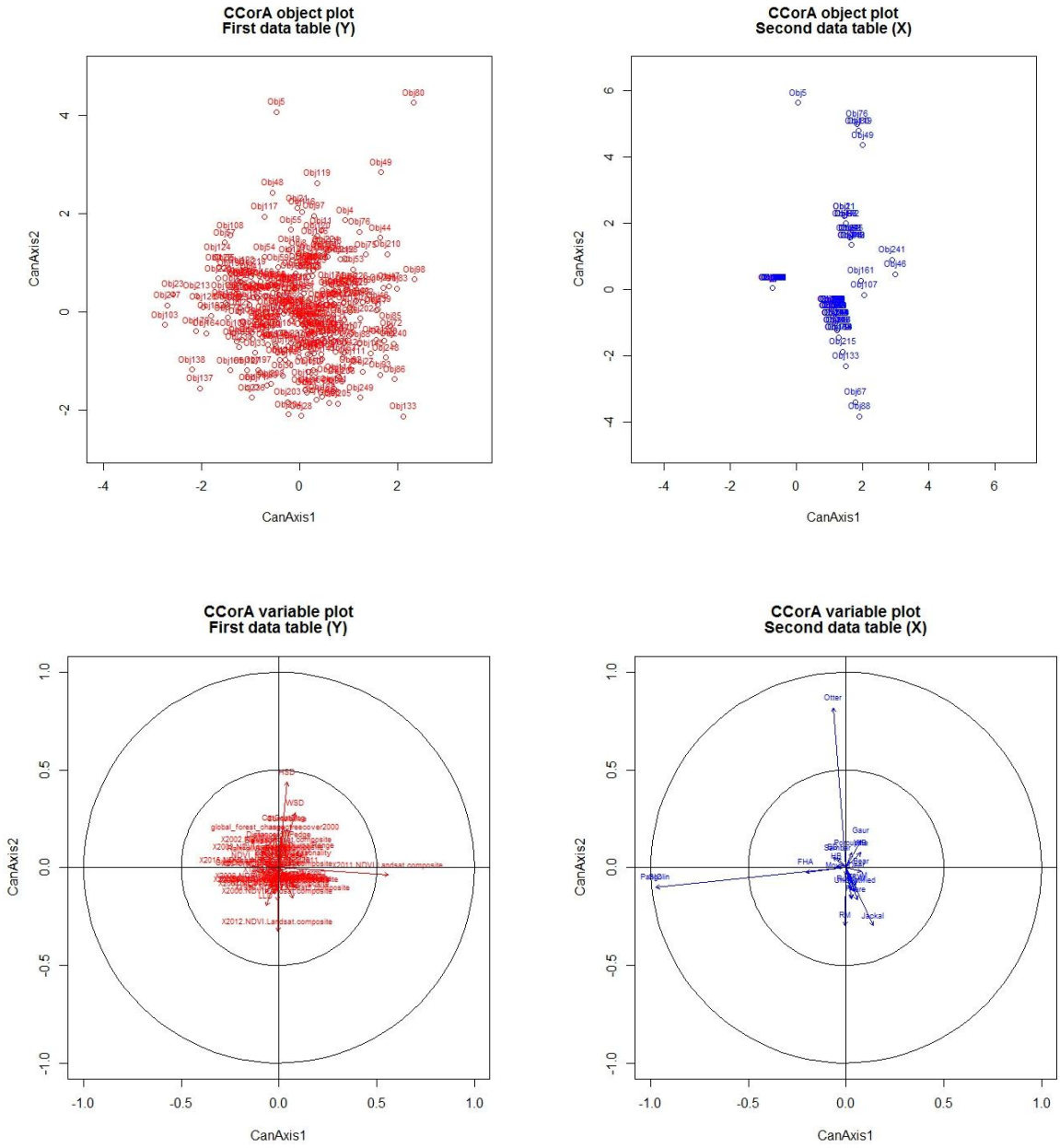
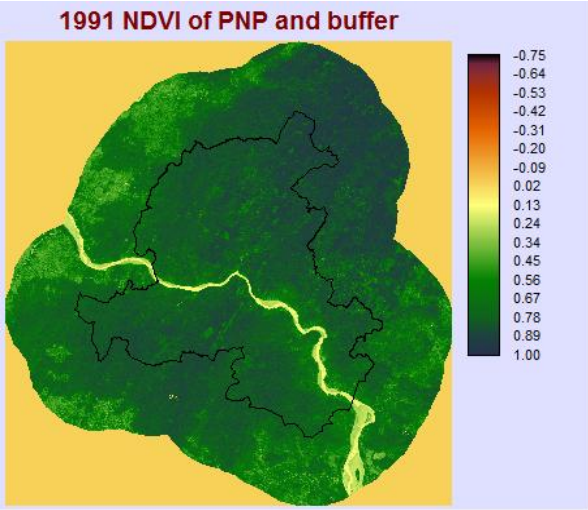
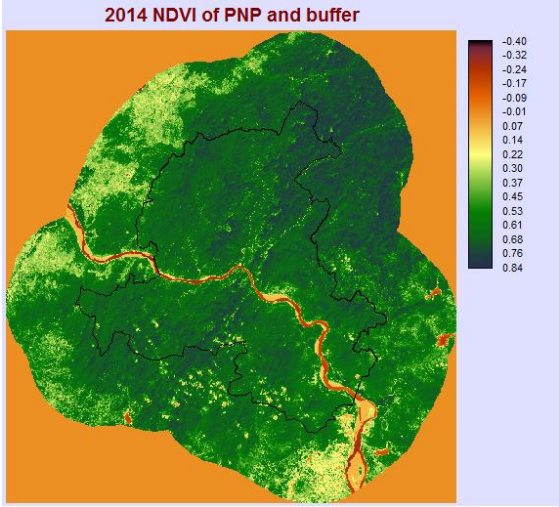
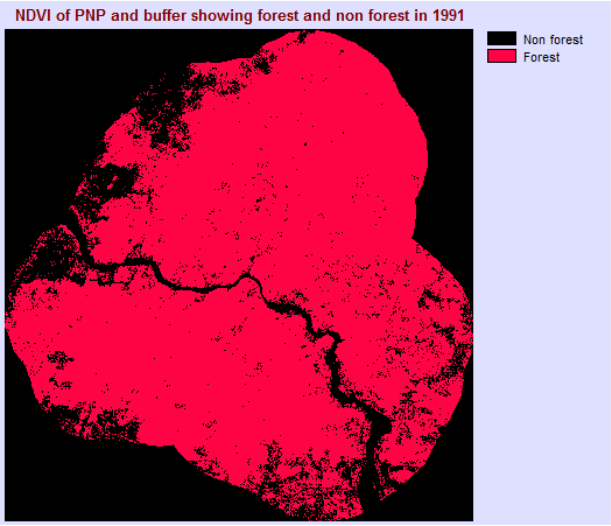


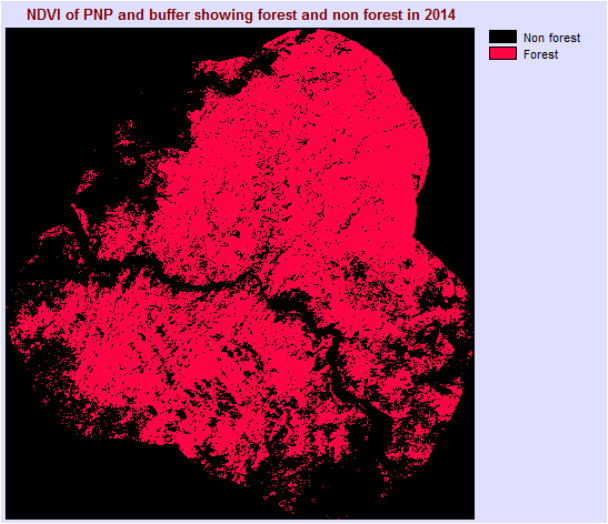
Figure 10a and 10b: NDVI of Papikonda NP and Papikonda NP along with its buffer in 1991 and 2014

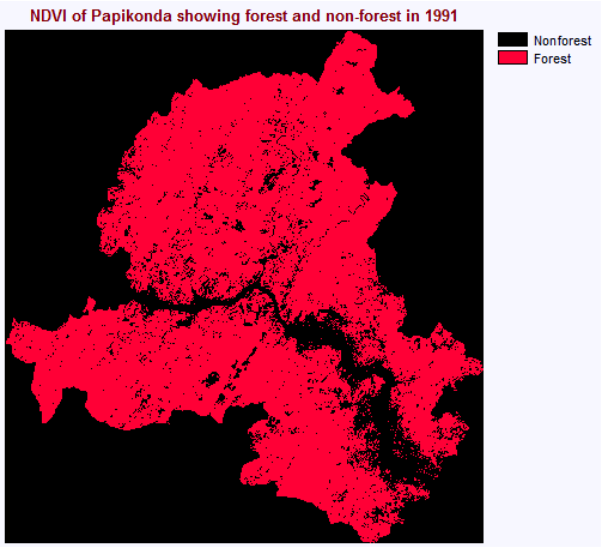


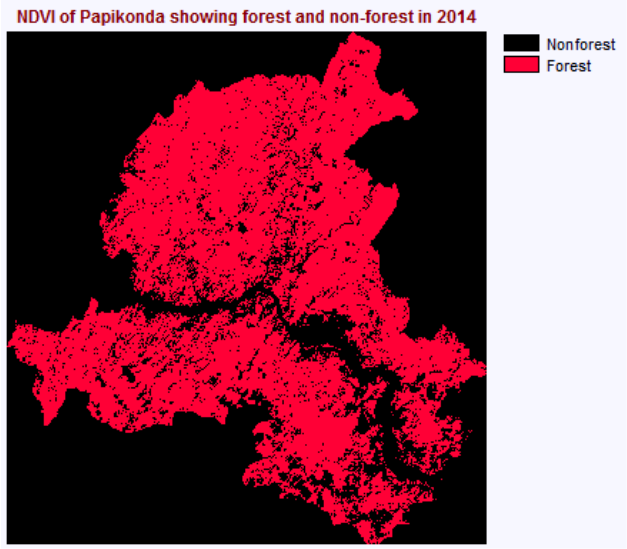


Figures 11, 12 and 13: NDVI of Papikonda NP along with its buffer, and buffer alone classified as forest (pink) and non-forest (black) in 1991 and 2014









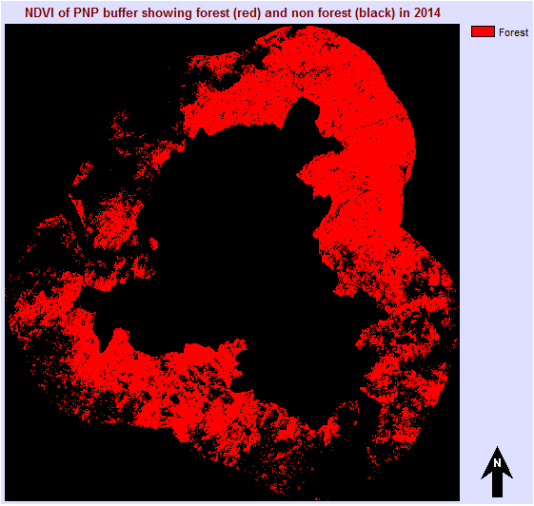


Figure 14 and 15: Change in forest cover in Papikonda NP and its buffer studied through NDVI time series analysis between 1991 - 2014 using LANDSAT imagery. Orange areas indicate existing forests, white indicates forests converted to non-forests between 1991-2014, and pink indicates existing non-forests.

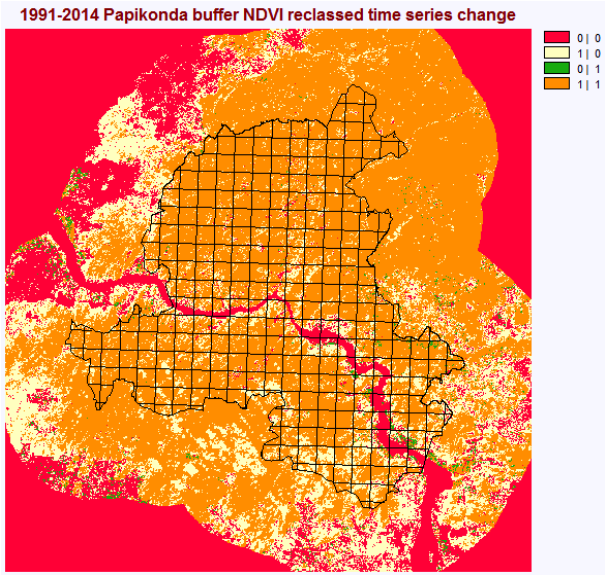
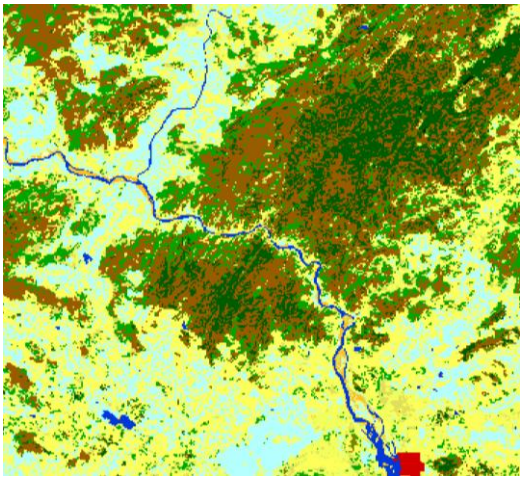


Figure 16 and 17: ESA's GlobCover 2009 and IGBP (MODIS based) vegetation classification over Papikonda NP and its contiguous forests



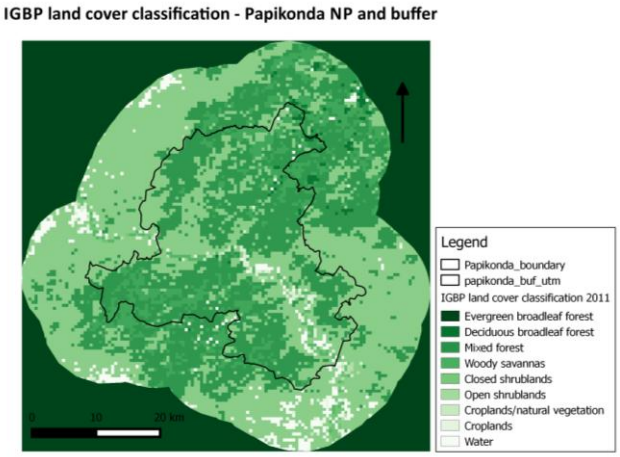


Figure 18: The GlobCover and MODIS IGBP land cover classification of Papikonda NP

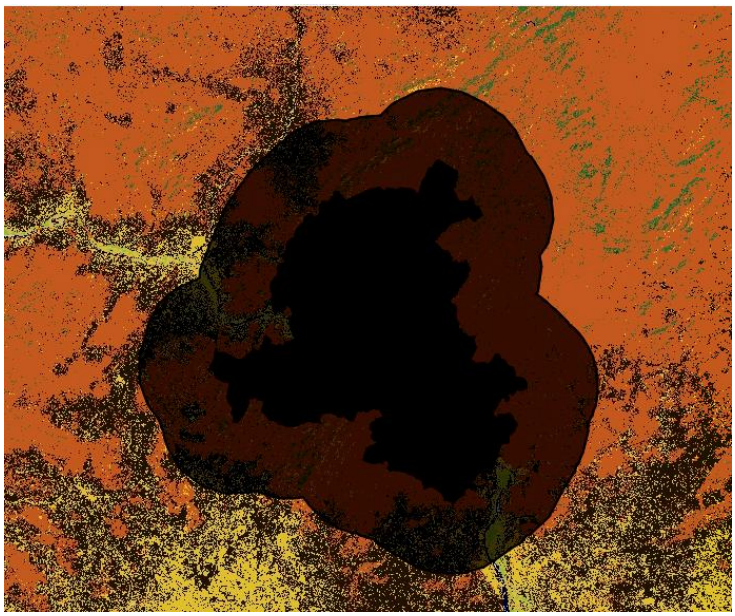
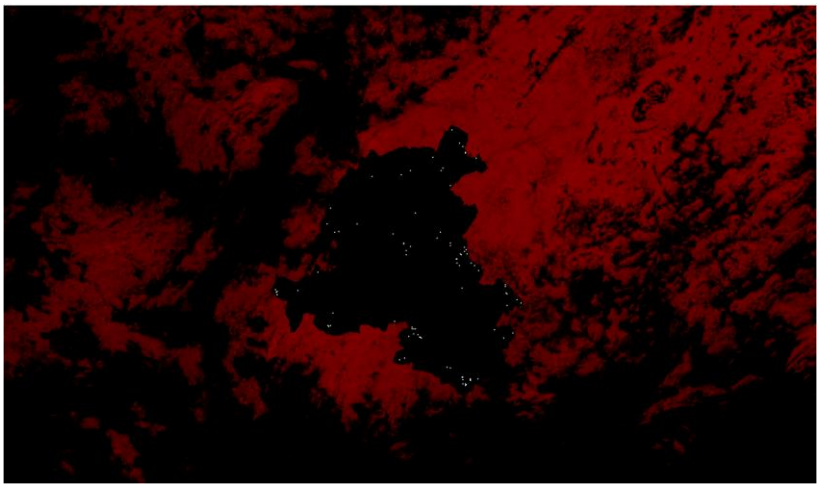


Figure 19a and 19b: Global Forest Watch (GFW) forest cover loss map over Papikonda NP (4a) and Papikonda NP with its 5 km buffer (4b). Red indicates existing forests and white spots indicate forest loss between 2000 – 2014



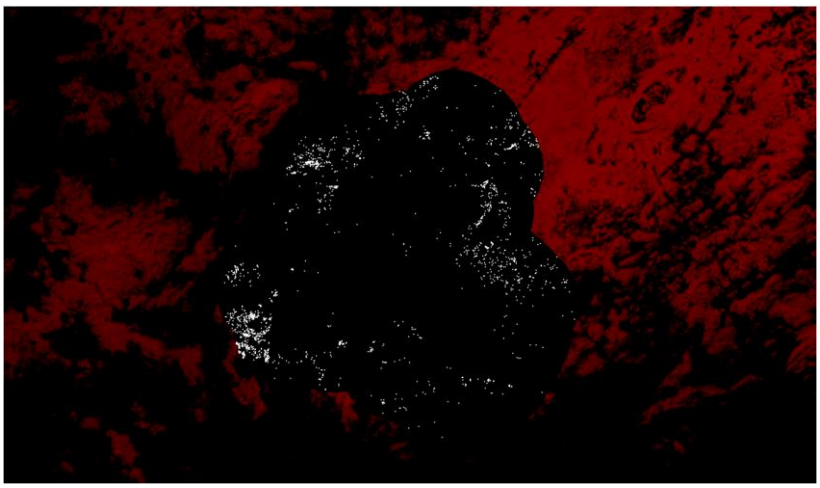
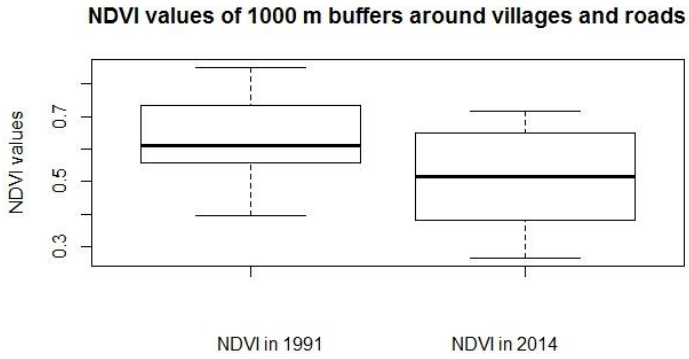
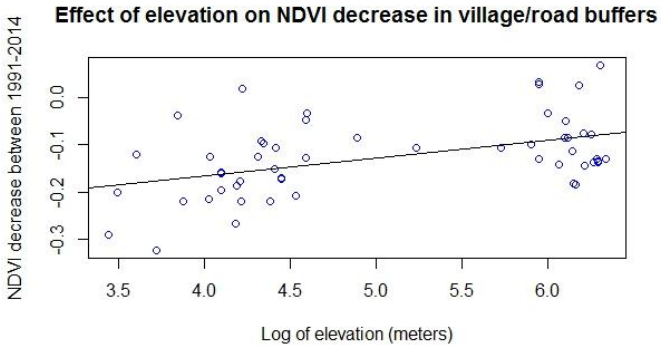


Figure 20: Box plot of decrease in NDVI values of 1000 m buffer areas around villages and roads in Papikonda NP between 19991 (mean = 0.6367 ± 0.1141) and 2014 (mean = 0.5112 ± 0.1447)



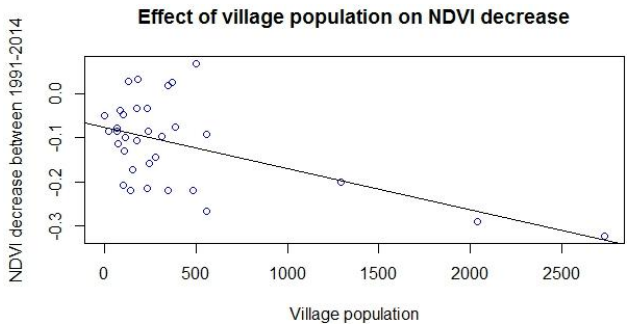
(ANOVA $F_{1, 51}$= 115.7, df = 1, 51 p = <0. 00001)

Figure 21: Scatter plot of the effect of elevation on the change in NDVI values of 1000 m buffer areas around villages and roads in Papikonda NP between 19991 and 2014.



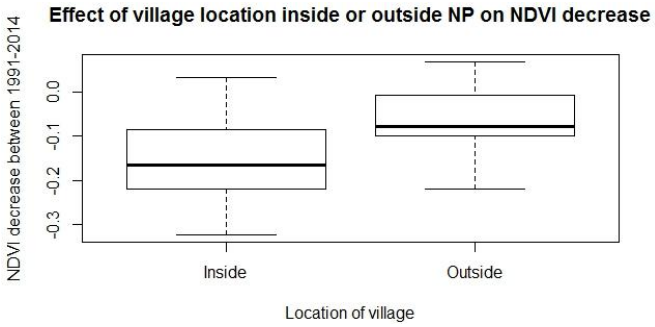
($F_{1, 51}$= 14.43, p = 0. 0003, R^2 = 0.22)

Figure 22: Scatter plot of the effect of village population on change in NDVI values of 1000 m buffers around villages between 19991 and 2014.



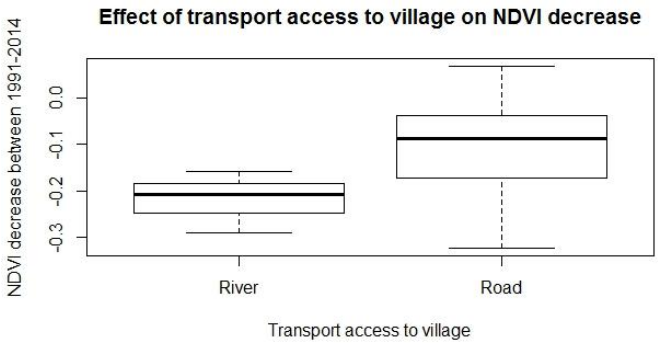
($F_{1, 31}$ = 13.09, p = 0.001, R^2 = 0.2969)

Figure 23: Box plot of the effect of location of village inside or outside the NP on change in NDVI values of 1000 m buffers around villages between 19991 and 2014.



(ANOVA $F_{1, 31}$ = 8.23, DF = 1, 31, p = 0.00734)

Figure 24: Box plot of the effect of road or river transport on the change in NDVI values of 1000 m buffer areas around villages between 19991 and 2014.



(ANOVA $F_{1, 31}$ = 4.228, DF = 1, 31, p = 0.0483 *)

Figure 25: Community responses on forest cover change across Papikonda NP and its buffer

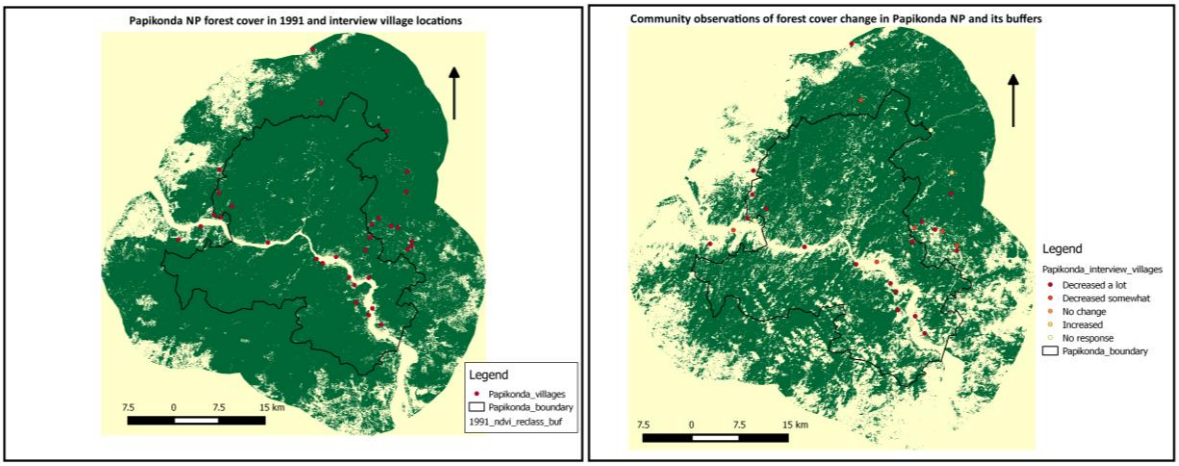
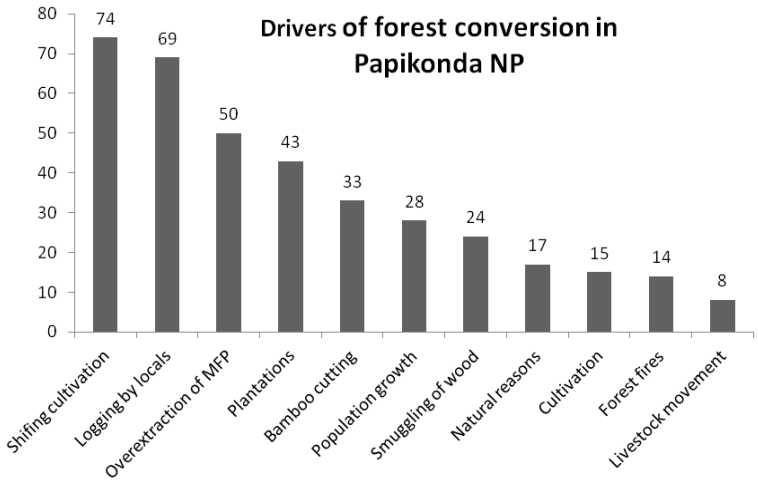


Figure 26: Community observations of the principal drivers of forest conversion in Papikonda NP and its buffer forests



Tables:

Table 1: Satellite imagery details of multi-date LANDSAT scenes that have been used for this study. All scenes are of Path 128/Row 49. The images were rectified and geo-referenced to the WGS 84 datum on the UTM (Zone 44N) and EPSG: 4326 coordinate systems

No	Scene/imagery name	Date acquired	Satellite	Sensor	Number of images
1	LC81410472014005LGN00	2014-01-05	LANDSAT-8	ETM+	1
2	LC81410482014005LGN00	2014-01-05	LANDSAT-8	ETM+	1
3	LC81420472014012LGN00	2014-01-12	LANDSAT-8	ETM+	1
4	LC81420482014012LGN00	2014-01-12	LANDSAT-8	ETM+	1
5	LE71410472001025SGS00	2001-01-25	LANDSAT-7	ETM+	1
6	LE71410482001025SGS00	2001-01-25	LANDSAT-7	ETM+	1
7	LE71420472000030SGS00	2000-01-30	LANDSAT-7	ETM+	1
8	LE71420482000030SGS00	2000-01-30	LANDSAT-7	ETM+	1
9	LT51410471991086ISP00	1991-03-27	LANDSAT-5	ETM+	1
10	LT51410481991086ISP00	1991-03-27	LANDSAT-5	ETM+	1
11	LT51420471992032BKT00	1992-02-01	LANDSAT-5	ETM+	1
12	LT51420481992032BKT00	1992-02-01	LANDSAT-5	ETM+	1

Table 2: Environmental variables studied at each camera trap in 5 m^2 plots

Habitat variable	Study method	Disturbance variable	Study method
Canopy cover (%)	4 corners of quadrat	Edge distance	Distance from plot
Canopy height	Eyeball estimate	Logging/lopping	Presence in/near plot
TWV	Count in quadrat	Cattle dung	Presence in/near plot
SC	Count in quadrat	NTFP	Distance from plot
WSD	1x1 m plot in center of quadrat	Settlements	Distance from plot
HSD	1x1 m plot in center of quadrat	Agriculture	Distance from plot

TS/FL	Count in quadrat	Hunting	Camera trap photos, direct sighting
LLD (cm)	1x1 m plot in quadrat center	Human presence	Camera trap
SSE (%)	Estimate in quadrat	Presence of domestic animals	Camera trap
Elevation	From GPS and extracted from GIS		
Landscape variable	**Study method**	**Bioclimatic/environmental variable**	**Study method**
Distance to NP edge	Extracted from GIS analysis	Mean Temperature	Extracted from WorldClim
Distance to nearest village	Extracted from GIS analysis	Max Temperature	Extracted from WorldClim
NDVI from 2016 to 1988	Extracted from GIS analysis	Min Temperature	Extracted from WorldClim
Difference in NDVI between 2016 and 1988	Extracted from GIS analysis	Temperature Annual Range (Difference between max and min)	Extracted from WorldClim
EVI in 1988	Extracted from GIS analysis	Mean Diurnal Range	Extracted from WorldClim
EVI in 2014	Extracted from GIS analysis	Temperature seasonality	Extracted from WorldClim
Global Forest Watch canopy cover %	Downloaded from Global Forest Watch	Rainfall	Extracted from WorldClim
GlobCover land cover classification	Downloaded from Google Earth Engine	Rainfall Seasonality	Extracted from WorldClim
IGBP land cover classification	Downloaded from Google Earth Engine	Rainfall of wettest quarter	Extracted from WorldClim
Aridity	Extracted from GIS analysis	Rainfall of driest quarter	Extracted from WorldClim

Aspect	Extracted from GIS analysis		
Slope	Extracted from GIS analysis		

Table 3: Checklist of species recorded in or with range present in Papikonda NP

IUCN Categories: LC- Least Concern; NT – Near Threatened; VU – Vulnerable; EN – Endangered

No	Family	Species scientific Name	Common English Name	Common Telugu name	IUCN Status	Population status in Papikonda	Mode of observation
		Order: Carnivora					
1	Felidae	*Panthera tigris* Linnaeus, 1758	Tiger	*Puli*	EN	Rare	CT
2		*Panthera pardus* Linnaeus, 1758	Leopard	*Chiruta puli*	VU	Rare	SS/LR
3		*Prionailurus bengalensis* Kerr, 1792	Leopard cat	*Chiruta pilli*	LC	Rare	CT
4		*Prionailurus rubiginosus* Geoffroy Saint-Hilaire, 1831	Rusty spotted cat	-	NT		CT
5		*Felis chaus* Schreber, 1777	Jungle cat	*Jangu pilli, Adavi pilli*	LC	Common	CT
6	Hyaenidae	*Hyaena hyaena* Linnaeus, 1758	Striped hyena	*Dummulgondi*	NT	Rare	LR
7	Canidae	*Cuon alpinus* Linnaeus, 1758	Asiatic Wild dog	*Rechu kukka*	EN	Common	SS/LR
8		*Canis aureus* Linnaeus, 1758	Golden Jackal	*Nakka*	LC	Common	Sighting

9		*Vulpes bengalensis* Shaw, 1800	Indian fox	*Gunta nakka*	LC	Rare	LR
10	Ursidae	*Melursus ursinus* Shaw, 1791	Sloth bear	*Elugubanti/ Goddelugu*	VU	Common	Sighting/CT/ SS
11	Viverridae	*Paradoxurus hermaphroditus* Pallas, 1777	Common palm civet	*Chinna punugu pilli*	LC	Common	CT
12		*Viverricula indica* É. Geoffroy Saint-Hilaire, 1803	Small Indian Civet	*Punugu pilli*	LC	Common	CT
13	Herpestidae	*Herpestes edwardsii* É. Geoffroy Saint-Hilaire, 1818	Indian Grey Mongoose	*Mungeesa*	LC	Common	CT
14		*Herpestes smithii* Gray, 1837	Ruddy Mongoose	*Mungeesa*	LC	Common	CT
15		*Herpestes vitticollis* Bennett, 1835	Stripe necked mongoose	*Mungeesa*	LC	Rare	SS
16	Mustelidae	*Lutrogale perspicillata* I. Geoffroy Saint-Hilaire, 1826	Smooth coated otter	*Yeti kukka/Neeti kukka*	VU	Common	CT, SS
17		*Mellivora capensis* Schreber, 1776	Honey-badger	*Vedinchu*	LC	Common	CT
		Order: Artiodactyla					
18	Cervidae	*Axis axis* Erxleben, 1777	Chital or Indian Spotted deer	*Chukkala jinka*	LC	Common	CT/SS
19		*Rusa unicolor* Kerr, 1792	Sambar	*Duppi*	VU	Common	CT/SS
20		*Muntiacus muntjak* Zimmermann, 1780	Indian Muntjac	*Konda gorre*	LC	Common	CT/SS/Sighti ng

21	Tragulidae	*Moschiola indica* Grey 1852	Indian Chevrotain	*Eluka jinka*	LC	Common	CT
22	Bovidae	*Bos gaurus* C.H. Smith, 1827	Gaur	*Adavi dunna/ Gorre geda/ Manubothu*	VU	Common	CT/SS/Sighting
23		*Boselaphus tragocamelus* Pallas, 1766	Nilgai or Blue Bull	*Nilgai*	LC	Rare	LR
24		*Tetracerus quadricornis* de Blainville, 1816	Four horned antelope	*Nalugu kommula jinka*	VU	Common	CT/SS
25	Suidae	*Sus scrofa* Linnaeus, 1758	Indian wild pig	*Adavi pandi*	LC	Common	CT/SS/Sighting
		Order: Lagomorpha					
26	Leporidae	*Lepus nigricollis* F. Cuvier, 1823	Black-naped Hare	*Kundelu*	LC	Common	CT/SS/Sighting
		Order: Primates					
27	Cercopethicidae	*Macaca mulatta* Zimmermann, 1780	Rhesus Macaque	*Kothi*	LC	Common	CT/SS/Sighting
28		*Macaca radiata* Geoffroy, 1812	Bonnet Macaque	*Kothi*	LC	Common	LR
29		*Semnopithecus entellus* Dufresne, 1797	Northern Plains Gray Langur	*Konda mucchu*	LC	Common	CT/ Sighting
30		*Semnopithecus dussumieri* Geoffroy, 1843	Southern Plains Grey Langur	*Konda mucchu*	LC	Common	CT/ Sighting
		Order: Pholidota					
31	Manidae	*Manis crassicaudata* É. Geoffroy, 1803	Indian Pangolin	*Alugu*	EN	Rare	CT/LR

		Order: Insectivora					
32	Soricidae	*Suncus murinus* Linnaeus, 1766	House shrew	*Gayyaali*	LC	Common	LR
		Order: Scandentia					
33	Tupaiidae	*Anathana ellioti* Waterhouse, 1850	Tree shrew	*Chettu Gayyaali*	LC	Common	Sighting/CT/LR
		Order: Chiroptera					
34	Pteropodidae	*Rousettus leschenaultii* Desmarest, 1820	Leschenault's Rousette or Leschenault's Fruit Bat	*Pandla Gabbilamu*	LC	Common	LR
35		*Pteropus giganteus* Brünnich, 1782	Indian Flying Fox	*Pandla Gabbilamu*	LC	Common	LR/Sighting
36		*Cynopterus sphinx* Vahl 1797	Greater Shortnosed Fruit Bat	*Pandla gabbilamu*	LC	Common	LR
37	Rhinopomatidae	*Rhinopoma hardwickii* Gray, 1831	Lesser Mouse-tailed Bat	*Gabbilamu*	LC	Common	LR
38	Emballonuridae	*Taphozous longimanus* Hardwicke, 1825	Long-winged Tomb Bat	*Gabbilamu*	LC	Uncommon	LR
39	Megadermatidae	*Megaderma lyra* É. Geoffroy, 1810	Greater False Vampire	*Gabbilamu*	LC	Common	LR
40	Rhinolophidae	*Rhinolophus rouxii* Temminck, 1835	Rufous Horseshoe Bat	*Gabbilamu*	LC	Common	LR
41		*Hipposideros speoris* Schneider, 1800	Schneider's Leaf-nosed Bat	*Gabbilamu*	LC	Common	LR
42		*Hipposideros fulvus*	Fulvus Leaf-	*Gabbilamu*	LC	Common	LR

		Gray, 1838	nosed Bat				
43	Vespertillionidae	*Pipistrellus ceylonicus* Kelaart, 1852	Kelaart's Pipistrelle	*Gabbilamu*	LC	Common	LR
44		*Pipistrellus tenuis* Temminck, 1840	Least Pipistrelle	*Gabbilamu*	LC	Common	LR
45		*Scotozous dormeri* Dobson, 1875	Dormer's Bat	*Gabbilamu*	LC	Common	LR
46		*Hesperoptenus tickelli* Blyth, 1851	Tickell's Bat	*Gabbilamu*	LC	Rare	LR
		Order: Rodentia					
47	Squiridae	*Funambulus pennantii* Wroughton, 1905	Five-striped Palm Squirrel	*Udata*	LC	Common	Sighting
48		*Funambulus palmarum* Linnaeus, 1766	Three-striped Palm Squirrel	*Udata*	LC	Common	
49		*Ratufa indica* Erxleben, 1777	Giant Squirrel	*Raachiluka*	LC	Uncommon	Sighting
50	Muridae	*Tatera indica* Hardwicke, 1807	Indian Gerbil	-	LC	Uncommon	LR
51		*Golunda ellioti* Gray, 1837	Indian Bush-rat	*Podala eluka*	LC	Common	LR
52		*Millardia meltada* Gray, 1837	Soft furred Field Rat	*Chinna eluka*	LC	Common	LR
53		*Rattus rattus* Linnaeus, 1758	House Rat	*Eluka*	LC	Common	Sighting
54		*Mus musculus* Linnaeus,1758	House Mouse	*Eluka*	LC	Common	Sighting
55		*Mus booduga* Gray, 1837	Little Indian Field Mouse	*Eluka*	LC	Common	Sighting

56		*Bandicota bengalensis* Gray, 1837	Lesser Bandicoot Rat	*Chinna Pandikokku*	LC	Common	Sighting
57		*Bandicota indica* Bechstein, 1800	Greater Bandicoot Rat	*Pedda Pandikokku*	LC	Common	Sighting
58	Hystricidae	*Hystrix indica* Kerr, 1792	Indian crested porcupine	*Mulla pandi*	LC	Common	CT/Sighting

Table 4: Mammal diversity patterns across the study area

Elevation Zone	Plots	Total captures	Mean captures	Species richness	Avg. species richness	Shannon Weiner	Simpson	Evenness
0-200	158	202	1.28	15	0.45	1.917	0.7882	0.4534
200-400	64	56	0.88	15	0.48	2.455	0.8992	0.776
400-600	45	78	1.73	10	0.53	1.616	0.6841	0.5031
Total	267	336	1.25	20	0.465	1.996	0.7905	0.5775

Table 5: Mammalian guild wise patterns across the habitat types

Guild	Low elevation	Mid elevation	Higher elevation	Total
Herbivores	129	30	67	226
Omnivores	62	11	3	76
Insectivore	0	1	0	1
Carnivore	191	42	70	303
Unidentified	4	2	6	12
Total	202	56	78	336

Table 6: Model selection to identify the significant environmental variables in determining mammal presence in the study area, using a logistic Generalized Linear Model

Mammal presence regressed against variables	Parameter	Delta AICc	AICcWt	Model. Wt	Cum.Wt	Log Likelihood
NDVI in 2014	2	324.05	0	0.54	0.54	-160
NDVI in 1991	2	325.9	1.85	0.21	0.75	-160.93
EVI in 2014	2	326.88	2.83	0.13	0.88	-161.42
HSD	2	330.73	6.69	0.02	0.9	-163.34
Presence of domestic animals	2	330.87	6.82	0.02	0.92	-163.41
Canopy Height	2	331.16	7.11	0.02	0.93	-163.56
Presence of domestic animals and humans	2	331.73	7.68	0.01	0.95	-163.84
Presence of humans	2	331.74	7.69	0.01	0.96	-163.85
TS/FL	2	332.16	8.11	0.01	0.97	-164.06
Rainfall	2	333.81	9.76	0	0.97	-164.88
LLD	2	333.83	9.78	0	0.98	-164.89
EVI in 1988	2	334.12	10.07	0	0.98	-165.04
IGBP classification number	2	334.21	10.16	0	0.98	-165.08
WSD	2	334.33	10.28	0	0.99	-165.14
Global Forest Watch canopy cover %	2	334.53	10.48	0	0.99	-165.24
GlobCover classification number	2	335.4	11.35	0	0.99	-165.68
SSE	2	335.46	11.41	0	0.99	-165.7
TWV	2	335.58	11.53	0	0.99	-165.76
Shrubs	2	335.63	11.59	0	0.99	-165.79
Aridity	2	336.04	11.99	0	1	-166
Min Temperature	2	336.39	12.34	0	1	-166.17
Elevation	2	336.55	12.5	0	1	-166.25
Mean Temperature	2	337.61	13.56	0	1	-166.78
Max Temperature	2	338.16	14.11	0	1	-167.06
Aspect	2	338.35	14.3	0	1	-167.15

Table 6a: 95% confidence set for the most significant variables determining animal presence across Papikonda NP and its buffer using raw sum of model (variable) probabilities

Model (Predictor variable)	Parameters	AICc	Delta_AICc	AICc.Wt
NDVI in 2014	2	324.05	0	0.54
NDVI in 1991	2	325.9	1.85	0.21
EVI in 2014	2	326.88	2.83	0.13
HSD	2	330.73	6.69	0.02
Presence of domestic animals	2	330.87	6.82	0.02
Canopy Height	2	331.16	7.11	0.02

Presence of domestic animals and humans	2	331.73	7.68	0.01
Presence of humans	2	331.74	7.69	0.01

Table 7: Model selection to identify the significant environmental variables in determining mammal richness in Papikonda NP and its buffer, using a Poisson Generalized Linear Model

Mammal richness regressed against variables	**Parameter**	**Delta AICc**	**AICcWt**	**Model. Wt**	**Cum. Wt**	**Log Likelihood**
NDVI in 1991	2	469.33	0	0.31	0.31	-232.64
NDVI in 2014	2	470.88	1.55	0.14	0.45	-233.41
HSD	2	471.67	2.34	0.1	0.54	-233.81
Presence of domestic animals	2	471.96	2.64	0.08	0.63	-233.96
Presence of domestic animals and humans	2	472.15	2.82	0.07	0.7	-234.05
Presence of humans	2	472.37	3.04	0.07	0.77	-234.16
LLD	2	473.12	3.79	0.05	0.81	-234.54
EVI in 2014	2	473.43	4.1	0.04	0.85	-234.69
Canopy Height	2	473.5	4.17	0.04	0.89	-234.73
TS/FL	2	474.59	5.27	0.02	0.91	-235.27
TWV	2	475.75	6.42	0.01	0.93	-235.85
Shrubs	2	475.9	6.58	0.01	0.94	-235.93
SSE	2	476.07	6.74	0.01	0.95	-236.01
WSD	2	476.11	6.78	0.01	0.96	-236.03
EVI in 1988	2	476.19	6.87	0.01	0.97	-236.07
GlobCover classification number	2	476.58	7.25	0.01	0.98	-236.27
Rainfall	2	477.11	7.78	0.01	0.98	-236.53
IGBP classification number	2	478.86	9.53	0	0.99	-237.4
Aspect	2	479.08	9.75	0	0.99	-237.52
Min Temperature	2	479.09	9.76	0	0.99	-237.52
Global Forest Watch canopy cover %	2	479.36	10.03	0	0.99	-237.66
Elevation	2	479.39	10.07	0	0.99	-237.67
Aridity	2	479.52	10.19	0	1	-237.74
Mean Temperature	2	479.76	10.43	0	1	-237.86
Max Temperature	2	479.9	10.57	0	1	-237.93

Table 7a: 95% confidence set for the most significant variables determining mammal richness across Papikonda NP and its buffer using raw sums of model (variables) probabilities

Model (Predictor variable)	Parameters	AICc	Delta_AICc	AICcWt
NDVI in 1991	2	469.33	0	0.31
NDVI in 2014	2	470.88	1.55	0.14
HSD	2	471.67	2.34	0.1
Presence of domestic animals	2	471.96	2.64	0.08
Presence of domestic animals and humans	2	472.15	2.82	0.07
Presence of humans	2	472.37	3.04	0.07
LLD	2	473.12	3.79	0.05
EVI in 2014	2	473.43	4.1	0.04
Canopy Height	2	473.5	4.17	0.04
TS/FL	2	474.59	5.27	0.02
TWV	2	475.75	6.42	0.01
Shrubs	2	475.9	6.58	0.01
SSE	2	476.07	6.74	0.01
WSD	2	476.11	6.78	0.01

Table 8: Change in NDVI of Papikonda NP, buffer of NP only, and Papikonda NP along with buffer between 1991 - 2014

	Area in 1991 (sq km)	Area in 2014 (sq km)	Change in area (Kappa = 0.673)	% change
Papikonda NP	856.35	754.21	102.14	11.9 %
Buffer only	1499.23	1009.00	490.23	32.69%
Papikonda NP and buffer	2448.08	1798.7	649.38	26.52%

References:

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