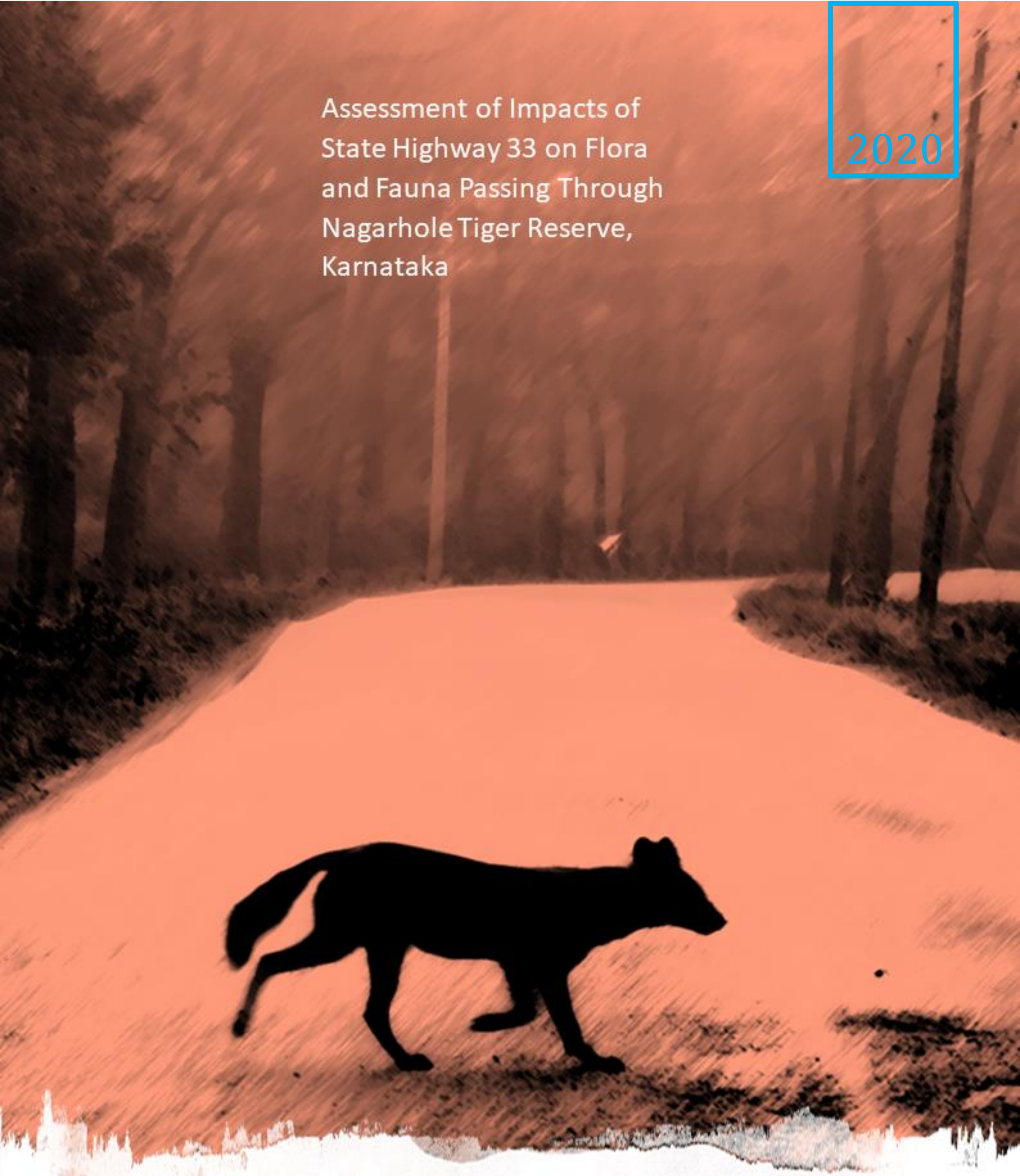
Assessment of Impacts of State Highway 33 on Flora and Fauna Passing Through Nagarhole Tiger Reserve, Karnataka

2020



ECOLOGICAL IMPACT ASSESSMENT OF EXISTING AND PROPOSED ROAD INFRASTRUCTURE ON IMPORTANT WILDLIFE CORRIDORS IN INDIA FOR STRATEGIC PLANNING OF SMART GREEN INFRASTRUCTURE

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

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Executive Summary

As part of the project funded by the National Tiger Conservation Authority, New Delhi, three sites were chosen for study- the Central Indian tiger landscape including major roads cutting across the animal corridors in the landscape, the National Highway 37 (now 715) cutting through the Kaziranga-Karbi Anglong landscape in Assam, and the State Highway 33 passing through the Nagarhole Tiger Reserve, Karnataka.

At Nagarhole Tiger reserve, we intended to study the difference in the impacts of the SH 33 along its two stretches – one that is completely closed to traffic (decommissioned segment) and the other stretch that is closed for night time traffic (night traffic closed segment). We compared the floral (tree species composition and richness), and faunal (ungulate group size and composition, habitat use and activity patterns) characteristics along the two road stretches.

We found that tree and sapling species richness was found to be higher in the decommissioned road segment as compared to the night traffic closed road segment, both of which comprised predominantly of native vegetation. On the other hand, shrubs and herbs had higher species richness in the night traffic closed road segment. We found higher species richness and cover of grasses, shrubs and herbs in the night traffic closed road segment, which can be attributed to the edge effect. Even though both the segments of the highway under study are homogenous in respect of rainfall regime, forest type and are managed as part of national park under the same management objectives (Gubbi et al. 2012), results of shrub and sapling study indicate that there exists some distinguishing factors along the two segments so as to favor different species. A further detailed study is required to point out the factors responsible.

Contrary to the general understanding, invasive species cover for two of the common invasive species (Lantana camara and Eupatorium odoratum) was higher in the area devoid of traffic as compared to the night traffic closed road segment. This can be attributed to increased light intensity on the forest floor due to lower canopy cover in the decommissioned road segment and higher animal activity, who acts as seed dispersers. Lower canopy cover in decommissioned road segment can be the result of breakage of canopy and crushing of new regeneration by higher presence and more frequent activity of large mammals, like elephants.

Mean group size of chital was found to be higher in the night traffic closed road segment, whereas mean crowding was higher in the decommissioned road segment. Higher presence of chital in the night traffic closed road segment can be because of availability of more fodder species and less risk of predation. In the decommissioned road segment, chital and wild pig's habitat use is not affected by the distance from the state highway, whereas, sambar and elephant's habitat choice is determined by distance from the highway.

There has been a 16% increase in the traffic volume from 553 vehicles /day in the last 9 years as reported by Gubbi et al. (2012), to 659 ± 139.70 as reported in our study. However, though there has been an increase in the traffic volume, it is at a slower rate as compared to the increase from 2003 to 2010 level. The average speed of vehicles ranged from 27.5 MPH to 35.4 MPH.

We found that in the night traffic closed road segment, animals have modified their activity periods to avoid the vehicular traffic. Most of the mammals are either active in the early morning hours before the road is opened for vehicular movement or late evenings after the road is closed. This suggests that there is a difference in activity pattern of these mammals along both the road segments, in order to understand which a further detailed study about behavior modification of mammals in relation to traffic and other road related disturbances needs to be carried out.

1. Introduction

Advancement of human society and improvement in the lifestyle of people of a country requires a great deal of social and economic developmental activities. One form of such activity is building of a network of linear infrastructure, which facilitates connectivity of people and transportation of goods.

India being one of the seventeen mega diverse countries of the world boasts of having a rich array of flora and fauna. Forests in India occupy 21.54% of the geographic area of the country (ISFR, 2017). They are a repository of over 45,000 species of plants and 91,000 species of animals (1). For preservation of this natural heritage, 5.02% of the geographic area of the country has been designated as protected, under different categories of the protected area network (WII ENVIS, 2019). Several projects have also been launched by the government that focuses on the protection and conservation of certain keystone and umbrella species like the Project Tiger or Project Elephant.

Delimiting and designating areas as protected ensures some degree of special protection to the wildlife. However, the viability of wildlife depends on contiguous patches of forests. Both plants and animals require uninterrupted forest patches for gene flow, dispersal and movement in search of food, shelter, mate or maintaining their home ranges.

While large networks of linear infrastructure are indicators of economic growth, they put immense pressure on the natural capital of an area. Expansion of roads is one of the primary causes of deforestation, habitat fragmentation and biodiversity loss. The impacts of road can be both direct and indirect.

1.1 Impact on Flora

Road building alters the soil and hydrology of any area. This leveled and paved infrastructure impedes drainage. It causes flooding in the upstream side of the road, inundating vegetation patches and killing them. Whereas, water flow is obstructed on the downstream side of the road fill, which may cause water stress to vegetation, especially in the dry seasons (Laurance et al. 2009). The level of dust, suspended particulate matter and other pollutants is high near roads and highways. This impacts the metabolism of plants and affects the rate of photosynthesis and may cause nutrient stress. The degree of stomata opening is also reduced which impacts the physiological activities of plants. Roads enhance the invasibility of an area. Construction of roads results in direct mortality of vegetation and clears up patches which are invaded by disturbance adapted species. They increase the availability of resources such as light, nutrients, water and space and decreases competition for these resources from the resident vegetation (Davis et al. 2000).

1.2 Impact on Fauna

Roads passing through wildlife habitat can severely alter the behavior of animals in response to the associated traffic and traffic emissions. Road and the associated traffic can either cause direct mortality of animals or can result in various forms of barrier effects. Barrier effect is a consequence of animal's response towards the road itself, the traffic emissions, or vehicles (D'Amico et al. 2015). Road kill as a result of collision with vehicles is one of the main sources of mortality (Forman and Alexander, 1998). Road kills can be of serious consequence if the species belongs to rare or endangered category. Road corridors cause a lot of disturbance like opening up of canopy, changes in light regimes, noise, pollution, vibrations and creation of urban heat island effects, due to which animals avoid it (D'Amico et al. 2015). Moreover, road corridor subdivides the populations which may lead to inbreeding and reduction in genetic variability. The negative impact of roads is not just limited up to the paved surface, but it entails a much larger road effect zone. Traffic emissions disturbances can extend further inwards and affect the activity and behavior of wildlife.

Detailed studies are required to assess the negative impacts of roads on both the physical and biotic attributes of the environment to combat both the direct and indirect negative impacts of roads.

2. Rationale

India has a total of 5.5 million km of road network. The road sector in India is growing at a fast rate with 892 km and 2,345 km of national highway projects being awarded and constructed respectively between April to August, 2018. The government is also looking at opportunities to boost up the investment in the road sector. A National Highway project worth ₹1, 10,154 crore was announced in March, 2019 (2). The growth in the development of roads sector has provided impetus to the automobile industry with India becoming the seventh largest producer of commercial vehicles in 2018. India is expected to become the leader of the world in the two wheeler and four wheeler markets by 2020 owing to the various initiatives being taken by the government and the automobile industry (3).

Areas exclusively set aside for wildlife protection are also not excluded from this rapid development process. Some of the prominent National Parks and Tiger Reserves in India are cut across by National Highways and State Highways. Examples include National Highway 72 and 74 crossing Rajaji Tiger Reserve; State Highway passing through Balram Ambaji Santuary; seven State Highways through Gir National Park and Sanctuary; Poily-Ranjitpura approach road passing through Jambughoda Wildlife Sanctuary (Joshi and Singh 2007; Joshi and Dixit 2012) and important Central Indian wildlife corridors like Nagzira-Navegaon, Kanha-Indravati and Bor-Melghat being impacted by NH-6 and Tadoba-Kawal, Tadoba-Bor and Tadoba Tipeshwar by NH-7 (Habib et al. 2015).

Unfortunately, roads that are the foundation on which other forms of economic development takes place, acts as linear intrusions for the environment.

To preserve the nature and maintain ecological balance, one of the most important steps is to assess the impacts of investment proposals. This procedure is essential for preventive control. Although Environmental Impact Assessment has been made mandatory by the government before any form of developmental projects are undertaken, their concerns are limited to the physical and socio- economic attributes of the environment. Ecological solutions suggested by EIA lacks proper implementation and are insufficient for addressing the concerns related to biodiversity. Key problems are the lack of availability of relevant data, inadequate understanding of complex ecological processes and procedural difficulties largely due to the lack of temporal flexibility in EIA procedures (Treweek 2012). Ecological Impact assessment has a more focused approach on the long-term impacts of man-made structures on the biotic components.

To collect relevant data for assessing the negative impacts of roads on wildlife and to ensure that progress is in sync with conservational activities, an extensive three years project was undertaken in three important tiger landscapes of India. The results of this project would be useful in understanding as to which road feature (road surface, road gap, traffic emissions or traffic volume) calls for the most negative response from species. Such distinction is important for taking up the most suitable mitigation measures (D'Amico et al. 2015). Through ecological impact assessment, the aim is to plan and design smart green infrastructure.

3. Study area

This study was carried out in Nagarhole Tiger Reserve (Rajiv Gandhi National Park), which forms a part of the Nilgiri Biosphere Reserve situated between 11°50'-12°15' N and 76°0' -76°15' E. the elevation range varies from 700m- 960m, extending from the foothills of the Bramhagiri range in the west to the Deccan Plateau on the east (Mahanty 2003). It is located in Mysore and Kodagu districts in the state of Karnataka. The National Park was constituted as the thirty-seventh Tiger Reserve in 1999. It is one of India's premier tiger reserve. Nagarhole is a Kannad name which translates to 'Naga' meaning 'snake' and 'hole' meaning 'stream'. It refers to the Kabini backwaters, which passes through the park in a winding pattern and separates it from the adjoining Bandipur Tiger Reserve.

Nagarhole national park is one of the best places to spot the Asiatic Elephants. Apart from elephants, the park hosts a vast array of animals. Some of the common predators found here include tigers, leopards, and dhole. It also holds a particularly good ungulate population which includes spotted dear, sambar, barking deer, mouse deer, wild pigs, and gaur. Apart from these, the park also has a good population of small mammal species like Indian grey mongoose and ruddy mongoose, civet, porcupine, jungle cat, Indian hare, Indian giant squirrel, etc. Some of the common bird species that can be sighted around the park are peacocks, jungle fowl, white throated kingfisher, crested serpent eagle, and parakeets.

The forest type found in the park follows the decreasing elevation and level of precipitation from west to east. The northern and western part of Nagarhole receives higher rainfall and is consequently moist as compared to the south-eastern part. The dominant forest type of the park is southern tropical moist deciduous forest which occurs in the western and southern part. Southern tropical semi- evergreen forests occupy small pockets of the western boundary. The eastern side of the park is composed of southern tropical dry deciduous forest and scrub. Swampy areas (known as hadlus) occur in low-lying patches, with grassy cover and scattered tree cover (Mahanty 2003). The major tree species present in the park are *Anogeissus latifolia, Terminalia tomentosa, Dalbergia latifolia, Phyllanthus emblica, Cassia fistula, Stereospermum tetragonum, Butea monosperma, Lagerstroemia lanceolata*, etc. Plantations of *Tectona grandis* and *Eucalyptus teriticornis* can also been found which were established between the early 1900s and the 1970s. Some of the shrub species found is *Zizyphus oenoplia, Zizyphus xylopyrus, Albizia julibrissin and Helicteres isora*. Common grass/ herb species like *Cynodon dactylon* and *Mimosa pudica* is also present in the forest. Along with the economically important timber species and native vegetation, infestation by weeds like *Lantana camara* and *Chromolaena odoratum* is a serious problem.

The park is also home to tribal people, namely Jenu Kuruba and Yerawa tribes. There have been multiple eviction and relocation of tribals since the implementation of the Wildlife Protection Act in 1972. After the park was declared a Tiger Reserve in 1999, a number of families voluntarily moved out of the park.

It has three distinctive seasons: winter (November to January), summer (March to May) and monsoon (June to September). The mean annual rainfall ranges from 900 mm in the east to 1500 in the west.

1.3 State Highway- 33

The park is located in the south-western corner of the state of Karnataka. Wayanad wildlife sanctuary of Kerala is located on its western boundary. State Highway 33 (Mysore Mananthavady route), which connects the city of Mysore to Mananthavady, a taluk in Wayanad district of Kerala, passes through the Tiger Reserve.

The area of the park that was selected for conducting the study consists of two ranges: Anthrasanthe range and D B kuppe range. The area was ideal for conducting research in the sense that the SH passes through these two ranges and thus its impact on both flora and fauna can be found out. Additionally, one segment of the highway passing through Anthrasanthe range was closed to any form of public usage and traffic 10 years ago and an alternate road from outside the park was constructed, that joins the D B kuppe range. Stretch of highway passing through D B Kuppe is also closed to traffic from 6 pm to 6 am (Gubbi et al. 2012). Thus, this gave us an opportunity to use the Anthrasanthe stretch (segment 1) as control stretch and the D B Kuppe stretch as treatment stretch (segment 2) for comparing the effects and response of wildlife in the absence and presence of traffic respectively. The study area has two main sources of water, Taraka dam located on the north-eastern side, and Kabini reservoir, located on the eastern side. Apart from these two, several seasonal streams originate in the area and it also consists of artificial tanks and water holes made for the animals.

Study was carried out on both sides of the highways up to 2 km inside the forest. A total of 19.1 km stretch of the highway was studied, 7.4 km falling in the Anthrasanthe range: decommissioned road segment (DCR- segment 1) and 11.7 km in the D B Kuppe range: night traffic closed road segment (NCR- segment 2) (Figure 1).

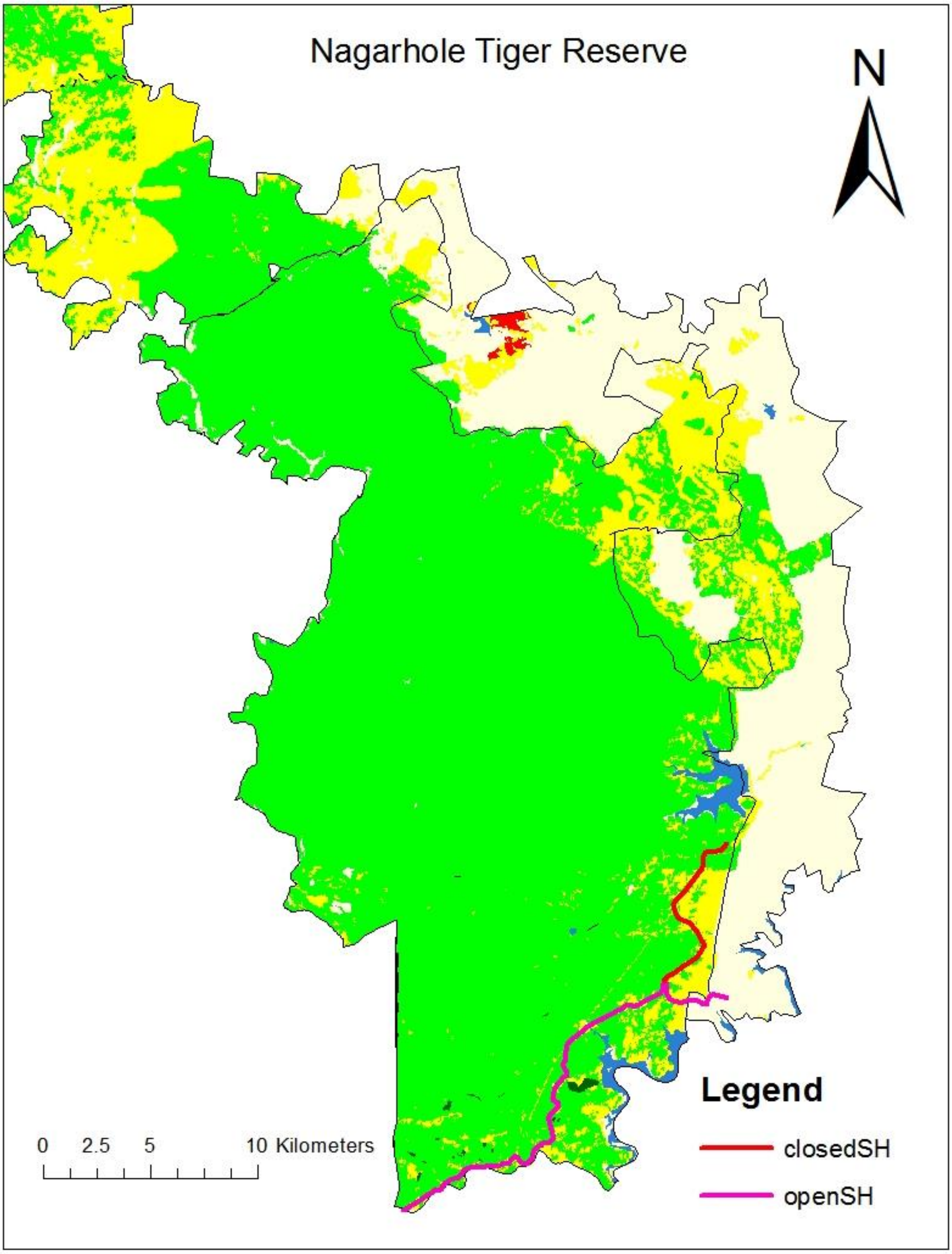


Figure 1: Study area map showing the two segments of State Highway 33 passing through Nagarhole Tiger Reserve, Karnataka, superimposed on LULC map of the area

4. Objectives

The objectives of this study were as follows:

i. To study the tree species composition and richness and compare it along the two segments of the State Highway.

Linear infrastructures alter the physical and chemical environment of the area where they are laid. This effect extends beyond the physical presence of road and persists even long after the construction is over. Soil temperature, light conditions, soil density, porosity, soil water content and runoff pattern are all altered due to road construction. Soil compaction is one of the serious consequences of road development, which continues to exist even if the use of road is discontinued. The amount of light incident on the forest floor also increases as the canopy is cleared for road construction. This enhanced light condition, favours selective species which is disturbance adapted and thrives under high levels of light (Trombulak and Frissell 1999). Forest patches located alongside highways are highly susceptible to enhanced invasion by exotic or invasive plant species, thus, displacing the native growth (Trammel and Carreiro 2011). Human and vehicular induced dispersal of seeds of invasive species is another cause of enhanced invasion of road verges by exotic species. SH 33 host all the conditions that favor the spread and establishment of invasive species and hence it necessitates a detailed vegetation analysis along roadside to find out the extent of invasion and condition of native vegetation. SH 33 also provide an opportunity to compare the variation in degree of invasion along a highway that is no longer used, with the one that is heavily traversed by humans and vehicles.

ii. To see the difference in group size and composition of ungulate species at various distances from the State Highway along the two segments of the road.

Information regarding group size of a species facilitates our knowledge regarding various ecological parameters such as habitat structure, spatio-temporal distribution of food, predation pressure, pathogen pressure, aggression, foraging success, metabolism and sexual selection in animal community (Reiczigel et al. 2008; Barrette 1991). Size of groups varies widely within and between species, as part of their adaptive measures to the surrounding environment (Barrette 1991). Linear infrastructure induced disturbance are bound to cause changes in animal behavior and sociality patterns. Nagarhole Tiger Reserve hosts a vast population of ungulate species and provides an opportunity to study the effect of vehicular traffic and road related effects on grouping behavior of ungulates.

iii. To find out the difference in habitat use pattern of major ungulate species along the two segments of the road.

Co- occurrence of different species at one place is governed by their spatial or temporal isolation in respect to available resources (Dar et al. 2012). Use of particular habitat is a function of the environmental characteristics of that area. This largely includes food availability, quality and security aspects (Lovari and Cosentino 1986). Information regarding habitat use provides useful tool in combining forest and wildlife management (Harkonen and Heikkila 1999). Microhabitat, diet and temporal activity time are the three main factors which differentiate between different species in terms of their habitat utilization. This choice becomes further complicated if human induced disturbance is introduced in the area. Linear infrastructures cause barrier effects. It causes fragmentation of the natural habitat (D'Amico et al. 2015). This objective was undertaken to determine how habitat preferences of ungulate species change in response to various road related effects in Nagarhole Tiger Reserve and how it varies between segments of road; one that has been closed to vehicular traffic and the other that is heavily used.

iv. To analyze the activity patterns of major prey- predator species in relation to traffic volume along both the segments.

Activity is a vital component of life for any animal but it involves elevated risk of exposure to predators and thermal stresses and thus is energetically costly. Therefore, animals need to optimize their time in such a way as to meet their daily requirements while minimizing the associated costs (Rowcliffe et al. 2014). Apart from risk of predation and other natural biotic and abiotic factors, there are several anthropogenic determinants of activity level. One of the most pervasive forms of anthropogenic disturbance is the road infrastructure. The direct effects of this are habitat loss and population decline, due to either road mortality or population isolation. The indirect effects are even more serious and difficult to quantify. These include altered species behaviors and interspecific interactions. To make informed conservation decisions and management plans, better understanding of the indirect impacts of roads and its associated effects on animals need to be studied (Frey et al. 2017). Nagarhole Tiger Reserve provides an opportunity to compare the activity level and pattern of animals in relation to road and various road related emissions.

5. Methods

All the grids were categorized into four different distance classes based on their distance from the highway. The four distance classes are: 0-500 m, 500-1000 m, 1000-1500 m and 1500-2100m. Although the number of grids sampled was more in NCR, for the purpose of comparison only 51 grids were taken into consideration during analysis.

Dataset and Software used:

- Remote sensing dataset- LANDSAT data of Land Use Land Cover map, Forest type map, DEM and Road networks map has been used.
- Software used:
  - Arc GIS 10.5
  - PAST version 3.25
  - Flocker 1.0
  - Traffic viewer pro software
  - R
  - SPSS
- Device used:
  - Garmin GPS 72
  - Nikon Prostaff 3i laser rangefinder
  - Cuddeback Camera Traps
  - PicoCount 4500 4 channel vehicle counter

a. Vegetation structure and composition

Vegetation sampling was done from January, 2019 to April, 2019. In order to see how vegetation composition change as one moves away from the road, sampling was done up to 2.1 km inside the forest on both sides of 19.1 km stretch of the road.

Data collection:

Variables regarding which data was collected includes species richness, number of individuals, girth, percentage canopy cover and height. Girth was measured using a measuring tape, while height was measured using Nikon Prostaff 3i laser rangefinder for the first few trees and thereafter by ocular estimation. Species identification was based on our previous observations and knowledge; some species' identification books on tree species were also referred. Apart from vegetation characteristics, data on other habitat variables like ground cover, signs of fire, grazing, lopping, presence of cattle dung piles were also collected.

Field methods:

0.5 sq km grids were generated along both sides of the highway and two random points were created inside each grid with Arc GIS.

↓

vegetation sampling was done in nested quadrat of 10x10 m and 5x5 m for trees and shrubs respectively.

↓

three 1x1 m quadrats were laid randomly inside 10x10 m quadrats for sampling grasses and herbs.

↓

ground cover of each quadrat was noted in percentage with the help of a graded stick at 3 random places.

A total of 111 grids and 222 random points were created. 51of the 111 grids were falling in the decommissioned segment and the remaining 60 in the night traffic closed road segment. The location where camera traps were fixed was taken as the third point for sampling. The points where camera traps were fixed was decided after ground truthing. Each point was kept at least 300 m apart from each- other. A total of 333 points were selected for sampling (Figure 2). The points which were falling in a water body, agricultural farms, or human habitation were not sampled. A total of 326 points were sampled. In each quadrat, individuals with >30 cm GBH were recorded as trees, and individuals with <30 cm GBH were classified as shrubs/saplings.

Analytical methods:

An inventory of species and families found along both sides of the road was made to differentiate among the composition of species present at different distance classes from the highway and along the two study segments. Species richness, number of individuals, girth and other data collected were used to calculate the density, frequency, abundance, A/F ratio, basal area and dominance. The Importance Value Index for tree species was found out by the following formula (Bano M et al. 2017; Ajayi and Obi 2015):

IVI= (relative frequency + relative density + relative dominance)

The species with the highest IVI value was designated as the dominant species (Ajayi and Obi 2015; Kunwar and Sharma 2004). For shrubs, saplings and herbs, density, abundance and A/F ratio were used to characterize the vegetation. The difference in invasive species cover between the two road segments was made based on percentage cover. For grasses, the percentage cover of each species present in both the road segments (DCR and NCR) and the average cover occupied by each species of the total area sampled were calculated.

The canopy cover was classified in to the four canopy cover classes given by FSI and the percentage of canopy falling into each class was computed. The four broad canopy classes given by FSI are as follows:

- Very dense forest- All lands with tree cover of canopy density of 70% and above.
- Moderately dense forest- All lands with tree cover of canopy density between 40% to 70%.
- Open forest- All lands with tree cover of canopy density between 10% to 40%.

- Scrub- All forest land with poor tree growth mainly of small and stunted trees having canopy density less than 10%.

The difference in percentage canopy cover at different distances from the state highway was also calculated.

Density and Species diversity indices were used to differentiate between the vegetation structure (trees, shrubs and herbs) along both segments of the highway as well as among different distance classes (Kuma and Shibru 2015; Yeom and Kim 2011). PAST version 3.25 was used to calculate the different diversity indices based on density of each species in different distance classes. Four diversity indices were used for comparison (4; 5; Hammer 1999):

- Simpson's index- It measures the evenness of the community. It is a dominance index and is based on the abundance of the most common species.
- Shannon diversity index- It takes into account the number of individuals as well as the number of taxa present. It also takes into consideration the rare species. It is an information statistic index.
- Brillouin's index- It is an information statistic index and places more emphasis on species richness.
- Berger-Parker index- It is a dominance index. It means the community is dominated by the most common species. The value of Berger-Parker index is inversely proportional to the evenness of the community.

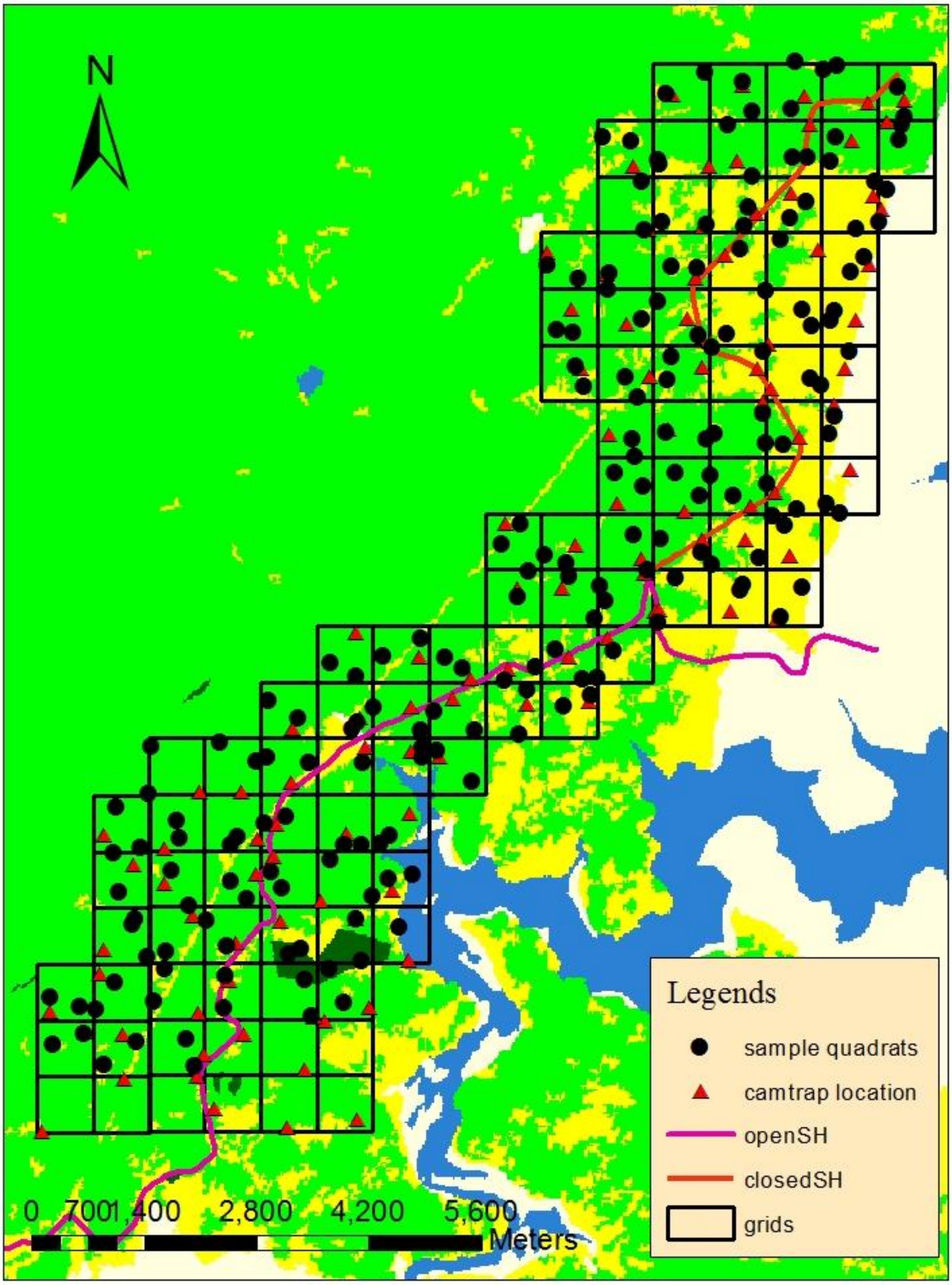


Figure 2: Vegetation sampling and camera trap points along the SH superimposed on land use map of Karnataka, India.

b. Group size and composition of ungulates

Data on group size and age/sex composition of five major ungulate species namely, Chital, Sambar, Barking deer, Wild pig and Gaur was collected through jeep surveys. Group size can be defined as the sum of number of individuals in different age classes; present in close proximity of each-other (Dar et al. 2012). Crowding can be defined as the group size which is experienced by any individual (Reiczigel et al. 2008). 19.1 km stretch of highway was surveyed for data collection at a single stretch, however, observations for DCR segment and NCR segment were noted down separately. Data for both the winter and summer season was collected as the survey was conducted from January 2019 to April 2019.

survey was conducted in the morning (6am- 9am) and evening hours (3pm- 6pm) (Dar et al. 2012)

↓

the number of individuals belonging to each age-sex class was counted and noted

↓

the distance of groups from the road was measured with a range finder

↓

data regarding the habitat type, topography, vegetation type and activity of ungulates was also collected

The difference among different gender and age classes were made on the basis of presence or absence of antlers, body size and coat color. Six categories of sex/age class were studied:

- Adult male
- Sub-adult male
- Yearling
- Adult female
- Sub-adult female
- Fawn

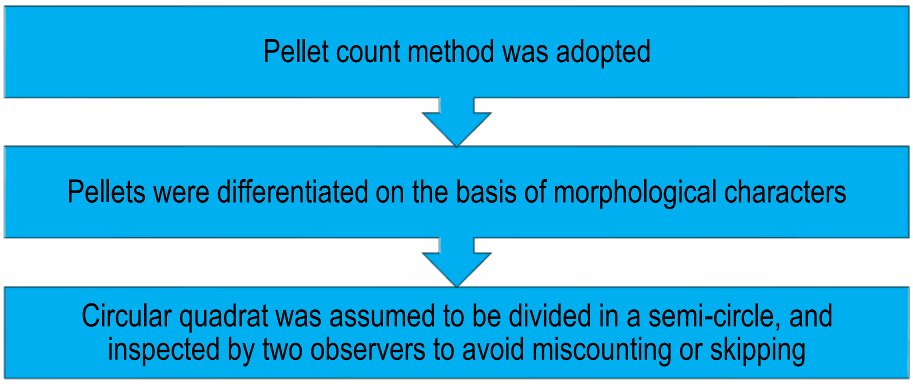
Analytical methods:

The statistical methods which are generally used for studying group size are often inconsistent and flawed. Data are highly skewed and converting it to approximately normal distribution is often impossible and even though it is transformed, the obtained results are difficult to interpret. Application of non-parametric methods such as the Mann-Whitney U test which takes into account the median is also not appropriate. This method holds good only under certain restrictive assumptions like the Shift model. This model assumes that the distribution curves to be compared should have the same shape, allowing only for a potential shift of location. This presumption is unrealistic when dealing with animal group size distributions (Reiczigel et al. 2008; Dar et al. 2012). To represent the relationship between distance from the highway and average group size/ number of groups, histograms were created with 5 m interval distance classes for both segments of the road. Flocker 1.0 software was used to find out the descriptive statistics about the group size; mean group size, median group size and mean crowding at 95% confidence limit of chital. The other ungulate species were omitted as there were not enough sightings to draw valid conclusion. The outliers were not excluded from analysis as that would have led to the loss of information. In case of group size, extreme values are real values sampled from a highly skewed distribution and are not considered as outliers (Reiczigel et al. 2008). The sex ratio and fawn/ yearling ratio was calculated by number of adult male to adult female and the number of fawn/yearling to adult female respectively.

c. Habitat utilisation by ungulate species

The 10 m radius quadrats, laid for vegetation sampling was also used for collecting data for determining the habitat utilization by ungulate species. Sampling was done from January 2019 to April 2019.

Field methods:



The number of pellet groups found was noted down species wise. Elephant dung piles were also counted.

Analytical methods:

Descriptive statistics of the pellet group data collected was calculated through SPSS to compare the mean density of pellet data along both the road segments of Nagarhole Tiger Reserve. Thereafter, generalized linear models were used to find out the variables which significantly contribute towards the determination of habitat utilization by each ungulate species whose pellets were found. The hypothesis of our study was; H_0: Distance from the state highway and other roads have no effect on the habitat utilization of ungulate species. H_a: Distance from the state highway and other roads affect the habitat utilization of ungulate species.

To test the hypothesis, two regression models were generated: environment model; that consisted of species presence as the response variable and presence of weed in the quadrat, distance of quadrats sampled from water body, land use, forest type, aspect, slope and elevation as the predictor variables. The other regression model was the road model which consisted of distance of quadrats sampled from road, distance from the state highway and livestock as the predictor variables in addition to all the other predictor variables used in the environment model. The value of each variable used in regression modeling was extracted from the LANDSAT data and street maps available. The quadrat points where sampling for pellet groups was done as well as the camera trap locations were overlaid with raster and vector layers and the point values were extracted. Modeling was done separately for day and night time for each species to find out the difference in variables involved. Modeling was also done for elephants. The model selection was done on the basis of AIC value.

d. Activity pattern of animals

Single sided Cuddeback camera traps were deployed in each of the 111 grids. Data collection was divided season wise on both segments of the road. Cameras were fixed in January and April and February and March in the decommissioned segment and in the night traffic closed segment respectively.

Field methods:

ground truthing was done, and an animal trail or clearence was selected for deploying the camera

↓

the vegetation around the camera was cleared to minimise blank captures

↓

date and time were set and the camera was fixed on the tree trunks, approximately at knee height

↓

geo-coordinates, habitat type, name of the forest range, camera ID was noted down and GPS reading was recorded

The cameras were checked at regular interval to make sure the date and time settings are right and the batteries are functional. The cameras were deployed for 20 days. A total of 51 cameras were fixed in DCR segment with an effort of 1020 camera trap days and a total of 60 cameras were fixed in NCR segment with an effort of 1200 camera trap days.

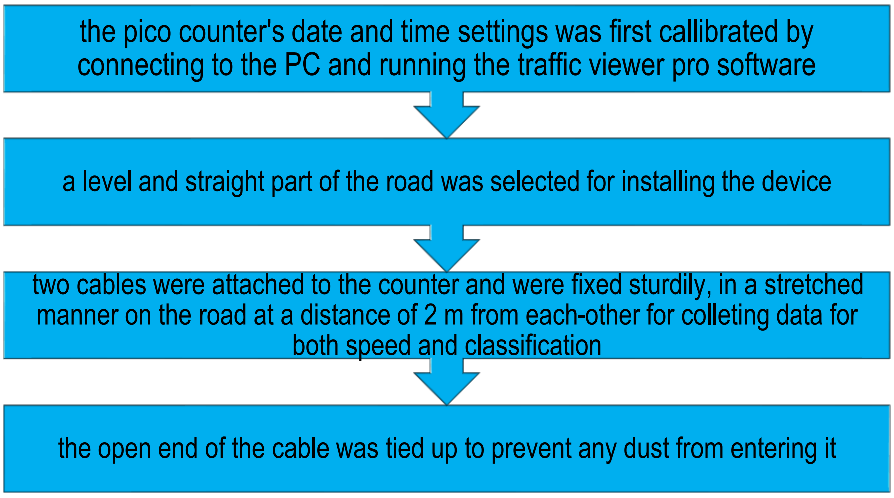
Analytical methods:

CamtrapR package in R studio version 3.6 was used to analyze the camera trap pictures and generate record tables, find out the activity histogram, activity density and activity overlap between different species with respect to time of the day and also between same species in the two segments of the road.

Activity of animals was compared with the average speed and volume of vehicles at different times during the day for NCR segment.

To collect data regarding the peak traffic hours, volume, speed and classification of vehicles passing through Nagarhole Tiger Reserve, PicoCount 4500 4 channel vehicle counter was used (6).

Field methods:



The data was collected for a period of fifteen days from 16th February 2019 to 2nd March 2019. Live reading was taken at times to check if the device is functioning properly or not. The data collected by pico counter was processed and downloaded with the help of software Traffic Viewer Pro (7).

Analytical methods:

The data was summarized to represent the average speed of vehicles for each day at different time intervals. Average speed of the vehicles was calculated and a histogram was generated to depict the relationship between average speed of vehicles and time of the day.

6. Results

a. Vegetation structure and composition

Trees Composition and structure:

A total of 40 species belonging to 20 families were found in the 4.804 ha area sampled along the decommissioned road segment, whereas a total of 38 species belonging to 23 families where found in the 4.521 ha area sampled in the night traffic closed road segment (Table 1). Total basal area was 55.64 m^2 per ha and 140.32 m^2 per ha in DCR and NCR segments respectively. The average diameter at breast height ranged from 9.5 cm to 70.02 cm in the DCR and 11.19 cm to 106.95 cm in the NCR segment. On the basis of IVI values, *Anogeissus latifolia* (65.465) and *Terminalia tomentosa* (32.087) are the dominant species in the DCR and NCR respectively (Figures 3 and 4, Appendix I). On the basis of relative density as well *Anogeissus latifolia* has the highest density (41.17%) followed by *Terminalia tomentosa* (26.14%) in the DCR segment, whereas, *Delonix regia* has the lowest density (0.081%). In the NCR segment, *Terminalia tomentosa* has the highest relative density (18.58%) followed by *Tectona grandis* (11.63%). The lowest relative density is of *Limonia accidissima* (0.11%) (Appendix 1).

Table 1: Composition and distribution of tree species in the decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve.

Species	Family	DCR	NCR
Anogeissus latifolia	Combreteceae	+	+
Dalbergia latifolia	Fabaceae	+	+
Bauhinia racemosa	Fabaceae	+	+
Bombax ceiba	Malvaceae	+	+
Terminalia tomentosa	Combreteceae	+	+
Tectona grandis	Verbenaceae	+	+
Stereospermum tetragonum	Bignoniaceae	+	+
Pterocarpus marsupiam	Fabaceae	+	+
Cassia fistula	Fabaceae	+	+
Haldina cordifolia	Rubiaceae	+	+
Randia dumetorum	Rubiaceae	+	+
Ziziphus xylopyrus	Rhamnaceae	+	+
Cordia macleodii	Boraginaceae	+	+
Mitragyna parviflora	Rubiaceae	+	+
Phyllanthus emblica	Phyllanthaceae	+	+
Santalum album	Santalaceae	+	-
Diospyros melanoxylon	Ebenaceae	+	+
Diospyros montana	Ebenaceae	+	+
Schrebera swietenioides	Oleaceae	+	-
Terminalia sp.	Combreteceae	+	+
Premna tomentosa	Lamiaceae	+	+

Schleichera oleosa	Sapindaceae	+	+
Ficus benghalensis	Moraceae	+	+
Terminalia bellerica	Combreteceae	+	-
Butea monosperma	Fabaceae	+	+
Dalbergia paniculata	Fabaceae	+	+
Cordia dichotoma	Boraginaceae	+	+
Lagerstroemis lanceolata	Lythraceae	+	+
Vitex altissima	Lamiaceae	+	-
Garuga pinnata	Burseraceae	+	+
Tamarindus indica	Fabaceae	+	-
Delonix regia	Fabaceae	+	-
Acacia leucopholea	Fabaceae	+	-
Acacia strangler	Fabaceae	+	-
Radermachera xylocarpa	Bignoniaceae	+	+
Miliusa tomentosa	Annonaceae	+	+
Limonia accidissima	Rutaceae	+	+
Randia sp	Rubiaceae	+	+
Dalbergia lanceolaria	Fabaceae	+	-
Grewia tiliaefolia	Tiliaceae	+	+
Semecarpus anacardium	Anacardiaceae	-	+
Melia sp.	Meliaceae	-	+
Pongamia pinnata	Fabaceae	-	+
Holarhenna antidysentrica	Apocynaceae	-	+
Sterculia foetida	Malvaceae	-	+
Lannea coromandelica	Anacardiaceae	-	+
Cassia siamea	Fabaceae	-	+

+ = presence, **-** = absence

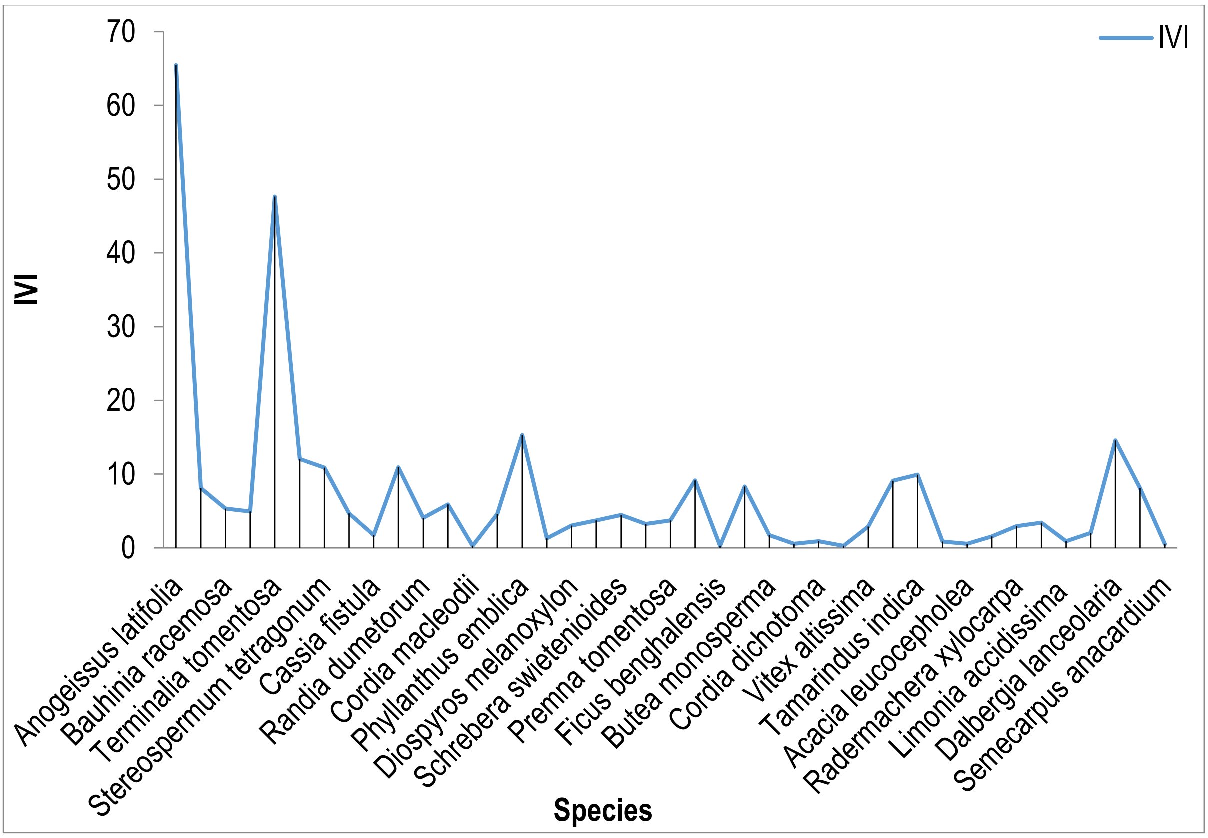


Figure 3: IVI values of tree species of decommissioned road segment

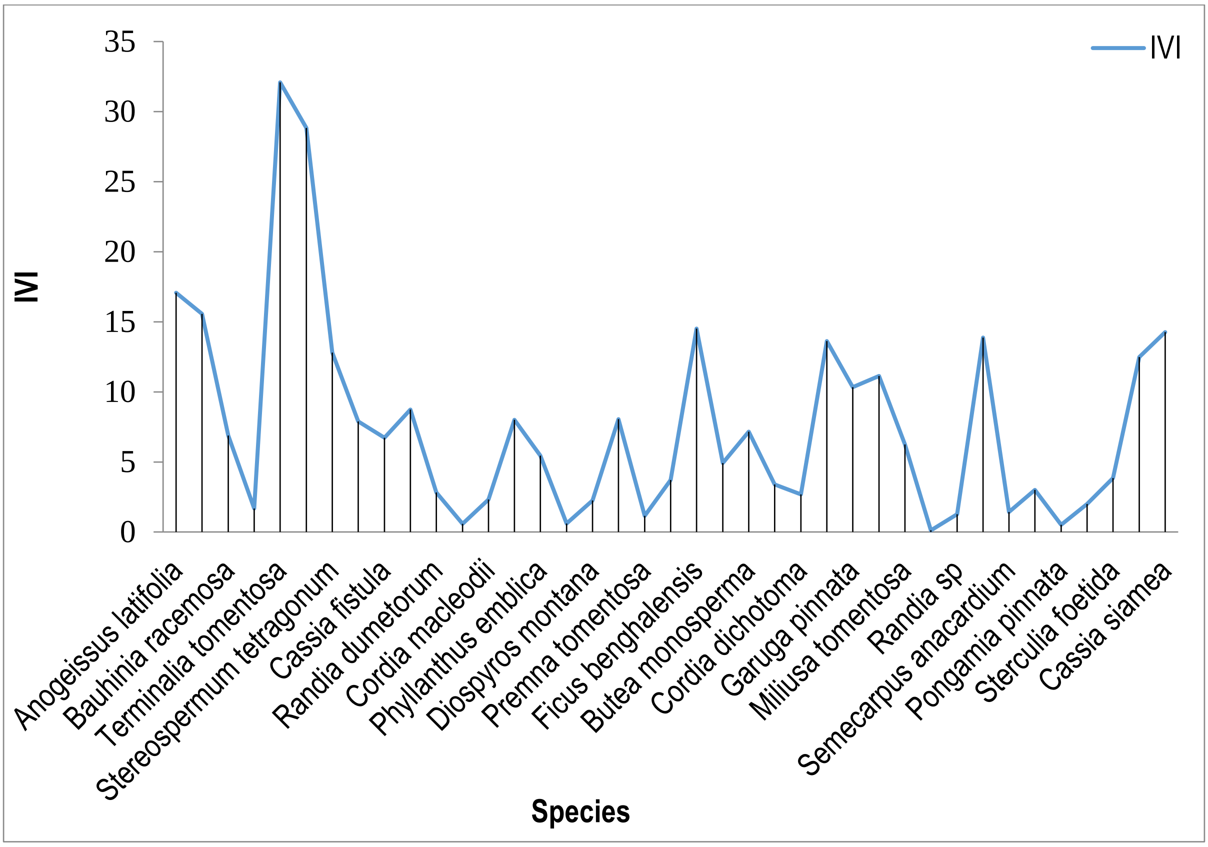


Figure 4: IVI values of tree species of night traffic closed road segment

Species Diversity:

Figure 5 represents the four diversity indices used to differentiate the species diversity between the two road segments. Two of the diversity indices used, viz. Simpson's diversity index and Shannon diversity index depicts higher species diversity in the NCR segment, whereas, Brillouin's diversity index and Berger Parker diversity index shows higher species diversity in the DCR segment.

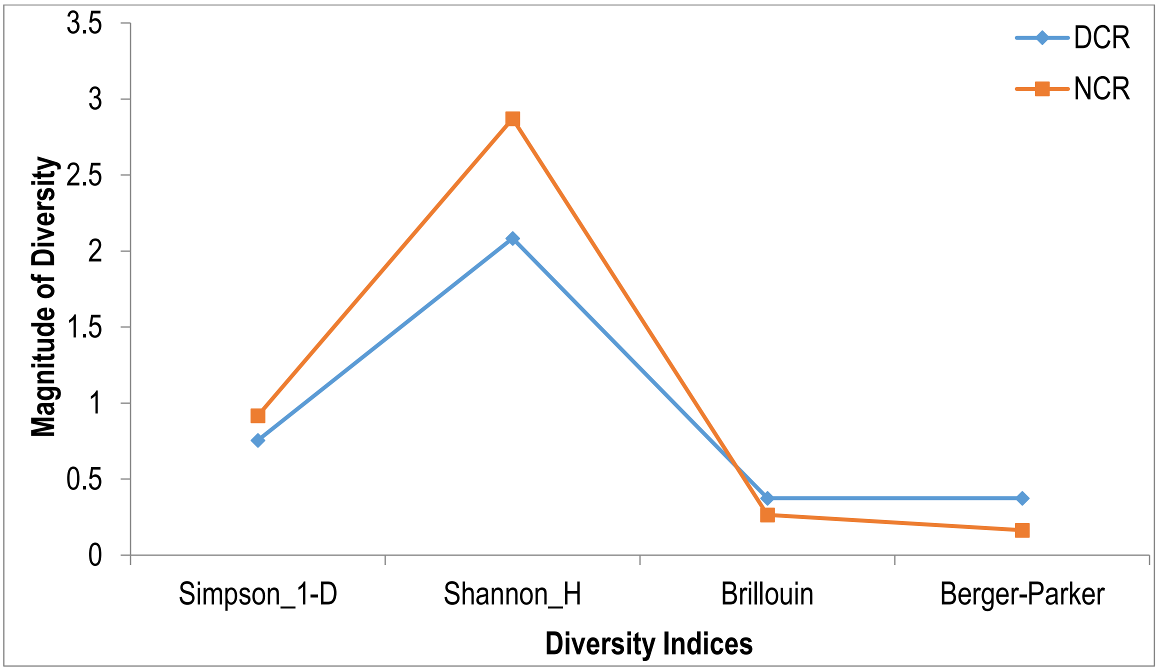


Figure 5: Tree species diversity in the decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve

Species diversity was also compared between the two roads for four different distance classes from the highway. For all the distance classes, species diversity was higher in the NCR segment according to three diversity indices; Simpson index, Shannon index and Brillouin index. According to Berger-Parker diversity index, the species diversity is higher in DCR segment for all the distance classes (Figure 6).

Shrub and Saplings composition and structure:

A total of 33 species of saplings belonging to 22 families and 9 species of shrubs belonging to 7 families were found in the 1.17 ha area sampled along the DCR segment. Whereas, a total of 32 species of saplings belonging to 22 families and 11 species of shrubs belonging to 7 families were found in the 1.13 ha area sampled in the NCR segment (Table 2 and 3). Among shrubs, *Randia dumetorum* and *Helicteres isora* has the highest relative density in the DCR and NCR segment respectively. Among saplings, *Diospyros melanoxylon* and *Cassia siamea* has the highest relative density in the DCR segment and NCR segment respectively (Appendix II).

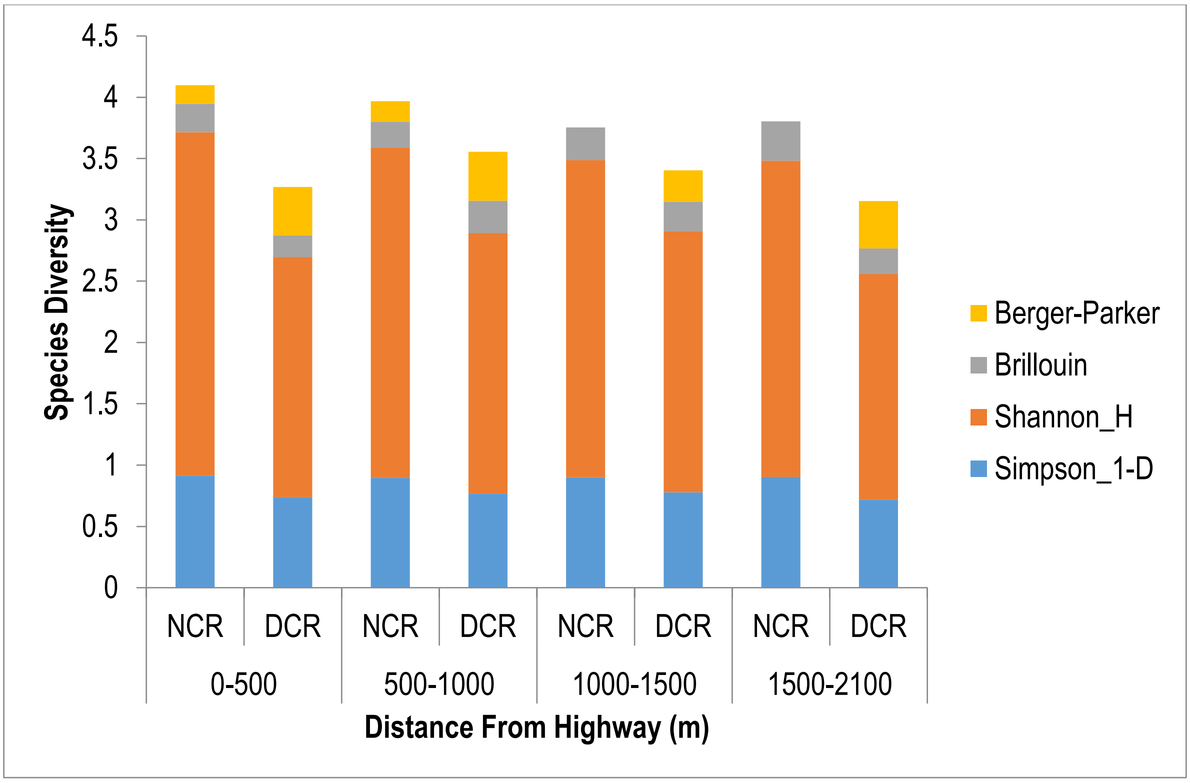


Figure 6: Value of tree species diversity indices for night traffic closed road segment and decommissioned road segment at different distances from the highway.

Table 2: Composition and distribution of shrub species in the decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve.

Species	***Family***	***DCR***	***NCR***
Asclepias curassavica	*Apocynaceae*	-	+
Cipadessa baccifera	*Meliaceae*	+	+
Grewia species	*Malvaceae*	+	+
Glycosmis pentaphylla	*Rutaceae*	-	+
Helicteres isora	*Malvaceae*	+	+
Holarrhena antidysentrica	*Apocynaceae*	+	+
Pavetta indica	*Rubiaceae*	+	+
Randia dumetorum	*Rubiaceae,*	+	+
Randia sp	*Rubiaceae,*	+	+
Solanum species	*Solanaceae*	-	+
Ziziphus oenoplia	*Rhamnaceae*	+	+
Ziziphus xylopyrus	*Rhamnaceae*	+	-

+ = presence, **-** = absence

Table 3: Composition and distribution of sapling species in the decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve.

Species	Family	DCR	NCR
Acacia ferruginea	*Fabaceae*	+	-
Acacia leucophloea	*Fabaceae*	+	-
Acacia sp (strangler)	*Fabaceae*	+	-
Acacia species	*Fabaceae*	+	+
Anogessius latifolia	*Combreteceae*	+	+
Bauhinia racemosa	*Fabaceae*	+	+
Butea monosperma	*Fabaceae*	+	+
Cassia fistula	*Fabaceae*	+	+
Cassia siamea	*Fabaceae*	-	+
Cassia species	*Fabaceae*	+	+
Chloroxylon swietenia	*Rutaceae*	+	-
Cordia dichotoma	*Boraginaceae*	+	+
Dalbergia latifolia	*Fabaceae*	+	+
Dalbergia paniculata	*Fabaceae*	+	+
Delonix regia	*Fabaceae*	+	+
Diospyros melanoxylon	*Ebenaceae*	+	+
Diospyros montana	*Ebenaceae*	+	+
Garuga pinnata	*Burseraceae*	-	+
Grewia tiliifolia	*Tiliaceae*	-	+
Haldina cordifolia	*Rubiaceae*	+	+
Lagerstroemia lanceolata	*Lythraceae*	-	+
Lagerstroemia parviflora	*Lythraceae*	-	+
Limonia acidissima	*Rutaceae*	+	+
Melia dubia	*Meliaceae*	-	+
Miliusa tomentosa	*Annonaceae*	+	+
Mitragyna parvifolia	*Rubiaceae*	+	+
Phyllanthus emblica	*Phyllanthaceae*	+	-
Premna tomentosa	*Lamiaceae*	+	+
Pterocarpus marsupium	*Fabaceae*	+	+
Santalum album	*Santalaceae*	+	-
Schleichera oleosa	*Sapindaceae*	+	+
Semecarpus anacardium	*Anacardiaceae*	+	-
Sterculia guttata	*Malvaceae*	-	+

Stereospermum tetragonum	*Bignoniaceae*	+	+
Strychnos potatorum	*Loganiaceae*	-	+
Syzygium cumini	*Myrtaceae*	+	-
Tectona grandis	*Lamiaceae*	+	+
Terminalia tomentosa	*Combreteceae*	+	+
Vitex altissima	*Lamiaceae*	+	+
Wrightia tinctoria	*Apocynaceae*	+	+
Ziziphus mauritiana	*Rhamnaceae*	+	-

+ = presence, **-** = absence

Species Diversity:

Figure 7 represents the four diversity indices used to differentiate the shrub species diversity between the two road segments. According to three of the diversity indices used, viz. Simpson's diversity index, Shannon diversity index and Berger- Parker diversity indices, there is negligible difference in species evenness and richness between the two road segments. However, according to Brillouin's diversity index, there is high species diversity in the NCR segment as compared to the DCR segment.

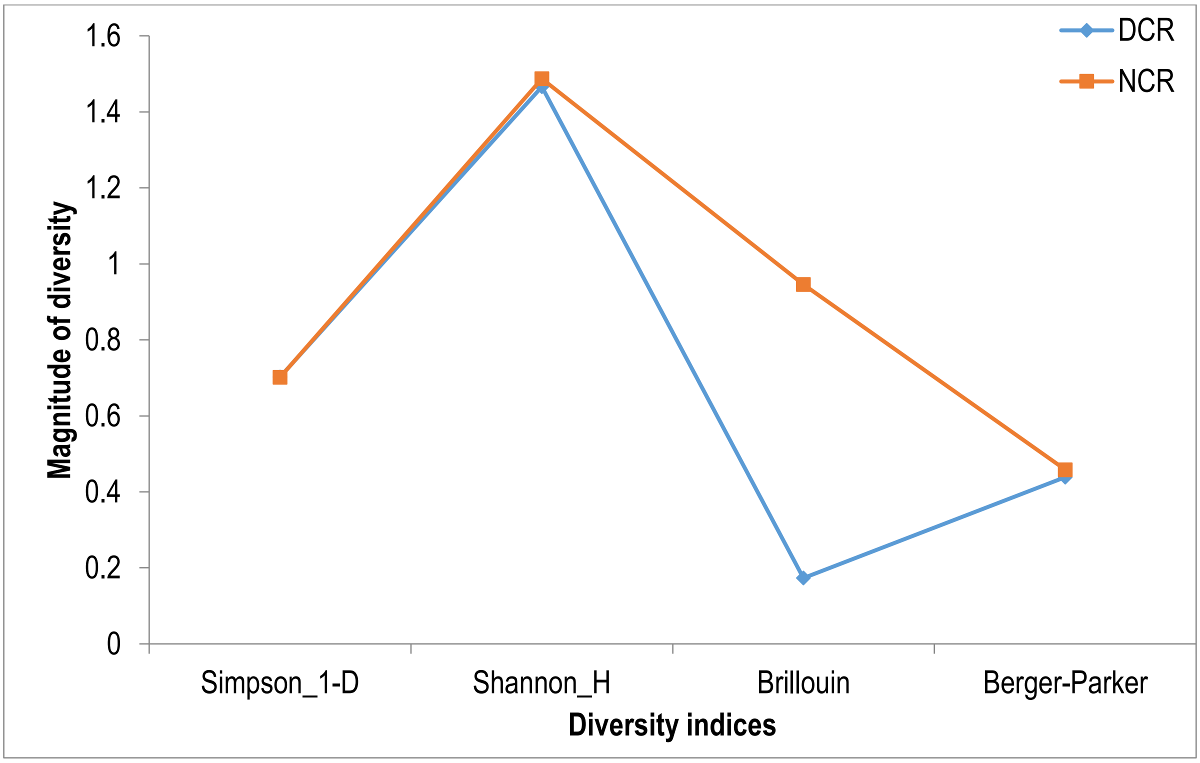


Figure 7: Shrub species diversity in the decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve.

Species diversity was also compared between the two roads for four different distance classes from the highway. According to Simpson index and Shannon index, within a distance of 0- 1000 m, species diversity is higher in the DCR segment, whereas according to Brillouin and Berger- Parker diversity index, it is higher in the NCR segment. Within a distance of 1000- 2100 m, species diversity is higher in the DCR segment (Figure 8).

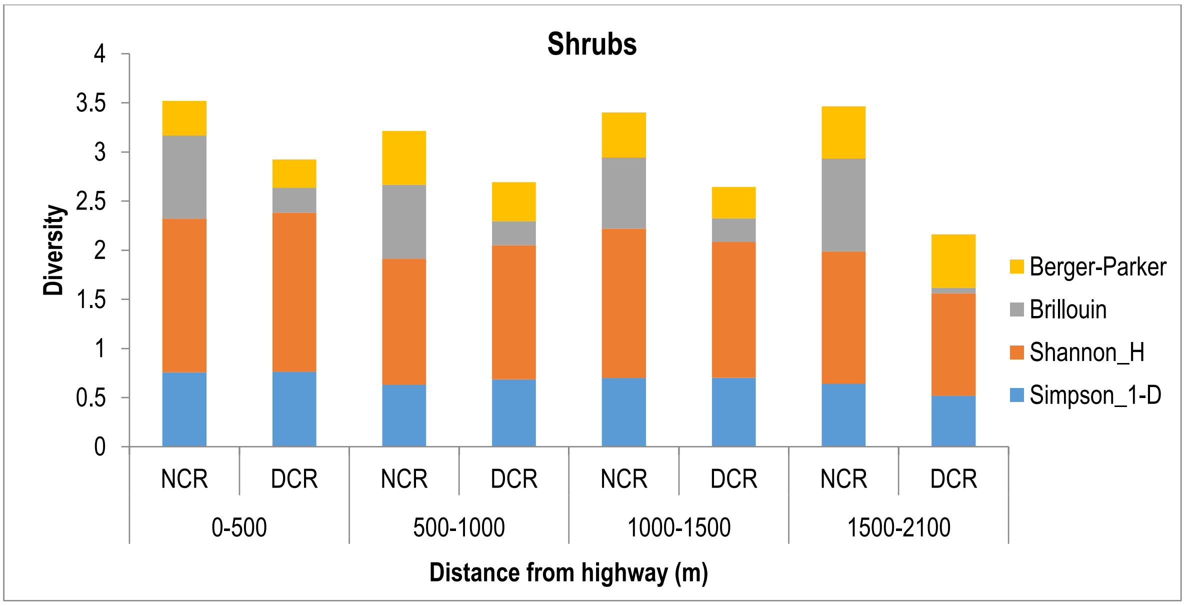


Figure 8: Value of shrub species diversity indices for night traffic closed road segment and decommissioned road segment at different distances from the highway.

Sapling richness and diversity were also compared along the two road segments in both DCR segment and NCR segment. Of the four diversity indices used, Berger- Parker diversity index show 0 richness for the DCR segment, whereas the other indices show a higher species diversity in the DCR segment (Figure 9).

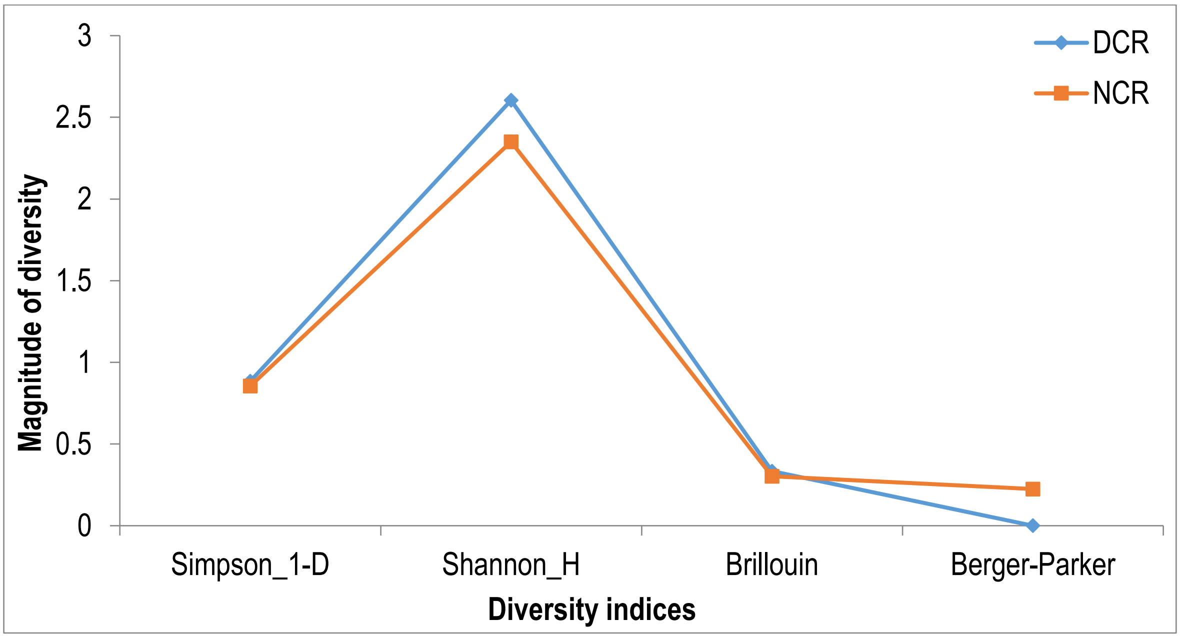


Figure 9: Sapling species diversity in the decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve.

Sapling diversity is higher in the DCR segment as compared to NCR segment for distance between 0-1000 m. within 1000- 1500 m sapling diversity is higher in the NCR segment. Within 1000- 2100 m, Berger- Parker, diversity index shows null diversity in the DCR segment as compared to the NCR segment (Figure 10).

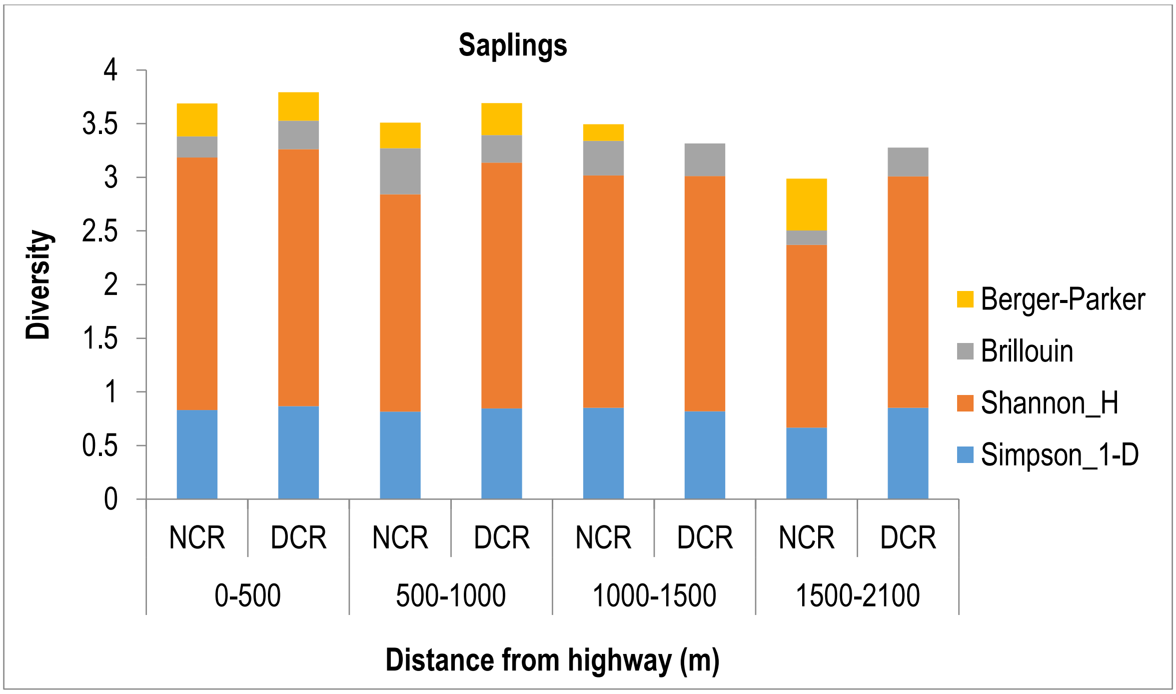


Figure 10: Value of sapling species diversity indices for night traffic closed road segment and decommissioned road segment at different distances from the highway of Nagarhole Tiger Reserve.

Invasive species

The most prominent species invading the Nagarhole Tiger Reserve is *Lantana camara* and *Eupatorium odoratum.* The overall invasive species percentage cover is very high in the DCR segment as compared to the NCR segment. The average percentage cover for *Lantana camara* was found to be 40.93% of the total area sampled in the DCR segment, whereas it was 27.06% of the total area sampled in the NCR segment. However, *Eupatorium odoratum* was found to have a slightly higher percentage cover area in the NCR segment (13.18%) as compared to the DCR segment (12.19%).

It was observed that the invasive species cover in case of *Lantana camara* gradually decreased as the distance from the highway increased in the NCR, whereas, there was no considerable decrease in the percentage cover of invasive species with increasing distance from the highway in the DCR segment (Figure 11).

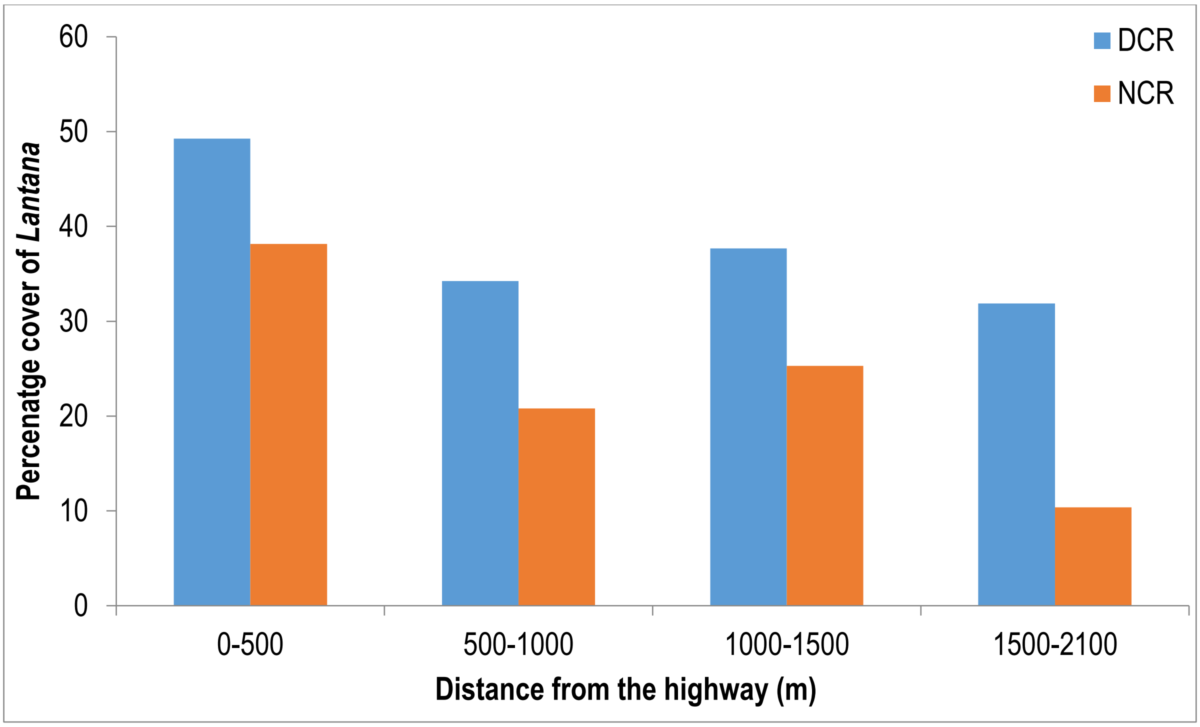


Figure 11: Percentage cover of *Lantana camara* at different distance from the state highway

In case of *Eupatorium odoratum*, the percentage cover increases steeply as distance from the highway increases in the DCR segment and then falls off again with further increase in distance. In the NCR segment there is not much difference in percentage cover of *Eupatorium sp.* in relation to the distance from the highway (Figure 12).

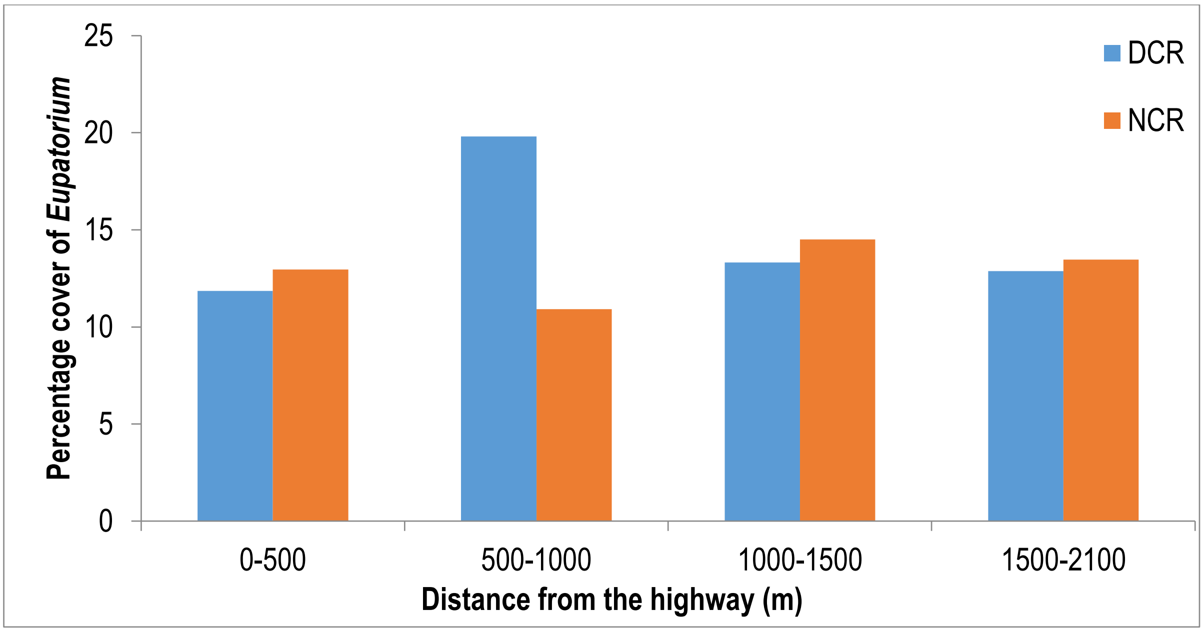


Figure 12: Percentage covers of *Eupatorium odoratum* at different distance from the state highway

Grass composition and structure:

A total of 3 species of grasses were encountered during sampling which accounts for 45.86% of the 0.044 ha area sampled in DCR segment and 47.24% of the 0.047 ha area sampled in the NCR segment (Table 4, Appendix III). On the basis of percentage cover, *Cynodon dactylon* is the most abundant species.

Table 4: Composition and distribution of grass species in the decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve.

Species	Common name	Family	DCR	NCR
Bambusa sp	*Bamboo*	*Poaceae*	+	+
Cynodon dactylon	*Doob*	*Poaceae*	+	+
Aristida hystrix	*Wiregrasses*	*Poaceae*	+	-

+ = presence, - = absence

Herbs composition and structure:

A total of 6 herb species belonging to 4 families were present in the 0.044 ha area sampled in the DCR segment, whereas, a total of 12 species belonging to 8 families were present in the 0.047 ha area sampled in the NCR segment of Nagarhole Tiger Reserve (Table 5). The highest relative density was of *Mimosa pudica* and *Alternanthera sessilis* in the DCR segment and NCR segment respectively. The lowest relative density was of *Baliospermum montanum* and *Euphorbia hirta* in the DCR segment and NCR segment respectively (Appendix IV).

Table 5: Composition and distribution of herb species in the decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve.

Species	Family	Common Name	DCR	NCR
Achyranthes aspera	Amaranthaceae	Chaff flower	-	+
Alternanthera sessilis	Amaranthaceae	Sessile joyweed	-	+
Baliospermum montanum	Euphorbiaceae	Wild castor	+	+
Sida sp	Malvaceae	Common wireweed	-	+
Curculigo orchioides	Hypoxidaceae	Golden eye-grass	-	+
Desmodium pulchellam	Fabaceae	Showy desmodium	+	+
Euphorbia hirta	Euphorbiaceae	Asthma-plant	-	+
Hemidesmus indicus	Apocynaceae	Indian sarsaparilla	+	+
Mimosa pudica	Fabaceae	Shame plant	+	+
Parthenium hysterophorus	Asteraceae	Congress grass	+	+
Solanum species	Solanaceae		-	+
Tridax procumbens	Asteraceae	Coatbuttons	+	+

+ = presence, - = absence

Species diversity

Figure 13 represents the four diversity indices used to differentiate the species diversity between the two road segments. Three of the diversity indices used, viz. Simpson's diversity index, Shannon diversity index and Berger- Parker diversity index depicts higher species diversity in the NCR segment, whereas, Brillouin's diversity index shows higher species diversity in the DCR segment.

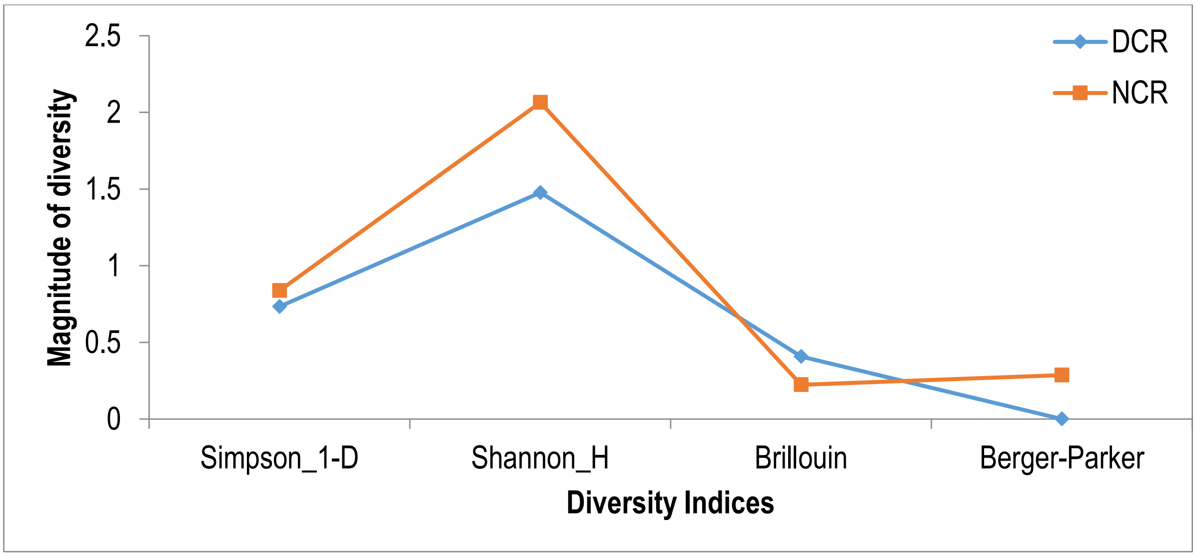


Figure 13: Species diversity index in the decommissioned road segment and night traffic closed road segment.

Species diversity was also compared between the two roads for four different distance classes from the highway. For all the four distance classes, species diversity was higher in the NCR segment according to two diversity indices; Simpson index, Shannon index. According to Brillouin's diversity index, species diversity is higher within 0- 1000 m distance from the state highway in the DCR segment and thereafter it decreases. Whereas in the NCR segment, the species diversity increases at 1000 m to 1500 m distance from the state highway and again decreases. According to Berger –Parker diversity index, the species diversity is higher in the NCR segment of Nagarhole Tiger Reserve (Figure 14).

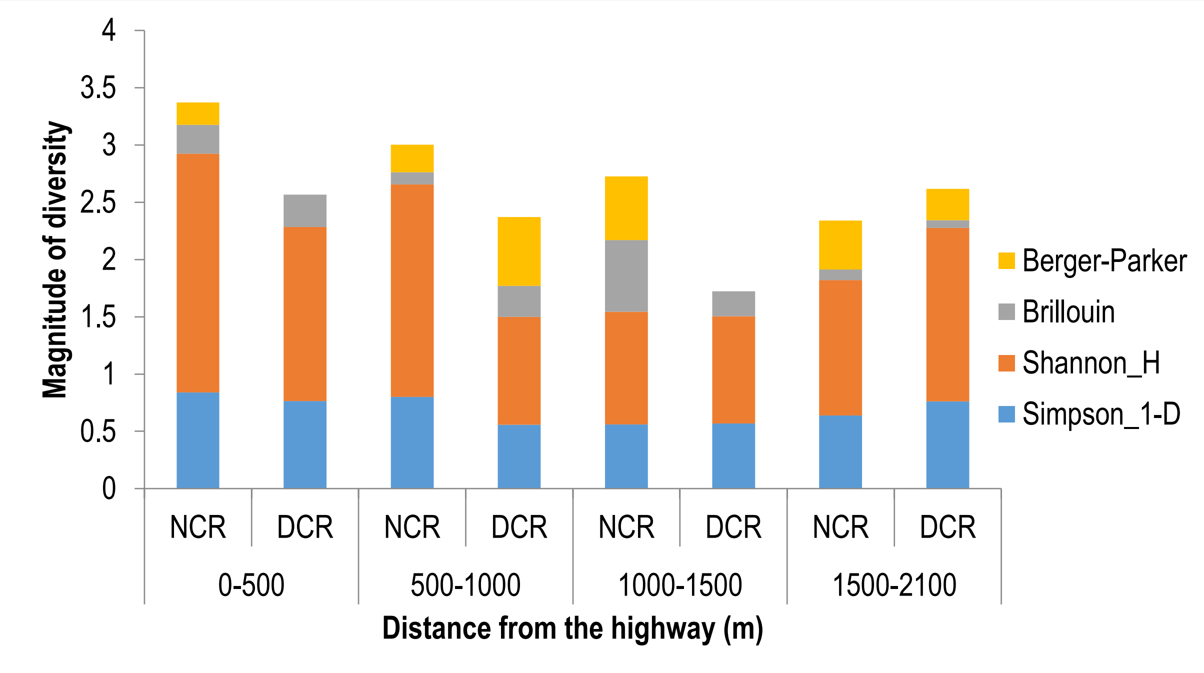


Figure 14: Value of herb diversity index at different distance from the state highway along night traffic closed road segment and decommissioned road segment of Nagarhole Tiger Reserve.

Canopy cover classification

A higher percentage of tree canopy cover was present in the NCR segment of Nagarhole Tiger Reserve. Of the total area sampled in both the segments of the road, the percentage of canopy cover falling under different categories are given in Table 6.

Table 6: Percentage of the area falling under different canopy cover classes in decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve

Canopy Cover class	DCR (%)	NCR (%)
Very dense forest (>70%)	-	-
Moderately dense forest (40%- 70%)	2.61	5.71
Open forest (10%- 40%)	45.09	74.28
Scrubs (<10%)	52.28	20

Scrubs constitute the major portion of the area sampled in the DCR followed by open forest. In the NCR segment, open forest constitutes the major portion of the area sampled followed by scrub which gradually decreases as the distance from the highway increase (Figure 15).

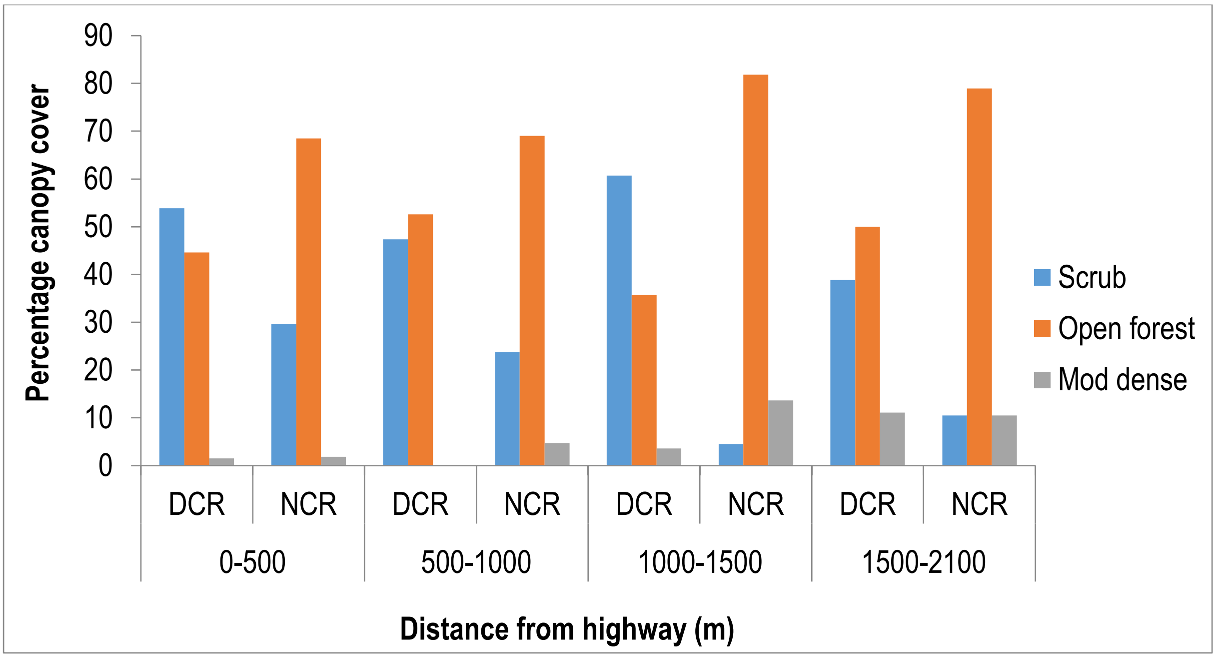


Figure 15: percentage of different canopy cover classes present along both decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve.

b. Group Size and Composition of Ungulates

In the DCR segment, the average group size of chital increased with increasing distance from the highway up to 95 m and thereafter it decreased. During the entire survey period, the maximum number of groups was observed within a distance of 0-15 m from the highway (Figure 16). In the NCR segment, distance from the highway did not have a considerable influence on the group size of chital and the maximum number of groups was observed within a distance of 20-25 m (Figure 17).

During surveys, chital was the most frequently sighted ungulate species. Sambar, wild pigs and gaur were occasionally observed and were very shy. Barking deer was rare to sight. The total number of individuals of all ungulate species and number of groups sighted during the entire survey period in both the road segments is given in Table 7.

Table 7: Total number of ungulate species sighted in both the road segments

Ungulate Species	Common Name	DCR		NCR	
		Total no. of individuals	Total no. of groups sighted	Total no. of individuals	Total no. of groups sighted
Axis axis	Chital	1338	312	3707	720
Rusa unicolor	Sambar	10	8	6	5
Muntiacus muntjak	Barking deer	2	2	11	11
Sus scrofa	Wild pig	18	6	10	3
Bos gaurus	Gaur	-	-	20	8

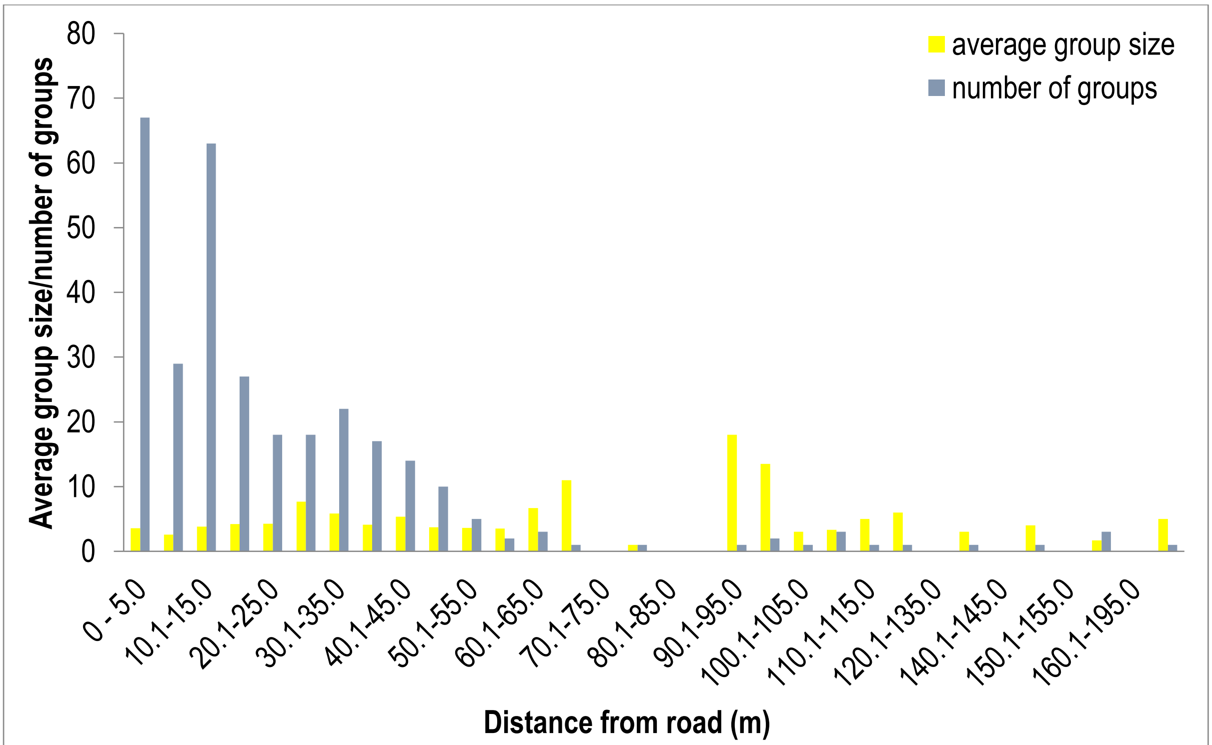


Figure 16: Histogram depicting the relationship between average group size and number of groups with distance from state highway in the decommissioned road segment.

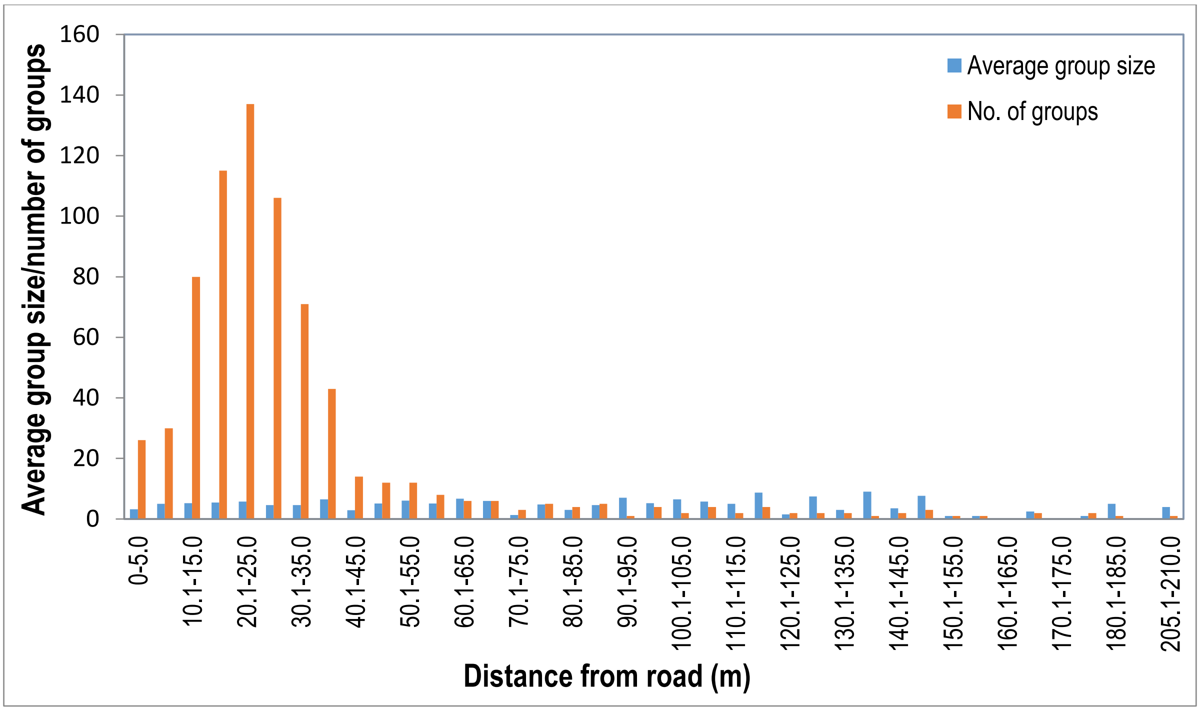


Figure 17: Histogram depicting the relationship between average group size and number of groups with distance from state highway in the night traffic closed road segment.

The mean group size and median group size at 95% confidence limit for chital was found to be higher in the NCR segment whereas the mean crowding with 95% confidence limit was higher in the DCR segment. For median group size, the exact confidence level is 100% for DCR segment and 98.2% for NCR segment (Table 8). There was no sighting of fawn/young ones of barking deer and sambar. In the DCR segment adult male barking deer was not sighted. The sex ratio and adult female and fawn/young ones ratio is given in Table 9.

Table 7: Group Size and Mean Crowding of Chital in decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve.

	DCR	NCR
Mean group size	4.42 (3.87- 4.99)	5.19 (4.89-5.49)
Median group size	3.00 (2.00- 3.00)	4.00 (4.00- 4.00)
Mean crowding	9.66 (8.01-11.76)	8.92 (8.21-10.11)

Table 8: Male/Female ratio and Female/Fawn ratio of ungulate species sighted in decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve, Karnataka, India.

Ungulate species	Common name	Male: Female		Female: Fawn/Young	
		DCR	NCR	DCR	NCR
Axis axis	Chital	599:413	1583:1243	413:165	1243:434
Rusa unicolor	Sambar	2:4	2:4	-	-
Muntiacus muntjak	Barking deer	-	3:8	-	-
Sus scrofa	Wild pig	5:8	2:2	8:3	2:5
Bos gaurus	Gaur	-	9:6	-	6:4

c. Habitat utilisation by ungulates

During survey, chital, sambar and barking deer's pellet groups were found. The density of pellet groups was found to be higher in the NCR segment of Nagarhole Tiger Reserve. The highest density was of Chital in both the road segments. The mean pellet density of all the three ungulate species found in both the road segments is given in Table 10.

Table 9: Mean density of pellet groups of ungulate species present along the decommissioned road segment and the night traffic closed road segment of Nagarhole Tiger Reserve.

Species	DCR	NCR
Chital	5.05 ± 0.378	13.63 ± 1.91
Sambar	1.58 ± 0.246	6.32 ± 0.541
Barking deer	0.32 ± 0.075	1.33 ± 0.171

The pellet density was found to be higher in the NCR segment for all the ungulate species, thus, GLM models were developed to check if the road related disturbances had any significant impact on their habitat utilization. Table 11 shows the different variables included in the model and their mean values.

Table 10: The variables used in habitat utilization model generation for ungulate species in both decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve.

Variables	Mean (±SE)
Distance from water body	1170.22 (±22.10)
Aspect (^{0})	1.53 (±1.78)
Slope (^{0})	5.05 (± 0.06)
Elevation (m)	744.34 (± 1.12)
Presence of weed	Categorical
Land use	Categorical
Forest type	Categorical
Distance from the nearest road	447.22 (± 14.91)
Distance from state highway	760.14 (± 31.46)

According to the model predictions for the DCR segment, distance from road and state highway does not affect the choice of habitat of chital and wild pig, whereas, it contributes significantly to the choice of habitat of sambar. Elephants are affected from the road related disturbance to a limited extent only during day time (Table 12-15).

Table 11: Environmental variables that significantly affect the habitat choice of ungulate species in the decommissioned road segment of Nagarhole Tiger Reserve.

Species	*Time*	*Distance from water body (m)*	*Slope*	*Aspect*	*Elevation*	*Carnivores*	*Forest type*
Chital	day	-	-	-	-	-	-
	night	-0.0003 ± 0.0001		0.002 ± 0.001			
Sambar	day	-	-	-	-	-	-
	night	-	-	-	-	-	-
Elephant	day	0.000002 ± 0.0000008	-0.18 ± 0.10	-	-	0.74 ± 0.32	-
	night	-	-	0.00001 ± 0.000006	-0.00005 ± 0.00003	0.76 ± 0.28	-0.004± 0.002
Wild pig	day	-	-	-	-	139.45 ± 62.98	-
	night	-	-63.24 ± 19.6	-	0.012 ± 0.005	-	-

Table 12: Road related variables that significantly affect the habitat choice of ungulate species in the decommissioned road segment of Nagarhole Tiger Reserve.

Species	*Time of day*	*Distance from water body*	*Slope*	*Aspect*	*Elevation*	*Carnivores*	*Distance from SH*
Chital	day	-	-	-	-	-	-
	night	-0.0003 ± 0.0001	-	-	-	-	-
Sambar	day	-	-	-	-	-	0.0001 ± 0.00004
	night	-	-	-	-	-	0.00008 ± 0.00004
Elephant	day	0.000002 ± 0.0000009	-0.19 ± 0.10	-	-	0.78 ± 0.32	-0.0000004 ± 0.0000002
	night	-	-	0.00001 ± 0.000006	-0.00006 ± 0.00003	0.74 ± 0.28	-
Wild Pig	day	-	-	-	-	140 ± 63.67	-
	night		-0.12 ± 0.04	-	0.00002 ± 0.00001		-

Table 13: Environmental variables that significantly affect the habitat choice of ungulate species in the night traffic closed road segment of Nagarhole Tiger Reserve.

Species	***Time***	***Distance from water body***	***Aspect***	***Carnivores***	***Land use***	***Livestock***
Chital	day	-	-	-	-1.16±0.35	-
	night	-0.002 ± 0.000007	-	-	-0.08 ± 0.02	-
Sambar	day		-0.002 ± 0.001	54.13 ± 29.29	-	-
	night	-	-	112.72 ± 22.47	-0.71 ± 0.28	-
Wild Pig	day	-	-	0.67 ± 0.20	-	-
	night	-	-	-	-	0.08 ± 0.01

Table 14: Road related variables that significantly affect the habitat choice of ungulate species in the night traffic closed road segment of Nagarhole Tiger Reserve.

Species	***Time of day***	***Distance from water body***	***Carnivores***	***Land use***	***Livestock***
Chital	day	-	-	-1.16 ± 0.35	-
	night	-0.0001 ± 0.000007	-	-0.08 ± 0.02	-
Sambar	day	-	66.33 ± 28.79	-	-
	night	-	116.2 ± 23.43	-0.71 ± 0.28	-
Wild pig	day	-	0.66 ± 0.21	-	-
	night	-	-	-	0.09 0.01

d. Activity pattern of animals

The activity pattern and behavior of animals are altered due to human induced disturbances. Night traffic closed road segment of SH- 33 is heavily traversed by vehicles from morning 6 am to evening 6 pm.

DCR segment of Nagarhole Tiger Reserve is completely devoid of traffic, except for the forest department vehicles. However, the NCR segment has high volumes of traffic traversing through it every day from 6 am to 6 pm. The average speed of vehicles is in the range of 29-35 MPH (Figure 18).

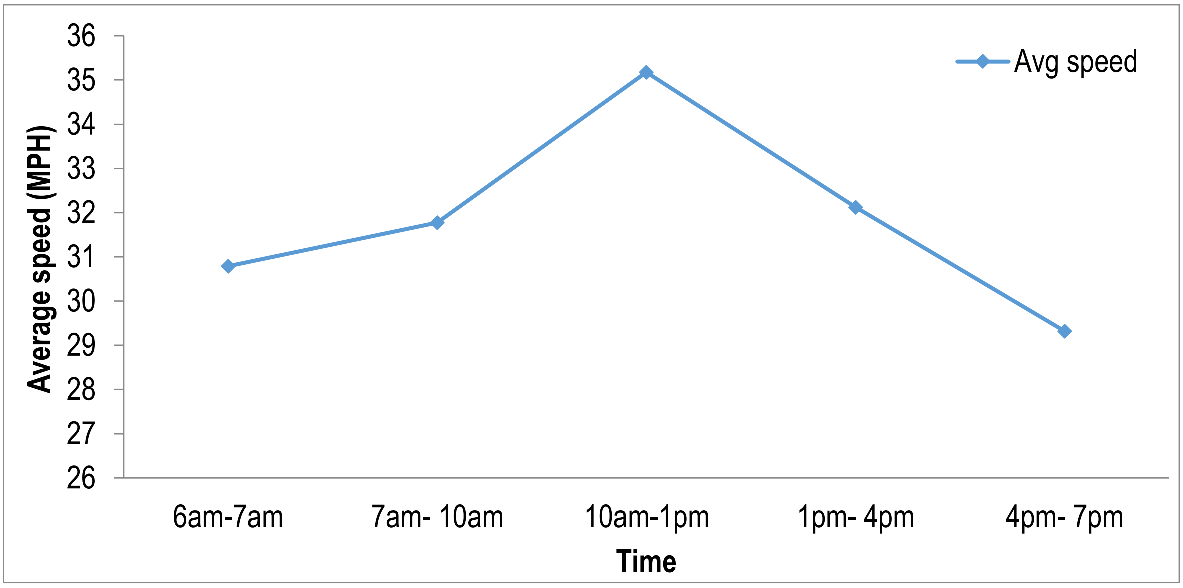


Figure 18: Average speed of vehicles during different time of the day in the night traffic closed road segment of Nagarhole Tiger Reserve.

Nagarhole Tiger Reserve experiences the highest volume of traffic during morning hours between 7 am to 9 am, just after the road is open to traffic and then again during late evening hours before closure of traffic (Figure 19).

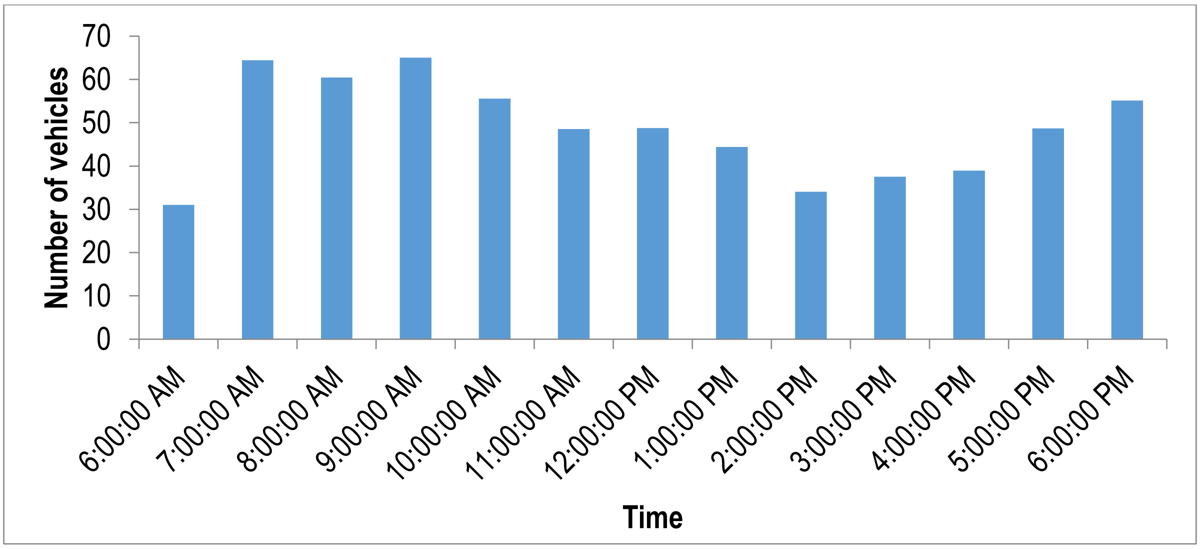
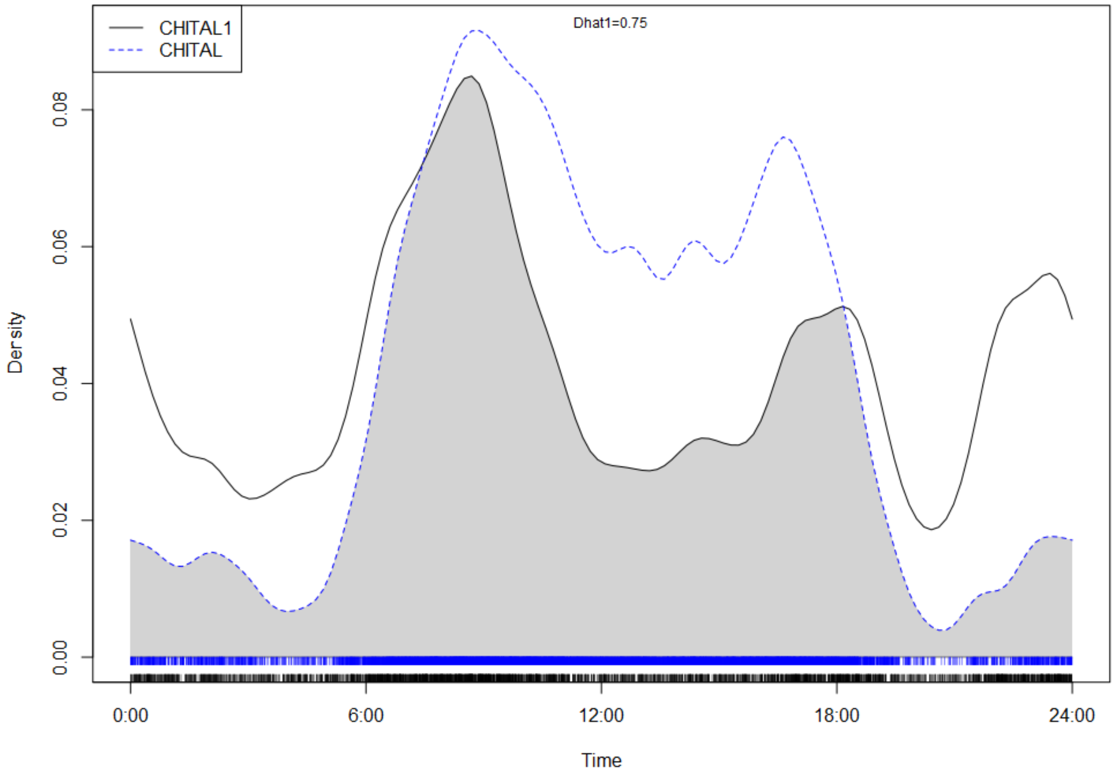


Figure 19: Number of vehicles traversing through night traffic closed road segment of Nagarhole Tiger Reserve at different time intervals of the day

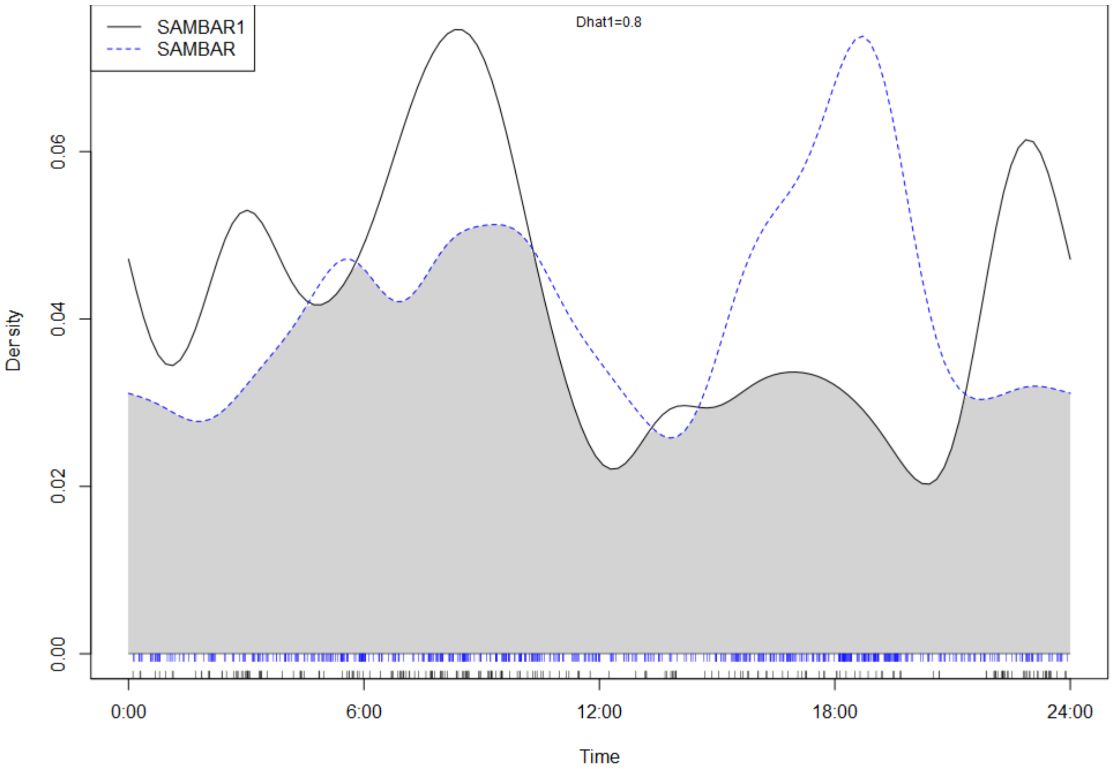
A number of mammals, and a few bird species were captured in the camera traps deployed along both segments of the road to see the difference in activity pattern of animals along the two segments. The mammals include the major predators and prey species of Nagarhole Tiger Reserve along with other small mammals. Birds captured include peacocks, peahens, jungle fowl and hoppoes. Mammals captured include tiger, leopard, dhole, sloth bear, elephants, sambar deer, chital, barking deer, wild pig and gaur. Other small mammals captured include mongoose, porcupine, hare and civet. Jungle cat and rusty spotted cat was captured only from DCR segment (Figure 21).

The main object of deploying camera trap was to check the peak activity time of animals and how this time differs along the two segments of the highway and is influenced by traffic and human presence. Detection of animals by camera traps coincides with the activity level of animals. Image captured at any time of the day is proportional to the activity level of the species at that time and the total amount of activity is proportional to the area under the trap rate curve (Rowcliffe et al. 2014).

Kernel activity density graph was created for all the mammals captured in both the road segments. Among the major ungulate species; gaur (5pm to 6pm) and wild pig's (6am to 8am) peak activity time was found to be approximately the same in both segments of the road. Spotted deer's and barking deer's peak activity time also coincides in both segments of the road (6 am to 8 am), however, barking deer is also active during late night in the DCR segment and spotted deer is active during the late evening hours (6 pm) in the NCR segment. Rest of the mammals had contrasting peak activity time (Figure 20).



(a)


SAMBAR1
SAMBAR
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0.06
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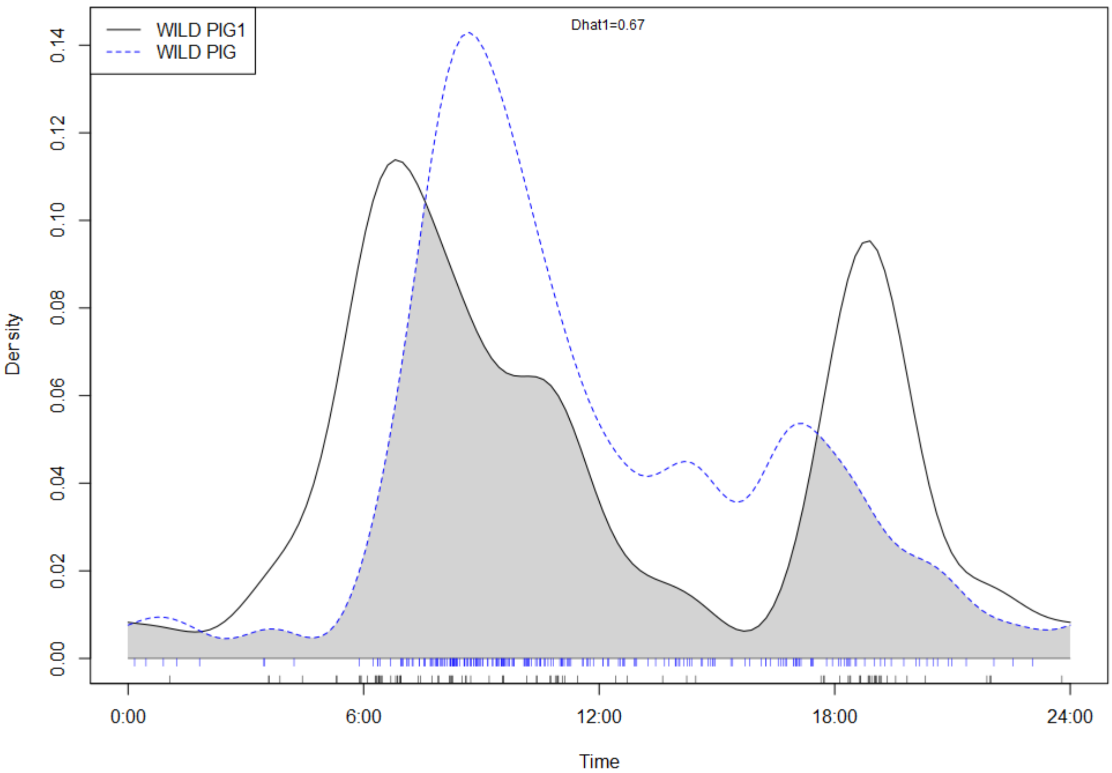
6:00
12:00
18:00
24:00
Time

(b)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WILD PIG
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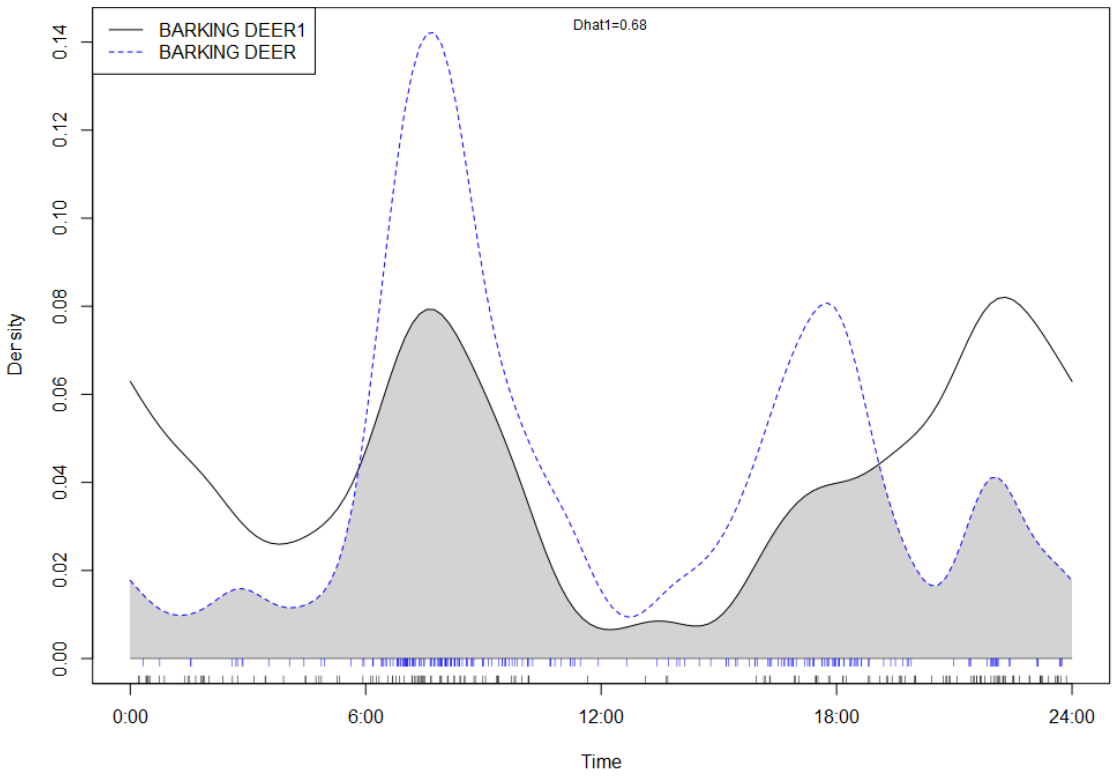
0.14
0:00
6:00
12:00
18:00
24:00
Time

(c)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BARKING DEER
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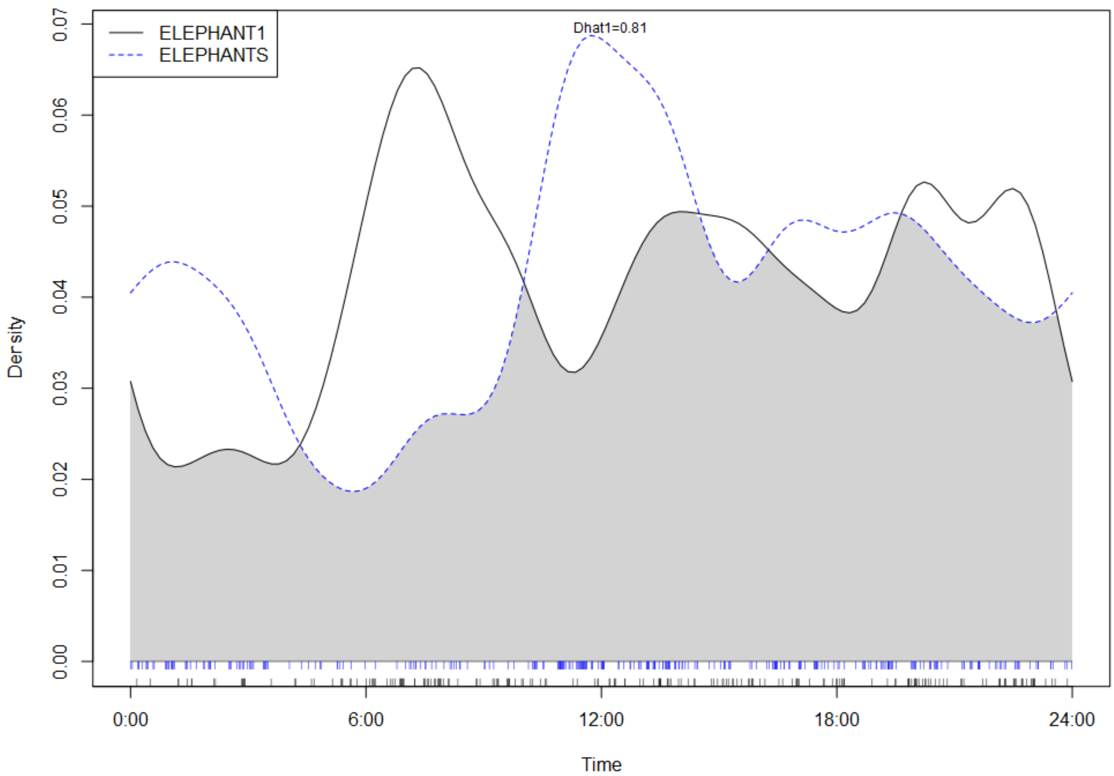
0.10
0.12
0.14
0:00
6:00
12:00
18:00
24:00
Time

(d)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ELEPHANTS
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0.05
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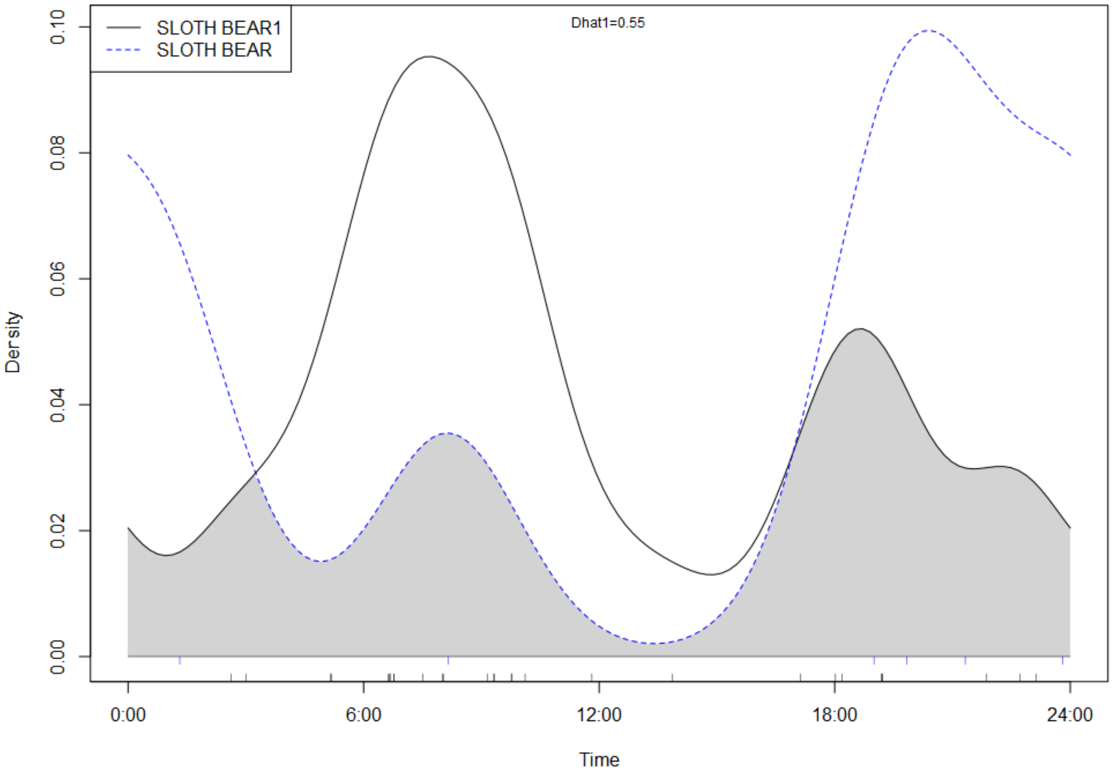
0.07
0:00
6:00
12:00
18:00
24:00
Time

(e)



SLOTH BEAR1
SLOTH BEAR
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Density
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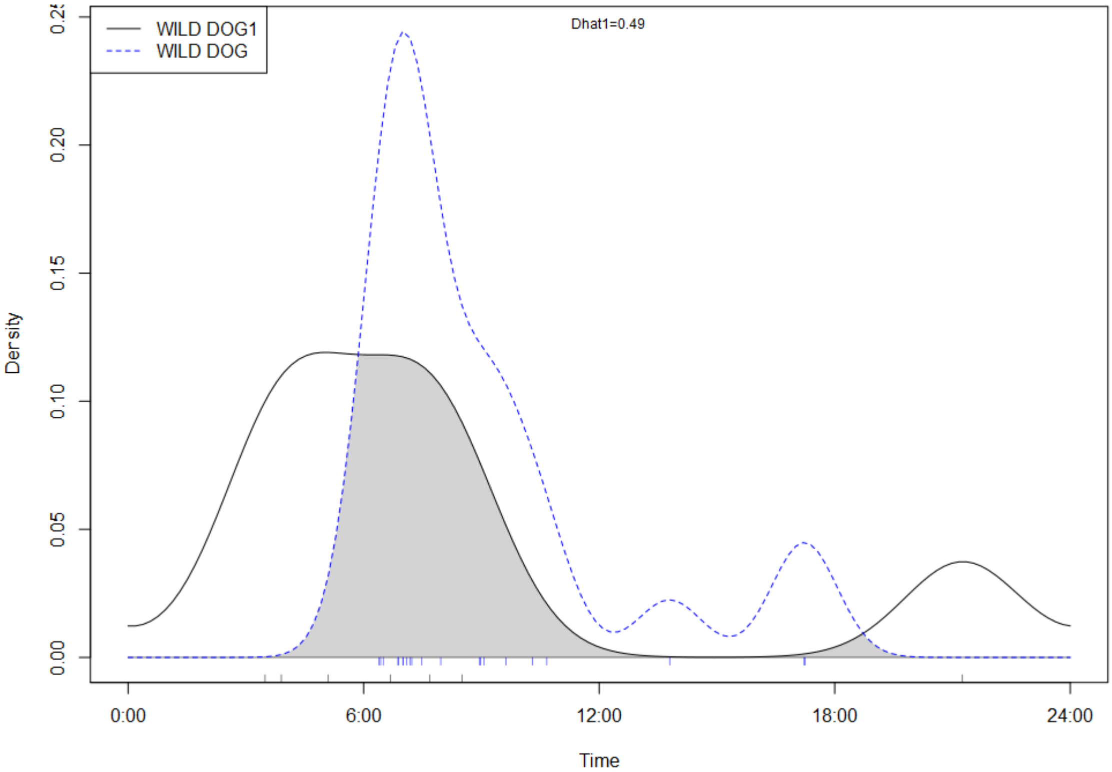
6:00
12:00
18:00
24:00
Time

(f)



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WILD DOG
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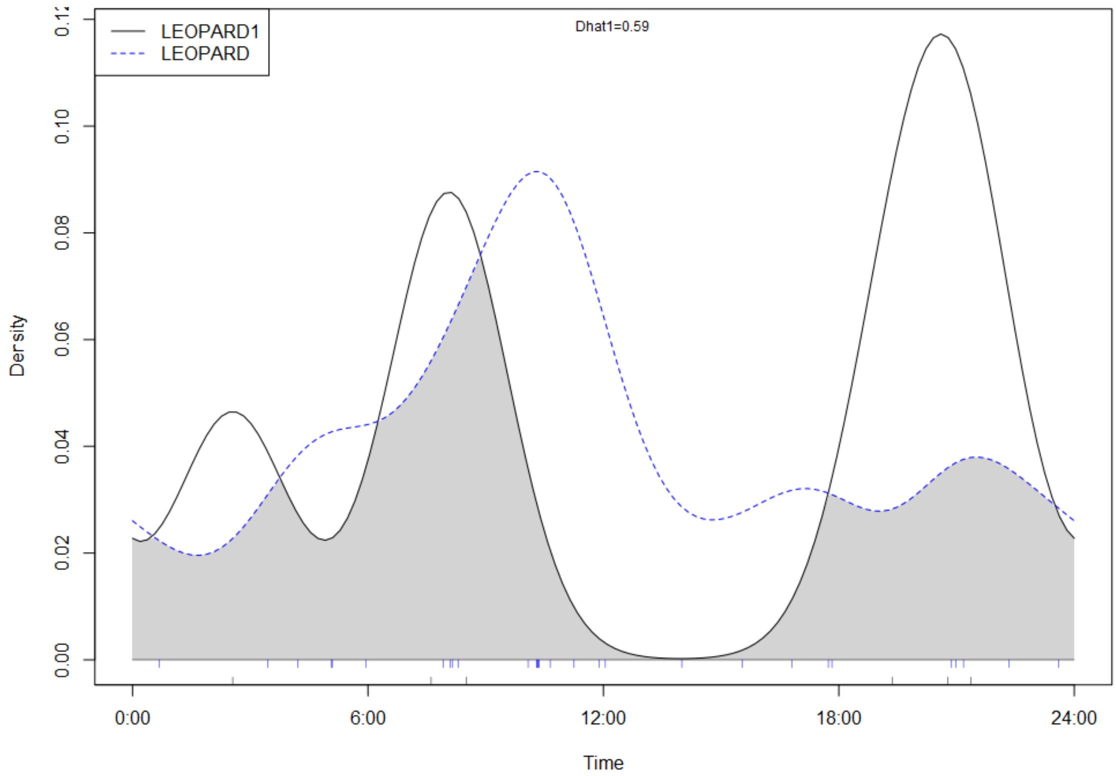
6:00
12:00
18:00
24:00
Time

(g)



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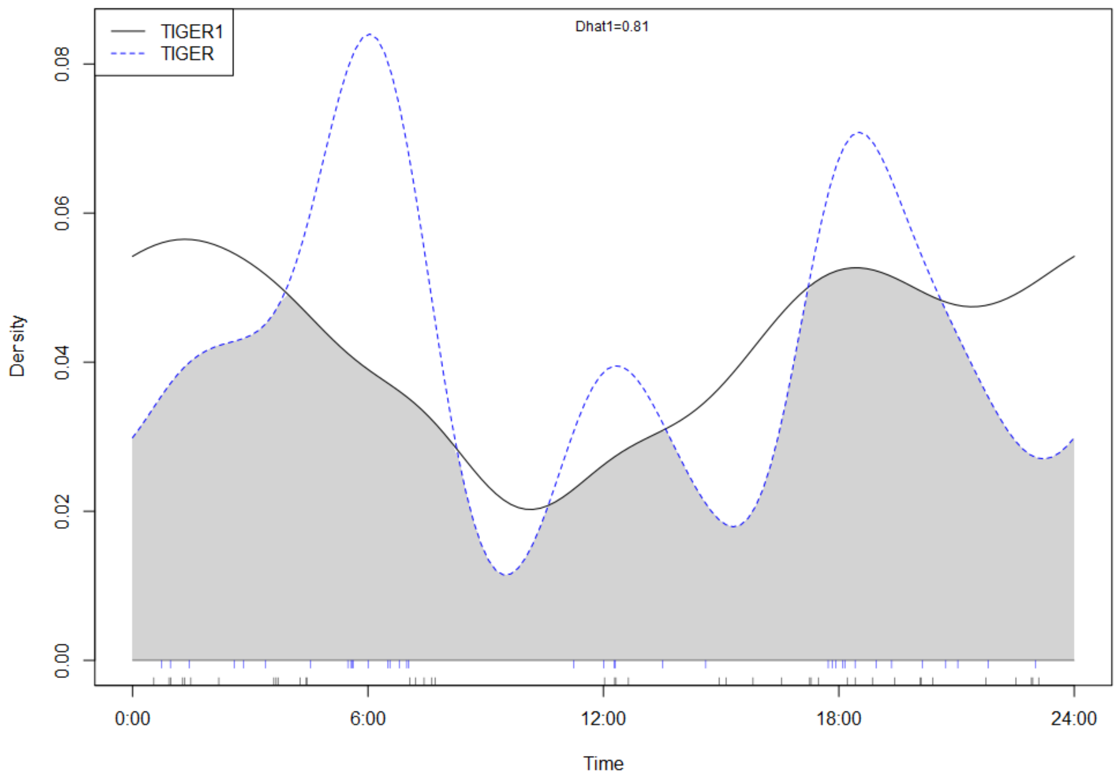


(i)

Figure 20: Kernel density graph showing the peak activity time of a species along decommissioned road segment and night traffic closed road segment of Nagarhole Tiger Reserve
(Solid black line shows the activity in decommissioned road segment and dotted blue line shows the activity in night traffic closed road segment)


3/27/2019 3:48 PM 004
Cuddeback

(A)


2/14/2019 9:48 PM 050
Cuddeback

(B)


4/4/2019 7:09 AM 007
Cuddeback

(C)


4/5/2019 6:22 AM 007
Cuddeback

(D)


4/16/2019 7:26 AM 007
Cuddeback

(E)


3/26/2019 7:02 AM 004
Cuddeback

(F)

(G) (H)

(I) (J)

(K) (L)

Figure 21: Mammals captured in the camera traps deployed along the highway segments in Nagarhole Tiger Reserve. (A- Tiger, B- Gaur, C- Sambar, D-Wild Pig, E- Barking Deer, F- Ruddy Mongoose, G-Chital, H- Sloth Bear, I- Wild Dog, J- Leopard, K- Civet, L-Mouse Deer)

7. Discussion

All forms of human activities have certain ecological consequences, which are only partially understood. The extent to which anthropogenic activities affect the natural systems is unclear and it is difficult to estimate the risk of irreversible damage to ecosystem components and functions which may be essential for human wellbeing (Treweek 1995).

Linear infrastructures including roads are the most conspicuous form of development activity. It connects people across the nation and facilitates transportation of goods, which is necessary for the socio-economic upliftment of our nation.

On the other hand, linear infrastructure also has myriads of negative impacts on the natural landscape of any area. Loss of biodiversity is one of the most evident results of this form of development. Pollution, climate change, deforestation, habitat fragmentation, mortality are the other side effects of human developmental activities. While some impacts, like road kill are fairly apparent, other negative impacts like modification of animal behaviour, alteration of their activity pattern, and impact on plant species and habitat quality are not well understood (Laurence et al. 2009).

To expand our knowledge regarding road related effects on wildlife, a detailed study on impact of road on various parameters of wildlife was undertaken along two segments of a state highway passing through Nagarhole Tiger Reserve. One of the segments has been closed to vehicular traffic, while the other segment forms an important link between Karnataka and Kerala, and thus is heavily traversed. A similar study design was adopted by Gubbi et al. (2012), to study the effect of road and associated traffic on wildlife.

Plant species composition, structure and diversity was evaluated and compared across the two Segments of highway. All three growth forms; herbs/grasses, shrubs and trees were studied.

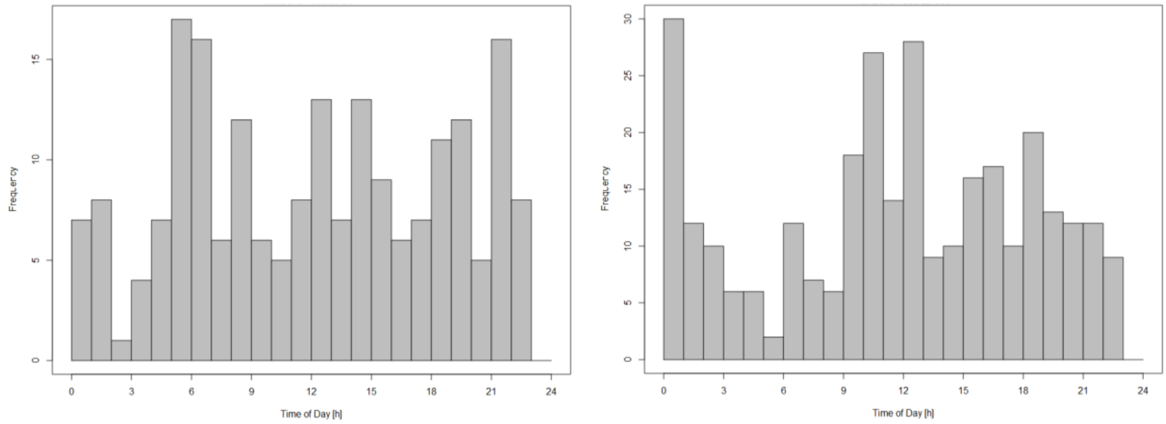
Species richness was found to be higher by 5% in the decommissioned road segment for trees, and for saplings by 3.03% as compared to the night traffic closed road segment. This indicates that even though night traffic closed road segment is heavily traversed, there has not a considerably high difference in species richness between it and the segment which has been closed to traffic. The tree and sapling community comprised predominantly of native vegetation. Similar observations were made by Trammel and Carreiro 2011, along interstate corridors in Louisville, KY, USA. On the other hand, shrubs (18%) and herbs (50%) have higher species richness in the night traffic closed road segment. Grasses occupy a higher percentage of the area sampled in the night traffic closed road segment (47.24%) as compared to the decommissioned road segment (45.86%). Higher species richness and cover of grasses, shrubs and herbs in the night traffic closed road segment can be attributed to the edge effect. Vegetation alongside roads tends to get increased amount and duration of light, higher temperature and increased moisture from road drainage. All this leads to establishment of more disturbance adapted species (Forman and Alexander 1998).

In the decommissioned road segment, *Anogeissus latifolia* was found to be the most dominant tree species, whereas in the night traffic closed road segment, *Terminalia tomentosa* was the dominant tree species. Combretaceae, Fabaceae and Rubiaceae are the dominant families present in the area. The results are in sync with the other studies carried out in tropical deciduous forests (Tarakeswara et al. 2018)

Shrub species having highest relative density in the decommissioned road segment was *Randia dumetorum* and in night traffic closed road segment was *Helicteres isora. Diospyros melanoxylon* and

Cassia siamea have the highest relative density among saplings in the decommissioned road segment and the night traffic closed road segment respectively. Even though, both the segments of the highway under study are homogenous in respect of rainfall regime, forest type and are managed as part of national park under the same management objectives (Gubbi et al. 2012), results of shrub and sapling study indicate that there exists some distinguishing factors along the two segments so as to favour different species. A further detailed study is required to point out the factors responsible.

Nagarhole Tiger Reserve is highly infested by two of the most common invasive species, i.e., *Lantana camara* and *Eupatorium odoratum.* Contrary to the general understanding; invasive species cover (of the total area sampled) was higher in the area devoid of traffic (40.93%) as compared to the night traffic closed road segment (27.06%). This can be attributed to increased light intensity on the forest floor due to lower canopy cover in the decommissioned road segment and higher animal activity, who acts as seed dispersers. Lower canopy cover in decommissioned road segment can be the result of breakage of canopy and crushing of new regeneration by higher presence and more frequent activity of large mammals, like elephants (Figure 22). Both the native species richness and invasive species cover was found to be higher in the decommissioned road segment. This may indicate that the combination of factors that facilitate the spread of invasive species, also contribute towards a higher dispersal of seeds of native growth (Pauchard and Alaback 2006).



(a) (b)

Figure 22: Histogram depicting frequency and peak time of elephant activity in (a) decommissioned road segment and (b) night traffic closed road segment of Nagarhole Tiger Reserve (x-axis shows time of the day and y-axis; the frequency of animal activity).

Vegetation analysis along both the segments of highway shows that the invasive species presence is very high adjacent to the roads as compared to the interiors of the forest. This is because seeds are carried and deposited by vehicles traversing through the road and changes in air turbulence caused by speeding vehicles. Regular spraying, mowing or burning of vegetation in linear clearings also promotes disturbance adapted species (Forman and Alexander 1998; Laurence et al. 2009). Similar results were obtained by a number of researchers from different regions and forest types around the world (Pauchard and Alaback 2006; Prasad 2008; Lemke et al. 2019). Lower percentage cover of invasive species, particularly *Lantana camara*, in the night traffic closed road segment can also be due to regular weeding operations carried out by the forest department in the fire season (April-May) every year. Although in case of *Eupatorium odoratum,* the night traffic closed road segment had a slightly higher percentage cover as compared to decommissioned road segment and its percentage cover with respect to distance from the road did not follow any linear trend.

Species diversity was found to be higher in the night traffic closed road segment of Nagarhole Tiger Reserve in case of trees. Also, the diversity increased, as the distance from the road increased. The saplings showed a higher species diversity in the decommissioned road segment which is an indicative of better regeneration status of native species in areas devoid of road related disturbances. Saplings showed a higher diversity adjacent to road in the decommissioned road segment, whereas in the night traffic closed road segment the sapling diversity was high in the areas away from the road. This can be due high traffic presence in the night traffic closed road segment. High sapling diversity adjacent to roads shows the high resilience power of forests to colonize areas in absence of anthropogenic disturbances. Shrub diversity was similar along both the road segments. Herb diversity was higher in the night traffic closed road segment and in the road verges. This is again due to environmental modifications caused by roads, such as increased light intensity due to low canopy cover and high seed dispersal by ungulates feeding on new sprouts. Higher species diversity in the night traffic closed road segment shows better adaptive capacity of species.

Nagarhole Tiger Reserve serves as the habitat of major ungulate species found in India; viz. Chital, Barking deer, Sambar, Gaur, Wild pig and Mouse deer (Karanth and Sunquist 1992). During the entire survey period from January, 2019 to April 2019, chital was the most widely sighted ungulate species along both the segments of the road during survey. The low sighting of other ungulate species can be due to their shy nature, less habituation to the human/traffic presence, nocturnal activity pattern, and missed observations. Sambar and Barking Deer were mostly observed solitary or in pairs. All sightings of barking deer were of solitary individuals. Study carried out by Karanth and Sunquist, 1992 in Nagarhole Tiger Reserve showed similar results. Mouse deer being a nocturnal species was never directly sighted. In the decommissioned road segment, around 80% of the groups of chital were sighted within 5 m distance from the state highway. This is due to complete absence of vehicular traffic and their ease of movement across road corridor. In the night traffic closed road segment, around 80% of the groups sighted were at a distance of 20 to 25 m from the state highway. This is clearly the result of speeding vehicles and disturbance present in the night traffic closed road segment. The number of groups of chital sighted decreased as the distance from the road increased along both the road segments. However, that can also be a result of obscured vision due to vegetation.

Mean group size of chital was found to be higher in the night traffic closed road segment, whereas mean crowding was higher in the decommissioned road segment. Similar result was obtained by Dar et al. (2012) and Karanth and Sunquist (1992). Higher presence in the night traffic closed road segment can be because of availability of more fodder species and less risk of predation. The sightings of other species were not sufficient for the analysis.

The adult sex ratio in case of chital and gaur was skewed towards males. This observation is contradictory to what was observed by Dar et al. (2012); Karanth and Sunquist (1992) and Bagchi et al. (2008). Skewness towards females in case of sambar, barking deer and wild pig was observed. However, that can be due to sampling error and analysis of very low number of observations.

Ungulates distribution is determined by the habitat type and the presence of predators within the habitat (Creel et al. 2014). Habitat type comprises of a combination of biotic and abiotic factors; and in the case of this study anthropogenic factors, particularly roads. The highest pellet density was found to be of chital, followed by sambar and barking deer. The result is in agreement with Dar et al. (2012).

In the decommissioned road segment, chital and wild pig's habitat use is not affected by the distance from the state highway, whereas, sambar and elephant's habitat choice is determined by distance from the highway. This is evident from the ungulate survey done; very few sambar and wild pigs were encountered. Distance to water body and aspect is the main deciding factor for choice of habitat by chital. The reason behind this being more forage availability in the warmer aspects. An elephant's choice of habitat is determined by slope, aspect, elevation, forest type and presence of carnivore species during night. Whereas in the day time, distance to water body, presence of carnivores, and distance from the state highway are the deciding factors. Nagarhole Tiger Reserve lies in the tropical region. The fairly high temperature necessitates availability of water source for regulating body temperature. Also the water sources are surrounded by open areas of lush green grass growth which provide abundant forage to the elephants (Babaasa 2000). Wild pig's choice of habitat is also determined by slope and elevation of the area at night, while during day the presence of carnivore species determines the habitat use of wild pigs. Although not as preferable as chital, wild pigs do serve as an important prey species in dry deciduous forests for tigers (Bagchi et al. 2003).

In the night traffic closed road segment also, chital's habitat choice is mostly affected by distance from water source. Additionally land use type also determines its habitat; in particular chital's preferred medium dense forest. This observation is based on direct sightings of ungulates and analysis of pellet count data. More canopy gap in the medium dense forest facilitates more grass growth. Also, preference to open areas may be an adaptive strategy to avoid predators, whose hunting success is dependent on undetected approach (Creel et al. 2014). Sambar's habitat choice is influenced by presence of carnivores in the area, both during day and night hours. Aspect also plays a role in habitat choice of sambars. Wild pig's choice of habitat is influenced by presence of predators, as was in the case of decommissioned road segment. Other factor that plays a role in its habitat choice is the presence of livestock. Sambar and wild pig both were either observed in pairs or solitary individuals or groups of sizes ≤ 4. This decreases their vigilance power against predators and hence they choose a habitat where the risk of predation is least.

The average number of vehicles per day passing through the night traffic closed road segment is 659.38 ± 139.70. There has been a 16% increase in the traffic volume from 553 vehicles /day in the last 9 years, as reported by Gubbi et al. (2012). However, based on the data reported by the same study of Gubbi et al. (2012), we can conclude that though there has been an increase in the traffic volume, it is at a slower rate as compared to the increase from 2003 to 2010 level. The average speed of vehicles ranged from 27.5 MPH to 35.4 MPH. All the major mammal species present in the reserve and a few bird species were captured in the camera traps deployed. The maximum number of captures was of chital from both the segments of the highway. This shows the high abundance of chital in Nagarhole Tiger Reserve. A comparison of activity pattern of major herbivores and carnivores of the reserve along the two road segments shows that there is not much difference in the activity pattern of 6 mammals: chital (Dhat= 0.75), sambar (Dhat= 0.8), wild pig (Dhat= 0.67), barking deer (Dhat= 0.68), elephant (Dhat= 0.81) and tiger (Dhat= 0.81). After analysis of data it can be concluded that in the night traffic closed road segment, animals have modified their activity periods to avoid the vehicular traffic. Most of the mammals are either active in the early morning hours, before the road is opened up for vehicular movement or late evenings after the road is closed. The coefficient of overlap in activity pattern along the two segments of the road is low in case of wild dog (Dhat= 0.49), sloth bear (Dhat= 0.55) and leopard (Dhat= 0.59). This suggests that there is a difference in activity pattern of these mammals along both the road segments, in order to understand which a further detailed study about behaviour modification of mammals in relation to traffic and other road related disturbances need to be carried out.

8. Conclusion

The present study on SH-33 passing through Nagarhole Tiger Reserve was conducted from January, 2019 to April, 2019. It can be concluded from the study that besides the socio-economic advantages that roads provide to the society, it can prove detrimental for the natural environment and wildlife. Highways lead to alteration in the native species composition, promoting the invasive species and leading to a reduction in species richness. The effect of invasive species on native community can be seen even long after the removal of disturbance, as is evident from Anthrasanthe range (decommissioned road segment) of Nagarhole Tiger Reserve.

Study of group size and composition of ungulates tells us that ungulates generally avoid road and that larger sized groups are found away from the road. Habitat use study shows that highway is a factor determining the choice of habitats use by ungulates, with animals preferring areas devoid of disturbance. The edge effect created by roads lead to an increase in palatable grass cover adjacent to the highway. This attracts the herbivores towards roads causing an increase in the risk of them getting hit by traversing vehicles while crossing. Roads in turn alter animal behavior and activity patterns.

Analysis of traffic showed an increase in traffic volume in a time span of nine years, even though the night traffic closed road segment of the reserve is open to vehicular traffic only for 12 hours. This increasing traffic rate is bound to put more pressure on the natural environment making it even more difficult for the animals to cope up with.

Amongst all the negative impacts of road on wildlife, study conducted in the decommissioned road segment shows that forests have high resilience and can revert to its original state if the anthropogenic disturbance is removed. Also, it was found that mortality of animals due to vehicle collision is negligible in Nagarhole Tiger Reserve. This is the result of better management practices adopted in the reserve like closure of road to traffic during periods of high animal activity, moderate permissible vehicular speed limit and efforts of the forest staffs. More measures of such kind should be adopted to minimize the anthropogenic impact on wildlife and environment.

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Appendix I

Table A1: The IVI of tree species present in decommissioned road segment.

Species	Density	Frequency	Dominance	Relative frequency	Relative density	Relative dominance	IVI
Anogeissus latifolia	3.29	78.43	0.00	23.30	41.18	0.99	65.47
Dalbergia latifolia	0.21	13.07	0.00	3.88	2.61	1.62	8.12
Bauhinia racemosa	0.14	9.80	0.00	2.91	1.80	0.64	5.35
Bombax ceiba	0.01	1.31	0.00	0.39	0.16	4.40	4.95
Terminalia tomentosa	2.09	68.63	0.00	20.39	26.14	1.10	47.63
Tectona grandis	0.14	11.11	0.00	3.30	1.80	6.95	12.05
Stereospermum tetragonum	0.27	18.95	0.00	5.63	3.35	1.92	10.90
Pterocarpus marsupiam	0.09	6.54	0.00	1.94	1.14	1.58	4.66
Cassia fistula	0.03	3.27	0.00	0.97	0.41	0.36	1.74
Haldina cordifolia	0.11	9.15	0.00	2.72	1.39	6.82	10.93
Randia dumetorum	0.15	5.88	0.00	1.75	1.88	0.46	4.09
Ziziphus xylopyrus	0.14	11.76	0.00	3.50	1.80	0.58	5.88
Cordia macleodii	0.01	0.65	0.00	0.19	0.08	0.00	0.28
Mitragyna parviflora	0.07	5.23	0.00	1.55	0.90	2.15	4.60
Phyllanthus emblica	0.46	29.41	0.00	8.74	5.80	0.76	15.30
Santalum album	0.03	1.96	0.00	0.58	0.33	0.37	1.28
Diospyros melanoxylon	0.07	5.88	0.00	1.75	0.90	0.37	3.02
Diospyros montana	0.05	4.58	0.00	1.36	0.57	1.82	3.75
Schrebera swietenioides	0.04	3.92	0.00	1.17	0.49	2.79	4.45
Terminalia sp.	0.06	3.92	0.00	1.17	0.74	1.33	3.23
Premna tomentosa	0.07	4.58	0.00	1.36	0.82	1.54	3.72
Schleichera oleosa	0.04	3.92	0.00	1.17	0.49	7.49	9.14
Ficus benghalensis	0.01	0.65	0.00	0.19	0.08	0.00	0.28
Terminalia bellerica	0.03	2.61	0.00	0.78	0.33	7.24	8.34
Butea monosperma	0.03	1.31	0.00	0.39	0.33	0.99	1.71
Dalbergia paniculata	0.01	1.31	0.00	0.39	0.16	0.00	0.55
Cordia dichotoma	0.01	1.31	0.00	0.39	0.16	0.36	0.91
Lagerstroemis lanceolata	0.01	0.65	0.00	0.19	0.08	0.00	0.28
Vitex altissima	0.07	3.92	0.00	1.17	0.82	0.92	2.90
Garuga pinnata	0.05	5.23	0.00	1.55	0.65	6.89	9.09
Tamarindus indica	0.01	0.65	0.00	0.19	0.16	9.57	9.93
Delonix regia	0.01	0.65	0.00	0.19	0.08	0.57	0.85
Acacia leucocepholea	0.01	0.65	0.00	0.19	0.08	0.28	0.56
Acacia strangler	0.02	1.96	0.00	0.58	0.25	0.72	1.55
Radermachera xylocarpa	0.02	1.96	0.00	0.58	0.25	2.13	2.96
Miliusa tomentosa	0.07	5.88	0.00	1.75	0.82	0.86	3.42
Limonia accidissima	0.02	1.31	0.00	0.39	0.25	0.27	0.90
Randia sp	0.02	1.96	0.00	0.58	0.25	1.21	2.04
Dalbergia lanceolaria	0.01	0.65	0.00	0.19	0.08	14.30	14.58
Grewia tiliaefolia	0.03	1.96	0.00	0.58	0.41	7.12	8.11
Semecarpus anacardium	0.00	0.00	0.00	0.00	0.00	0.53	0.53

Table A2: The IVI of tree species present in night traffic closed road segment.

Species	Density	Frequency	Dominance	Relative frequency	Relative density	Relative dominance	IVI
Anogeissus latifolia	0.50	22.22	0.00	7.48	8.21	1.39	17.07
Dalbergia latifolia	0.31	23.61	0.00	7.94	5.02	2.60	15.56
Bauhinia racemosa	0.25	6.94	0.00	2.34	4.10	0.44	6.88
Bombax ceiba	0.01	0.69	0.00	0.23	0.11	1.33	1.68
Terminalia tomentosa	1.13	36.81	0.00	12.38	18.59	1.12	32.09
Tectona grandis	0.71	34.03	0.00	11.45	11.63	5.75	28.83
Stereospermum tetragonum	0.28	16.67	0.00	5.61	4.56	2.64	12.81
Pterocarpus marsupiam	0.06	6.25	0.00	2.10	1.03	4.77	7.90
Cassia fistula	0.17	11.11	0.00	3.74	2.74	0.25	6.72
Haldinia cordifolia	0.13	10.42	0.00	3.50	2.05	3.18	8.73
Randia dumetorum	0.06	4.86	0.00	1.64	1.03	0.17	2.83
Ziziphus xylopyrus	0.01	0.69	0.00	0.23	0.11	0.23	0.58
Cordia macleodii	0.04	3.47	0.00	1.17	0.68	0.46	2.31
Mitragyna parviflora	0.24	9.03	0.00	3.04	3.99	0.97	8.00
Phyllanthus emblica	0.10	8.33	0.00	2.80	1.60	1.05	5.45
Diospyros melanoxylon	0.01	0.69	0.00	0.23	0.11	0.27	0.61
Diospyros montana	0.04	3.47	0.00	1.17	0.68	0.39	2.24
Terminalia sp.	0.02	0.69	0.00	0.23	0.34	7.47	8.04
Premna tomentosa	0.02	0.69	0.00	0.23	0.34	0.59	1.16
Schleichera oleosa	0.04	4.17	0.00	1.40	0.68	1.63	3.72
Ficus benghalensis	0.01	0.69	0.00	0.23	0.11	14.16	14.51
Terminalia bellerica	0.00	2.08	0.00	0.70	0.00	4.22	4.92
Butea monosperma	0.24	7.64	0.00	2.57	3.88	0.72	7.16
Dalbergia paniculata	0.02	2.08	0.00	0.70	0.34	2.34	3.39
Cordia dichotoma	0.06	4.17	0.00	1.40	1.03	0.25	2.68
Lagerstroemia lanceolata	0.37	11.81	0.00	3.97	6.04	3.61	13.62
Garuga pinnata	0.05	4.86	0.00	1.64	0.80	7.91	10.35
Radermachera xylocarpa	0.25	17.36	0.00	5.84	4.10	1.19	11.13
Miliusa tomentosa	0.05	4.17	0.00	1.40	0.80	4.05	6.25
Limonia accidissima	0.01	0.00	0.00	0.00	0.11	0.00	0.11
Randia sp	0.02	1.39	0.00	0.47	0.34	0.47	1.28
Grewia tiliaefolia	0.22	15.28	0.00	5.14	3.53	5.20	13.88
Semecarpus anacardium	0.02	0.69	0.00	0.23	0.34	0.84	1.42
Melia sp.	0.03	1.39	0.00	0.47	0.46	2.08	3.00
Pongamia pinnata	0.01	0.69	0.00	0.23	0.11	0.16	0.51
Holarhenna antidysentrica	0.04	3.47	0.00	1.17	0.68	0.16	2.01
Sterculia foetida	0.01	0.69	0.00	0.23	0.11	3.50	3.85
Lannea coromandelica	0.01	0.69	0.00	0.23	0.11	12.13	12.48
Cassia siamea	0.58	13.19	0.00	4.44	9.46	0.36	14.27

Appendix II

Table A3: Structure of shrub species present in decommissioned road segment.

Species	Density	Frequency	Abundance	A/F	RD	RF
Asclepias curassavica	0	0	0	0	0	0
Cipadessa baccifera	0.28667	9.33333333	3.07142857	0.32908	4.0797	5.62249
Grewia species	0.06	2	3	1.5	0.85389	1.20482
Glycosmis pentaphylla	0	0	0	0	0	0
Helicteres isora	0.9	16	5.625	0.35156	12.8083	9.63855
Holarrhena antidysentrica	0.79333	18.6666667	4.25	0.22768	11.2903	11.245
Pavetta indica	0.17333	2	8.66666667	4.33333	2.46679	1.20482
Randia dumetorum	3.14	57.3333333	5.47674419	0.09552	44.6869	34.5382
Randia sp	0.00667	0.66666667	1	1.5	0.09488	0.40161
Solanum species	0	0	0	0	0	0
Ziziphus oenoplia	1.65333	58.6666667	2.81818182	0.04804	23.5294	35.3414
Ziziphus xylopyrus	0.01333	1.33333333	1	0.75	0.18975	0.80321

Table A4: Structure of shrub species present in night traffic closed road segment.

Species	Density	Frequency	Abundance	A/F	RD	RF
Asclepias curassavica	0.17241	0.689655	25	36.25	0.60798	0.22026
Cipadessa baccifera	3.46897	40.68966	8.5254237	0.20952	12.2325	12.9956
Grewia species	0.0069	0.689655	1	1.45	0.02432	0.22026
Glycosmis pentaphylla	0.36552	3.448276	10.6	3.074	1.28891	1.10132
Helicteres isora	13.4483	77.93103	17.256637	0.22143	47.4222	24.8899
Holarrhena antidysentrica	2.17931	48.96552	4.4507042	0.09089	7.68482	15.6388
Pavetta indica	0.06897	1.37931	5	3.625	0.24319	0.44053
Randia dumetorum	6.04828	74.48276	8.1203704	0.10902	21.3278	23.7885
Randia sp	0.2	8.275862	2.4166667	0.29201	0.70525	2.64317
Solanum species	0.0069	0.689655	1	1.45	0.02432	0.22026
Ziziphus oenoplia	2.3931	55.86207	4.2839506	0.07669	8.43872	17.8414
Ziziphus xylopyrus	0	0	0	0	0	0

Table A5: Structure of sapling species present in decommissioned road segment.

Species	Density	Frequency	Abundance	A/F	RD	RF
Acacia ferruginea	0.00667	0.66666667	1	1.5	0.2004	0.48544
Acacia leucophloea	0.00667	0.66666667	1	1.5	0.2004	0.48544
Acacia sp (strangler)	0.02	1.33333333	1.5	1.125	0.6012	0.97087
Acacia species	0.19333	4.66666667	4.14285714	0.88776	5.81162	3.39806
Anogessius latifolia	0.48	8.66666667	5.53846154	0.63905	14.4289	6.31068
Bauhinia racemosa	0.11333	7.33333333	1.54545455	0.21074	3.40681	5.33981
Butea monosperma	0.01333	1.33333333	1	0.75	0.4008	0.97087
Cassia fistula	0.24667	14.6666667	1.68181818	0.11467	7.41483	10.6796
Cassia siamea	0.00667	0.66666667	1	1.5	0.2004	0.48544
Cassia species	0	0	0	0	0	0
Chloroxylon swietenia	0.00667	0.66666667	1	1.5	0.2004	0.48544
Cordia dichotoma	0.01333	1.33333333	1	0.75	0.4008	0.97087
Dalbergia latifolia	0.09333	6.66666667	1.4	0.21	2.80561	4.85437
Dalbergia paniculata	0.00667	0.66666667	1	1.5	0.2004	0.48544
Delonix regia	0.03333	2.66666667	1.25	0.46875	1.002	1.94175
Diospyros melanoxylon	0.79333	21.3333333	3.71875	0.17432	23.8477	15.534
Diospyros montana	0.17333	7.33333333	2.36363636	0.32231	5.21042	5.33981
Garuga pinnata	0	0	0	0	0	0
Grewia tiliifolia	0	0	0	0	0	0
Haldina cordifolia	0.01333	0.66666667	2	3	0.4008	0.48544
Lagerstroemia lanceolata	0	0	0	0	0	0
Lagerstroemia parviflora	0	0	0	0	0	0
Limonia acidissima	0.08	5.33333333	1.5	0.28125	2.40481	3.8835
Melia dubia	0	0	0	0	0	0
Miliusa tomentosa	0.06	5.33333333	1.125	0.21094	1.80361	3.8835
Mitragyna parvifolia	0.00667	0.66666667	1	1.5	0.2004	0.48544
Phyllanthus emblica	0.03333	3.33333333	1	0.3	1.002	2.42718
Premna tomentosa	0.00667	0.66666667	1	1.5	0.2004	0.48544
Pterocarpus marsupium	0.01333	0.66666667	2	3	0.4008	0.48544
Sandal	0.00667	0.66666667	1	1.5	0.2004	0.48544
Schleichera oleosa	0.03333	2	1.66666667	0.83333	1.002	1.45631
Semecarpus anacardium	0.14	4.66666667	3	0.64286	4.20842	3.39806
Sterculia guttata	0	0	0	0	0	0
Stereospermum tetragonum	0.01333	0.66666667	2	3	0.4008	0.48544
Strychnos potatorum	0	0	0	0	0	0
Syzygium cumini	0.00667	0.66666667	1	1.5	0.2004	0.48544
Teak	0.12667	4.66666667	2.71428571	0.58163	3.80762	3.39806
Terminalia tomentosa	0.48667	18	2.7037037	0.15021	14.6293	13.1068
Vitex altissima	0.06667	6.66666667	1	0.15	2.00401	4.85437
Wrightia tinctoria	0.00667	0.66666667	1	1.5	0.2004	0.48544
Ziziphus mauritiana	0.02	1.33333333	1.5	1.125	0.6012	0.97087

Table A6: Structure of sapling species present in night traffic closed road segment.

Species	Density	Frequency	Abundance	A/F	RD	RF
Acacia ferruginea	0	0	0	0	0	0
Acacia leucophloea	0	0	0	0	0	0
Acacia sp (strangler)	0	0	0	0	0	0
Acacia species	0.11724	4.137931	2.8333333	0.68472	1.31579	1.51899
Anogessius latifolia	0.01379	0.689655	2	2.9	0.1548	0.25316
Bauhinia racemosa	0.08276	6.206897	1.3333333	0.21481	0.92879	2.27848
Butea monosperma	0.04138	2.758621	1.5	0.54375	0.4644	1.01266
Cassia fistula	1.38621	48.27586	2.8714286	0.05948	15.5573	17.7215
Cassia siamea	2.14483	18.62069	11.518519	0.61859	24.0712	6.83544
Cassia species	0.3931	6.206897	6.3333333	1.02037	4.41176	2.27848
Chloroxylon swietenia	0	0	0	0	0	0
Cordia dichotoma	0.11034	8.275862	1.3333333	0.16111	1.23839	3.03797
Dalbergia latifolia	0.30345	11.03448	2.75	0.24922	3.40557	4.05063
Dalbergia paniculata	0.10345	7.586207	1.3636364	0.17975	1.16099	2.78481
Delonix regia	0.01379	1.37931	1	0.725	0.1548	0.50633
Diospyros melanoxylon	0.01379	0.689655	2	2.9	0.1548	0.25316
Diospyros montana	1.95172	41.37931	4.7166667	0.11399	21.904	15.1899
Garuga pinnata	0.05517	4.827586	1.1428571	0.23673	0.6192	1.77215
Grewia tiliifolia	0.56552	20.68966	2.7333333	0.13211	6.34675	7.59494
Haldina cordifolia	0.0069	0.689655	1	1.45	0.0774	0.25316
Lagerstroemia lanceolata	0.01379	1.37931	1	0.725	0.1548	0.50633
Lagerstroemia parviflora	0.11724	4.137931	2.8333333	0.68472	1.31579	1.51899
Limonia acidissima	0.06207	3.448276	1.8	0.522	0.69659	1.26582
Melia dubia	0.0069	0.689655	1	1.45	0.0774	0.25316
Miliusa tomentosa	0.36552	23.44828	1.5588235	0.06648	4.10217	8.60759
Mitragyna parvifolia	0.0069	0.689655	1	1.45	0.0774	0.25316
Phyllanthus emblica	0	0	0	0	0	0
Premna tomentosa	0.0069	0.689655	1	1.45	0.0774	0.25316
Pterocarpus marsupium	0.01379	1.37931	1	0.725	0.1548	0.50633
Sandal	0	0	0	0	0	0
Schleichera oleosa	0.38621	24.13793	1.6	0.06629	4.33437	8.86076
Semecarpus anacardium	0	0	0	0	0	0
Sterculia guttata	0.04828	1.37931	3.5	2.5375	0.5418	0.50633
Stereospermum tetragonum	0.01379	1.37931	1	0.725	0.1548	0.50633
Strychnos potatorum	0.03448	3.448276	1	0.29	0.387	1.26582
Syzygium cumini	0	0	0	0	0	0
Teak	0.43448	15.86207	2.7391304	0.17268	4.87616	5.82278
Terminalia tomentosa	0.01379	0.689655	2	2.9	0.1548	0.25316
Vitex altissima	0.0069	0.689655	1	1.45	0.0774	0.25316
Wrightia tinctoria	0.07586	5.517241	1.375	0.24922	0.85139	2.02532
Ziziphus mauritiana	0	0	0	0	0	0

Appendix III

Table A7: Percentage covers of grass species present in decommissioned road segment of Nagarhole Tiger Reserve.

Grass species	Total cover (%)	Average cover (%)	Relative cover
Bambusa sp	516	4.648649	0.101355333
Cynadon dactylon	4445	40.04505	0.873109409
Aristida hystrix	130	1.171171	0.025535258

Table A8: Percentage covers of grass species present in night traffic closed road segment of Nagarhole Tiger Reserve.

Grass species	Total cover (%)	Average cover (%)	Relative cover
Bambusa sp	625	5.29661	0.112107623
Cynadon dactylon	4950	41.94915	0.887892377
Aristida hystrix	0	0	0

Appendix IV

Table A9: The structure of herb species present in decommissioned road segment.

Species	Density	Frequency	RD	RF	Abundance	A/F
Achyranthes aspera	0	0	0	0	0	0
Alternanthera sessilis	0	0	0	0	0	0
Baliospermum montanum	0.018018018	0.900901	2.061856	2.5	2	2.22
Sida sp	0	0	0	0	0	0
Curculigo orchioides	0	0	0	0	0	0
Desmodium pulchellum	0.216216216	14.41441	24.74227	40	1.5	0.104063
Euphorbia hirta	0	0	0	0	0	0
Hemidesmus indicus	0.18018018	9.009009	20.61856	25	2	0.222
Mimosa pudica	0.342342342	6.306306	39.17526	17.5	5.428571	0.860816
Parthenium hysterophorus	0.045045045	2.702703	5.154639	7.5	1.666667	0.616667
Solanum species	0	0	0	0	0	0
Tridax procumbens	0.072072072	2.702703	8.247423	7.5	2.666667	0.986667

Table A10: The structure of herb species present in night traffic closed road segment.

Species	Density	Frequency	RD	RF	Abundance	A/F
Achyranthes aspera	0.084746	5.932203	2.890173	8.536585	1.428571	0.240816
Alternanthera sessilis	0.864407	2.542373	29.47977	3.658537	34	13.37333
Baliospermum montanum	0.033898	3.389831	1.156069	4.878049	1	0.295
Sida sp	0.050847	1.694915	1.734104	2.439024	3	1.77
Curculigo orchioides	0.228814	3.389831	7.803468	4.878049	6.75	1.99125
Desmodium pulchellam	0.127119	11.01695	4.33526	15.85366	1.153846	0.104734
Euphorbia hirta	0.016949	0.847458	0.578035	1.219512	2	2.36
Hemidesmus indicus	0.279661	12.71186	9.537572	18.29268	2.2	0.173067
Mimosa pudica	0.516949	10.16949	17.63006	14.63415	5.083333	0.499861
Parthenium hysterophorus	0.40678	5.084746	13.87283	7.317073	8	1.573333
Solanum species	0.101695	5.932203	3.468208	8.536585	1.714286	0.28898
Tridax procumbens	0.220339	6.779661	7.514451	9.756098	3.25	0.479375

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