Habitat use by the wild ungulate, sambar deer (*Cervus unicolor*) in the shola-grassland ecosystem

Thesis submitted in partial fulfilment of the requirements of

Five Year BS-MS Dual Degree Program

Indian Institute of Science Education and Research, Pune

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Certificate

This is to certify that this dissertation entitled "**Habitat use by the wild ungulate, sambar deer (*Cervus unicolor*) in the shola-grassland ecosystem**" towards the partial fulfilment of the BS-MS dual degree programme at the Indian Institute of Science Education and Research, Pune represents original research carried out by **Ms. Dincy Mariyam** at the National Centre for Biological Sciences, Bangalore under the supervision of **Dr. Mahesh Sankaran**, Reader, Ecology and Evolution during the academic year 2014-2015.

20-3-2015

Mahesh Sankaran Date

<u>Declaration</u>

I hereby declare that the matter embodied in the report entitled "**Habitat use by the wild ungulate, sambar deer (*Cervus unicolor*) in the shola-grassland ecosystem**" are the results of the investigations carried out by me at the National Centre for Biological Sciences, Bangalore under the supervision of **Dr. Mahesh Sankaran** and the same has not been submitted elsewhere for any other degree.

24-3-2015

Dincy Mariyam　　　　　　　　　　　　　　　　　　　　　　Date

Abstract

Habitat use studies help to understand the biological requirements of an organism. The pattern of habitat use is governed by various resources and parameters. The study looked at habitat use by the mammalian herbivore, sambar deer (*Cervus unicolor*), a common deer species in an invaded shola-grassland ecosystem in the Western Ghats. Shola-grasslands are threatened ecosystems due to the rapid colonisation by exotics like wattle (*Acacia meanrsii*). There is limited understanding of how herbivores use this mosaic of forests and grasslands, which are being constantly invaded although these herbivores are shown to affect their dynamics. A qualitative model for habitat use was proposed linking herbivore abundance and predictive habitat parameters such as vegetation height, canopy cover and percentage ground cover. Landscape features such as elevation, distance to water, road, forest patch and wattle plantation were examined to explain the sambar distribution pattern in the landscape and also the faecal matter was collected and analysed for studying the diet composition. Relative ungulate abundance estimation using faecal pellets showed that the land use types are not used in proportion to their cover in the system. Wattle plantations are used the most, shola forests the least and grasslands intermediate. Vegetation composition was able to explain the variation in the pattern in habitat use the most. Stable carbon isotope analysis of sambar faecal matter supported the fact that they are primarily browsers in this landscape and occasionally switch to a mixed diet. Landscape features were insignificant predictors to describe the distribution of sambar deer. The findings in the study provide insights into interaction of a herbivore with an invasive species which can give pertinent management implications.

List of figures

Sl. No	Title	Page
1	Google earth image of the study area, Nilgiri south division	9
2	Google earth image of the seasonal plots	10
3	Google earth image of the plots laid for studying temporal variation in dung deposition rate	11
4	Comparison of total dung counts in the land use types- seasonal plots	15
5	Percentage cover of habitat features in the land use types- seasonal plots	17
6	Temporal variation in dung deposition rate	18
7	Percentage cover of habitat features in the land use types- temporal variation in dung deposition rate	20
8	Diet composition of sambar deer from late wet season to early dry season	21

List of tables

Sl. No	Title	Page
1	Vegetation structure measurements in each land use type – seasonal plots	16
2	Vegetation structure measurements in each land use type – temporal variation in dung deposition rate	19

Acknowledgements

I am very grateful to my mentor, Dr. Mahesh Sankaran (NCBS, Bangalore), for providing me the opportunity to work with him on my master's thesis. His support, patience and encouragement made this thesis work possible and also the statistical and editorial advice was helpful in crafting this piece of literature. I am thankful to Dr. Deepak Barua (IISER Pune), who gave me ecology lessons, for readily accepting to be part of my thesis advisory committee. I express my sincere gratitude to the Tamil Nadu Forest Department for giving permission to collect data for this study and also the forest staff for their on-field support.

My Thanks also goes to Dr. Jayashree Ratnam (NCBS, Bangalore) for helping in designing the study and also for the motivation and enthusiasm throughout the project. I thank Dr. Ravindersingh Bhalla (FERAL) and team for their valuable support in the field and also for helping me with their GIS expertise; and also Dr. M. S. Sheshshayee (UAS, GKVK, Bangalore) and his lab for performing the isotopic ratio mass spectrometric analyses. My field assistants, Manikandan and Suseelan were of valuable assistance in the field without whom field season wouldn't have been interesting. Their wonderful cooking and entertainment kept me alive in the field. I am obliged to the members of Lab 22 (NCBS, Bangalore) for sharing their knowledge and for providing a great working environment especially Atul Joshi, Yadugiri V. T. and Harinandanan P.V. for their great help in the field and Varun Varma for sharing his knowledge on GIS. I'm grateful to my friend, M. Sainath for sharing his programming knowledge while doing statistics. I'm thankful for the existence of my dear friends, Neha M and Krishna Anujan for helping considerably with structuring the draft that improved this thesis and also for the good-spirited discussions.

I am indebted to my institute, IISER Pune, for sowing the seed of research in me and also for providing the support during this year long project. I would like to thank the INSPIRE programme for the financial support. My family receives my deepest gratitude and love for their faith, support and encouragement during my thesis. Last, but not the least, I thank the almighty for his blessings throughout my project.

Introduction

Habitat is an important feature that determines the distribution and abundance of a species and also one of the most common dimensions partitioned (Schoener, 1974). Habitats are generally used for foraging, shelter, cover and escape. Organisms prefer an environment in which their survival and reproduction is maximum. Hence, habitat preference is known to exist in animals and this has been well documented in case of mammalian herbivores (Aulak and Babinska-Werka, 1990; Bagchi et al., 2003; Ben-Shahar and Skinner, 1988; Fritz et al., 1996; Heinze et al., 2011; Pienaar, 1974). The independent and interactive effects of biotic and abiotic factors like forage quality and quantity (Beest et al., 2010), ecological interactions like competition and predation (Brashares and Arcese, 2002), temperature, rainfall (Ogutu and Owen-Smith, 2003), landscape variables like terrain ruggedness, distance to water sources (Bagchi et al., 2003; Bailey et al., 1996), human disturbances like settlements and roads etc. are shown to drive the choice of habitats. Mammalian herbivores are thought to spend more time foraging in habitats that provide high quality and quantity forage. Forage quality and quantity in turn depends on abiotic features like temperature, rainfall, soil nutrients etc. The temporal changes in these biotic and abiotic features are expected to reflect in the spatial abundance and distribution of herbivores.

Habitat use is the way in which an animal uses the physical and biological resources in a habitat. Studies have documented habitat use by herbivores in different ecosystems across the world (Aulak and Babinska-Werka, 1990; Ben-Shahar and Skinner, 1988; Heinze et al., 2011; Madhusudan and Johnsingh, 1998; Pienaar, 1974). Frame work for conservation strategies have been built based on these habitat use studies.

Grasslands ecosystems harbour a range of uniquely adapted plants and animals. In recent decades, many of these grasslands are facing major threats due to various anthropogenic activities (Bunyan et al., 2012; Robin and Nandini, 2012; Thomas and Palmer, 2007).

Shola-grassland ecosystem

Shola-grasslands are one of the grassland ecosystems found in the southern part of India. These are unique ecosystems characterised by a mosaic of stunted 'sholas' or the tropical montane forests, and montane grasslands that stretch across the upper reaches of the Western Ghats. These habitats usually occur at higher elevations, typically greater than 2000 metres above mean sea level. The shola patches are restricted to the folds and valleys in the mountain, separated from the grasslands. Some studies from the mid nineteenth century have suggested frost as a factor responsible for this mosaic (Thomas and Palmer, 2007). Sholas have been referred to as living fossils (Vishnu-Mittre and Gupta, 1968) because of their ability to expand being limited by the microclimatic condition of the area (Sukumar et al., 1995). The sholas are known to have a high water retention capacity and thus preserve water for the organisms in this system. Sholas are also origins of many rivers and streams in the Western Ghats. They are home to various endemic floral and faunal species including the endangered mountain goat, the Nilgiri tahr (*Nilgiritragus hylocrius*), which has been meticulously studied (Bunyan et al., 2012; Madhusudan and Johnsingh, 1998).

Threats to the shola-grassland ecosystem

There has been less focus on the shola-grassland systems in India although they are facing major crisis due to global climate change and anthropogenic interventions (Robin and Nandini, 2012; Sukumar et al., 1995). Most studies done in this ecosystem have looked at the diversity and distribution of various species (Babu and Kumar, 1997; Mohandass et al., 2015; Robin and Nandini, 2012; Robin et al., 2014). Shola-grasslands have been recognized as an ecologically sensitive ecosystem (Bunyan et al., 2012). Habitat modification and climate change have been shown to affect the dynamics of these montane ecosystems (Sukumar et al., 1995).

Forestry activities dating back to early nineteenth century have converted a large portion of the system to agricultural lands, grazing pastures, plantations like pine (*Pinus patula*), eucalyptus (*Eucalyptus globulus*) and wattle (*Acacia mearnsii*) along with other commercial plantations like tea and coffee (Robin et al., 2014). These were introduced for domestic and industrial purposes. These human transformations can affect ecological services and functioning. These monocultures have changed the soil quality (Thomas and Palmer, 2007) resulting in soil erosion (Sukumar et al., 1995). Plantations like wattle, which was introduced for fire wood, have been taking over the system at a very rapid pace. Other exotic grass and shrub species are also encroaching into the system.

Mammalian herbivores and shola-grassland ecosystems

Mammalian herbivory is well established as a major factor that is involved in maintaining the structure and composition of grassland ecosystems, other factors being fire, rainfall and soil nutrients (Augustine and McNaughton, 2004; Augustine and McNaughton, 2007; Belsky, 1986; Langevelde et al., 2003). Although mammalian herbivory has been shown to be an important factor affecting grassland ecosystems, it has not been adequately studied in the shola-grassland system. It is well known that wild ungulates such as sambar deer (C*ervus unicolor*), Nilgiri tahr, muntjac (*Muntiacus muntjak*) and gaur (*Bos gaurus*) are common in these systems (Joseph et al., 2007), but no study has looked at the functional roles of these mammals in these invaded ecosystems.

The study organism, sambar deer, is the most widespread deer species in Asia and also adapted to various habitat types and environmental conditions (Sankar and Acharya, 2004).They are the preferred prey species of tiger (*Panthera tigris*) and leopard (*Panthera pardus*) (Kumaraguru et al., 2010; Simcharoen et al., 2014; Varman and Sukumar, 1993). Sambar is quite flexible in its habitat requirements and consumes a varied diet. They are less specialized unlike other deer species. Their diet depends on the availability of browse and grass in the habitat at any given point of time (Forsyth and Davis, 2011; Sankar and Acharya, 2004). Though they are flexible and less specialized, temporal variation in resources in a habitat could change the pattern of use of that habitat. This study tried to look at how sambar uses the different land use types, namely, shola forests, grasslands, and wattle plantations during wet seasons and also how this use change from wet season to dry season.

Few studies have looked at the interaction of herbivores with plantations with emphasis on foraging (Ismail and Jiwan, 2015; Kumara et al., 2004). This study has looked at the use of wattle, which is a plantation and also now an invasive species in the shola-grassland ecosystem, by the mammalian herbivore, sambar deer. The study also aims to contribute to the pool of knowledge of habitat use by mammalian herbivores in the context of invasion.

It was hypothesized that there exists variation in habitat use in the large herbivore, sambar deer, and this is expected to vary spatially and temporally.

The following predictions were tested:

1) Sambar being a major browser that prefers tree canopy cover (Sankar and Acharya, 2004) should use shola forests more compared to grasslands in the wet season. They are also known to use plantations (Ismail and Jiwan, 2015). Wattle plantations should be used intermediately as they have lower cover than shola forests but more compared to grasslands.
2) A shift in habitat use is expected as there is a shift from wet season to dry season when the forage quality becomes the limiting factor. Sambar being a large herbivore will have to forage more to meet the nutrient requirements (Ahrestani et al., 2012). When resources become limited in the dry season, a more uniform use of the land use types is expected.
3) The abundance of the herbivore is expected to decrease with distance from the nearest water source and forest patch (Simcharoen et al., 2014); and to increase with distance from human presence like roads (Yen et al., 2013).
4) Sambar deer have been classified as browsers (Ahrestani et al., 2012)and intermediate feeders in different studies (Forsyth and Davis, 2011) indicating opportunistic feeding. This could be the result of available resources in the habitat at a given point of time. The habitat use is expected to reflect in the diet of sambar which is measured using the browse to grass ratio in dung pellets. Following from prediction 2, sambar should be browsers during the wet season and shift to mixed feeding during dry season.

Materials and Methods

Study site

The study was done in the hills of the Nilgiris south division (Figure 1, ~30sq.km; Latitude: 11°14 N to 11°17 N; Longitude 76°33 E to 76°35E) forming a part of the Nilgiri Biosphere Reserve in the Western Ghats from August 2014 to December 2014. Nilgiris or the Blue Mountains are a range of mountains that are part of the larger Western Ghats chain. Tropical montane evergreen forests known as sholas are distributed as patches in the valleys of the grasslands. A major part of this ecosystem has been converted to commercial and non-commercial plantations during the early ninety's. Plantations like wattle have become a threat to this system as they are a major invader at present, expanding at a great pace. Exotic shrub species like Scotch broom *Cytisus scoparius* and Gorse *Ulex europaeus* are also colonizing the landscape.

The elevation ranges between 2000 and 2500m above sea level. Mean annual rainfall received in the Nilgiri distict ranged from 1467 to 2446 mm for the years 2009 to 2013 (Indian Meteorological Department). Rainfall is monsoon driven and the landscape receives both the south-west (SW) monsoon (June to September) and north-east (NE) monsoon (October & November). The dry season starts from December and lasts till April.

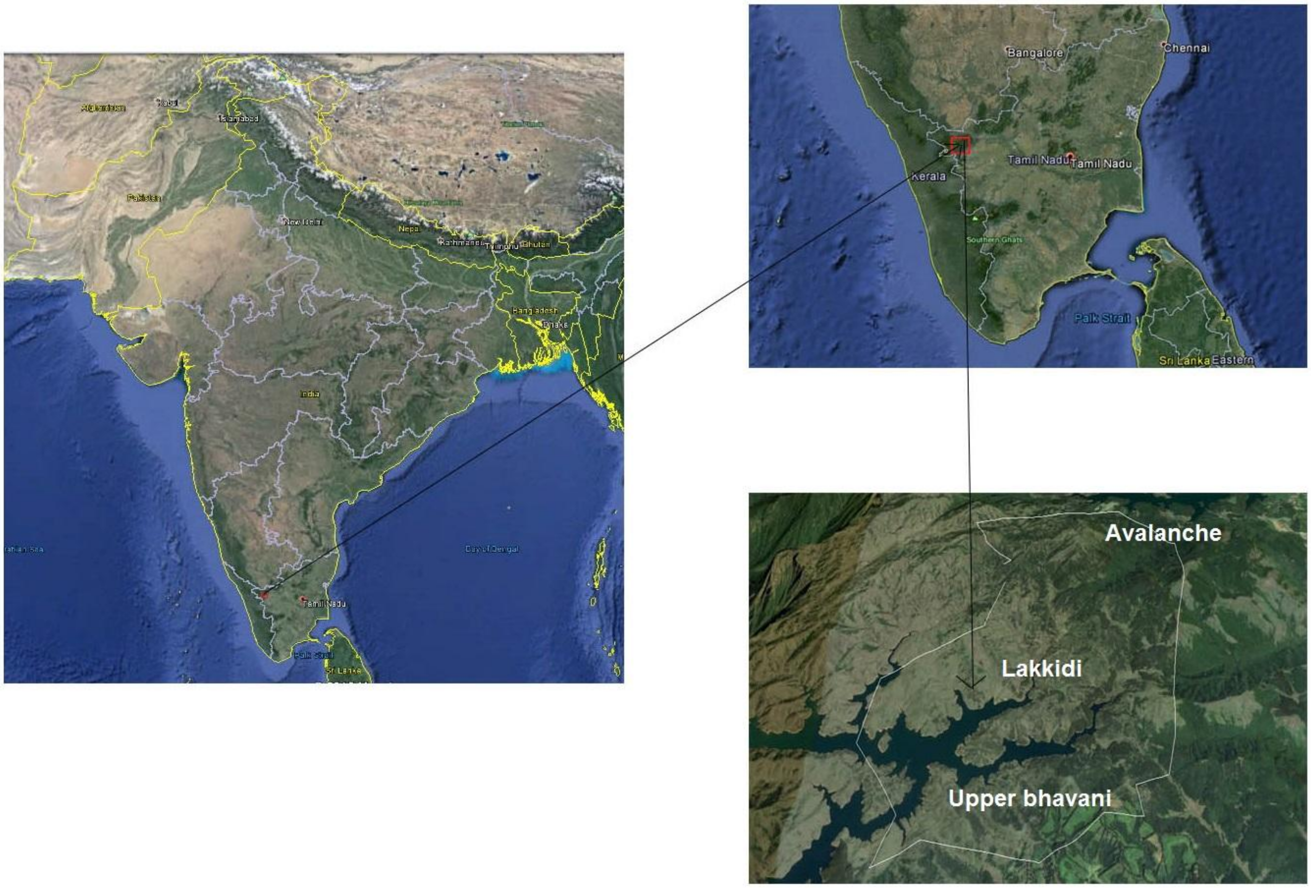

Figure1: Google earth image showing the study area, hills of the Nilgiri south division. The polygon in the bottom right image represents the sampled area.

Data acquisition

Relative abundance estimation using faecal pellet count

Dung density estimation method was adopted to quantify the relative abundance of sambar in the land use types in the study. This is an indirect method used to estimate the population density of the species (Li et al., 2014; Newey et al., 2003; Plumptre and Harris, 1995; Putman, 1984). Direct density estimation by observation and enumeration was difficult because of the nocturnal behaviour and small group size (Leslie, 2011; Sankar and Acharya, 2004). Additionally, this method was adopted as the relative abundance of sambar deer in the land use types was being estimated and not absolute densities.

Seasonal plots

The area covered by grasslands (43.4%), shola forests (21.6%) and plantations (35%) in the sampled region (in the vegetation map obtained from the India biodiversity portal) were different and hence they were sampled in proportion to their corresponding areas. The study area was divided into 250m x 250m square grids using GIS (QGIS Valmiera 2.2, 2014). During the peak of wet season which was in the months of August and September of 2014, 120 dung plots were sampled (Figure 2). The sampling points were randomly chosen using a random number generator. Out of the 120 plots, 52 points were in grasslands, 42 in plantations and 26 in shola forest as grassland covered the largest area followed by plantations and then shola forest.

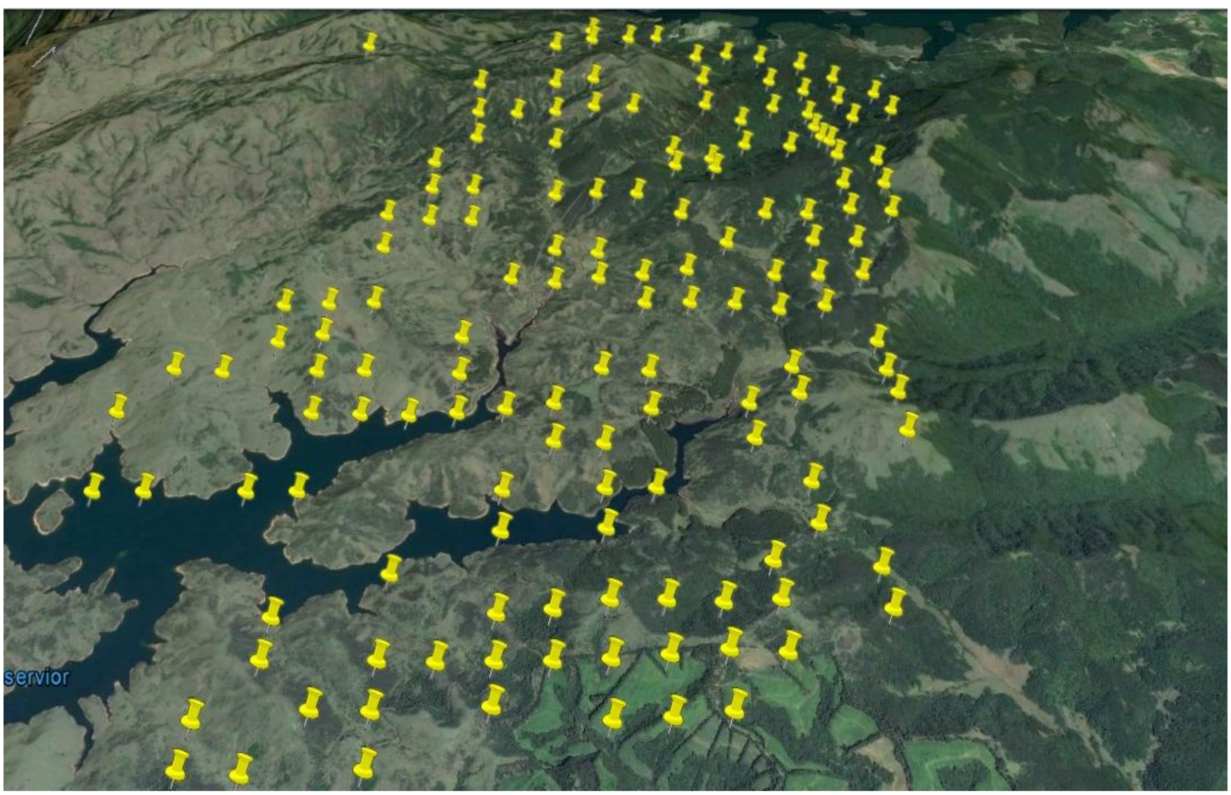

Figure 2: Google earth image of the 120 seasonal plots sampled in the landscape in proportion to the area covered by each land use type.

Temporal variation in dung deposition rate

Fifteen plots each (gridded and randomly chosen) were laid in the 3 land use types and monitored every 15 days to look for change in dung deposition rate. These plots were laid aiming to capture the shift in habitat use from wet season to dry season. Pellets in these plots were cleared after counting in each visit. This process was repeated five times from late September to early December, 2014 marking late wet season and early dry season respectively.

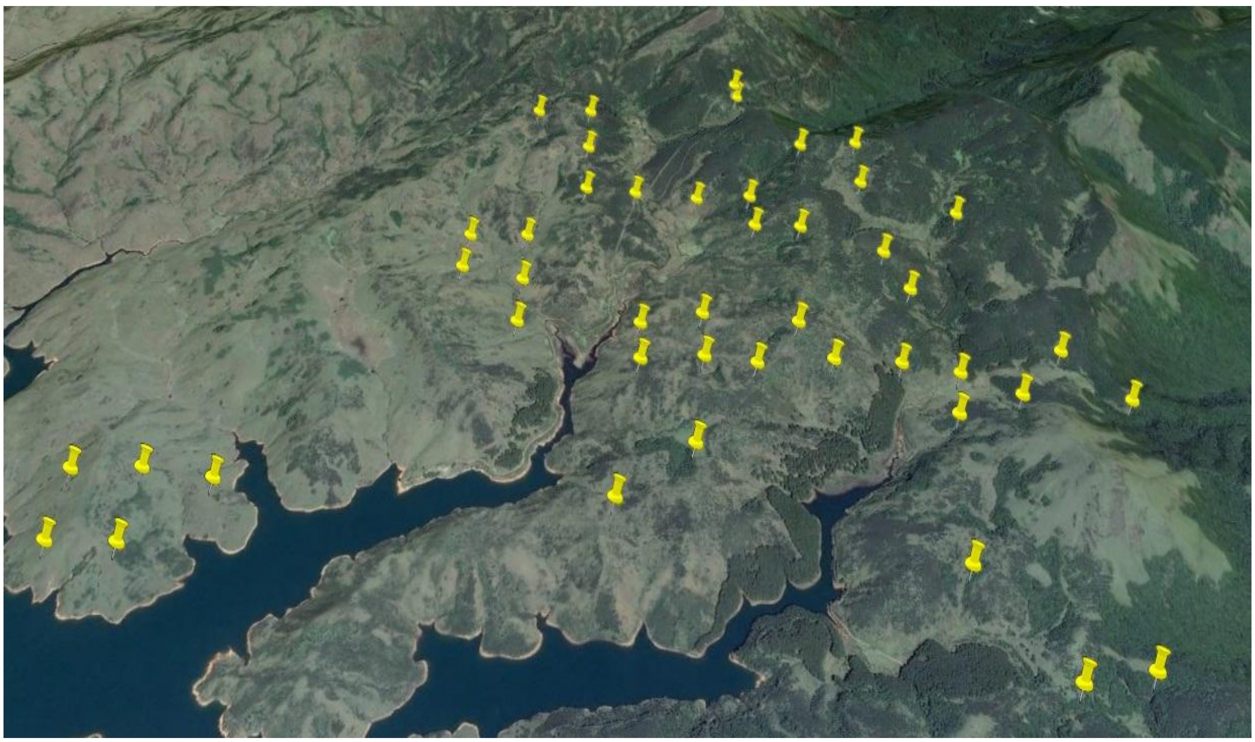

Figure 3: Google earth image of the 15x3 plots sampled to measure changes in dung deposition rate in each land use types.

Sampling

Points were located using a Garmin etrex global positioning system, compass & Google earth. Plots of 25m x 2m were established in which deer dung pellets were counted and habitat variables (discussed below) measured. Plots were placed along a predetermined compass bearing and the cardinal direction chosen was east. If the sampling was not feasible in this direction, a bearing of 45 degree clockwise from this original direction was chosen. This was to avoid bias while placing the plots.

Pellets observed in the plots were counted and aged as old (more than a week & completely dry), intermediate (a week old, medium wet) and new (fresh, green, wet). Habitat variables measured were tree canopy cover, understory vegetation height and percentage cover of grass (grass/sedge), fern and shrub (herb/shrub/climber), bare ground, litter, moss and stream points. Habitat variable measurements were recorded at every one metre along the 25 metre plot.

Vegetation height was measured using a 1 metre ruler. The maximum height of the vegetation within a 10cm x 10cm plot placed at every one metre was recorded. Tree canopy cover was scored as 0 if the sky could be seen and 1 otherwise. The most abundant cover present within the 10x10cm plot at each point was noted.

$\delta\,^{13}C$ analysis for determining browse to grass ratio

Mammalian faeces have been used as a readily accessible sample material for dietary reconstruction as observing animals foraging could be difficult (Ahrestani et al., 2012; Codron et al., 2005; Corriale and Loponte, 2015). The ratio of carbon isotopes, ^{13}C and ^{12}C, $\delta^{13}C$ present in the faeces has been used as a proxy to estimate the type of diet followed by the organism at a given time. The ratio of $^{13}C/^{12}C$ is expressed in delta (δ) notation. It is calculated using the equation $\delta R = [(R_{sample} / R_{standard}) - 1] \times 10^3$, where R is the isotopic ratio of the element (Codron and Codron, 2009).

Plants following the Calvin cycle or the C3 photosynthetic pathway have average $\delta^{13}C$ values of -26.5‰ (range: -22 to -34) and the ones following the Hatch-Slack cycle or the C4 photosynthetic pathway have average $\delta^{13}C$ values of -12.5‰ (range: -8 to -16) (Codron et al., 2005; Corriale and Loponte, 2015). Higher $\delta^{13}C$ values in the faeces indicate a C4 based diet and lower values indicate C3 based diet. Most of the grass species follow C4 pathway while *Pteridium aquilinum*, the only fern recorded, forbs, herbs, shrubs follow C3 pathway(Corriale and Loponte, 2015; Sukumar et al., 1995). Isotopic ratio mass spectrometry (for carbon) was used to determine the $\delta^{13}C$ value which is indicative of the proportion of plant functional types consumed (C3 versus C4 photosynthetic pathway). The spectrometric analysis using faecal matter has been shown to be advantageous over the methods used in the past for dietary reconstruction as direct observation is not required.

Sambar faecal pellets were collected to determine the ratio of grass to browse in their diet. Fresh pellets (n=15-20) from distinct depositions were collected periodically between mid-September and mid-December, 2014. They were air dried and pooled to make bimonthly composite samples for analysis. The diet composition was determined using $\delta^{13}C$ values obtained from stable carbon isotope ratio analysis of the subsamples (n=3) from composite samples. The isotopic ratio mass spectrometry analyses of sambar faecal matter were done in the Department of Crop Physiology, University of Agricultural Sciences, Bengaluru, India.

Statistical analysis

All analyses were performed using R version 3.1.2 (R Core Team, 2014) and GIS (QGIS Valmiera 2.2, 2014).

Habitat use by sambar

The total dung count was used for relative abundance estimation for seasonal plots as well as deposition rate studies. A Generalized linear model with negative binomial error terms (Venables and Ripley, 2002) was used to explain the relative abundance of the herbivore in the habitat types. The graphical package ‘ggplot2’ (Wickham, 2009) was used to create bar graphs. The packages ‘plyr’ and ‘reshape2’ was used for data managing (Wickham, 2007, 2011).

Habitat variables

The plot averages of all variables were used for all analyses. Percentage tree canopy cover was calculated by averaging canopy intercepts (1’s). The mean height of vegetations namely, grass and shrub was calculated.

Landscape variables

The total dung count in the 120 plots and the total dung count in the 45 plots of the dung deposition rate study when it was first laid were combined to study the effect of landscape variables on sambar deer distribution. Landscape variables viz. elevation and distance to nearest water source, road, forest patch, and wattle plantation were calculated from each plot. This was done in QGIS and GRASS GIS using the stream maps obtained from the Foundation for Ecological Research, Advocacy and Learning, India, the digitized road maps and the NBR vegetation map obtained from India biodiversity portal. The relation between landscape variables, which were the predictors, and dung density, the response variable, in the plots was examined using a generalized linear model with negative binomial error terms (Simcharoen et al., 2014). The interaction between the predictors and response variable was also tested using the same model.

Grass to browse ratio

The predictors which were the bimonthly time starting from late September to early December and the response variables were the $\delta^{13}C$ values obtained for each subsample using the stable carbon isotope was analyzed using one way ANOVA to see if there is shift in the diet composition from wet season (browser) to dry season (mixed feeder). Tukey's post hoc test was used to compare means. The graphical package ggplot2 (Wickham, 2009) was used to create the graph.

Results

Seasonal plots

The results obtained shows that the dung deposition differed significantly between the habitat types. The deposition was highest in grasslands and plantations followed by shola forests (Figure 4).

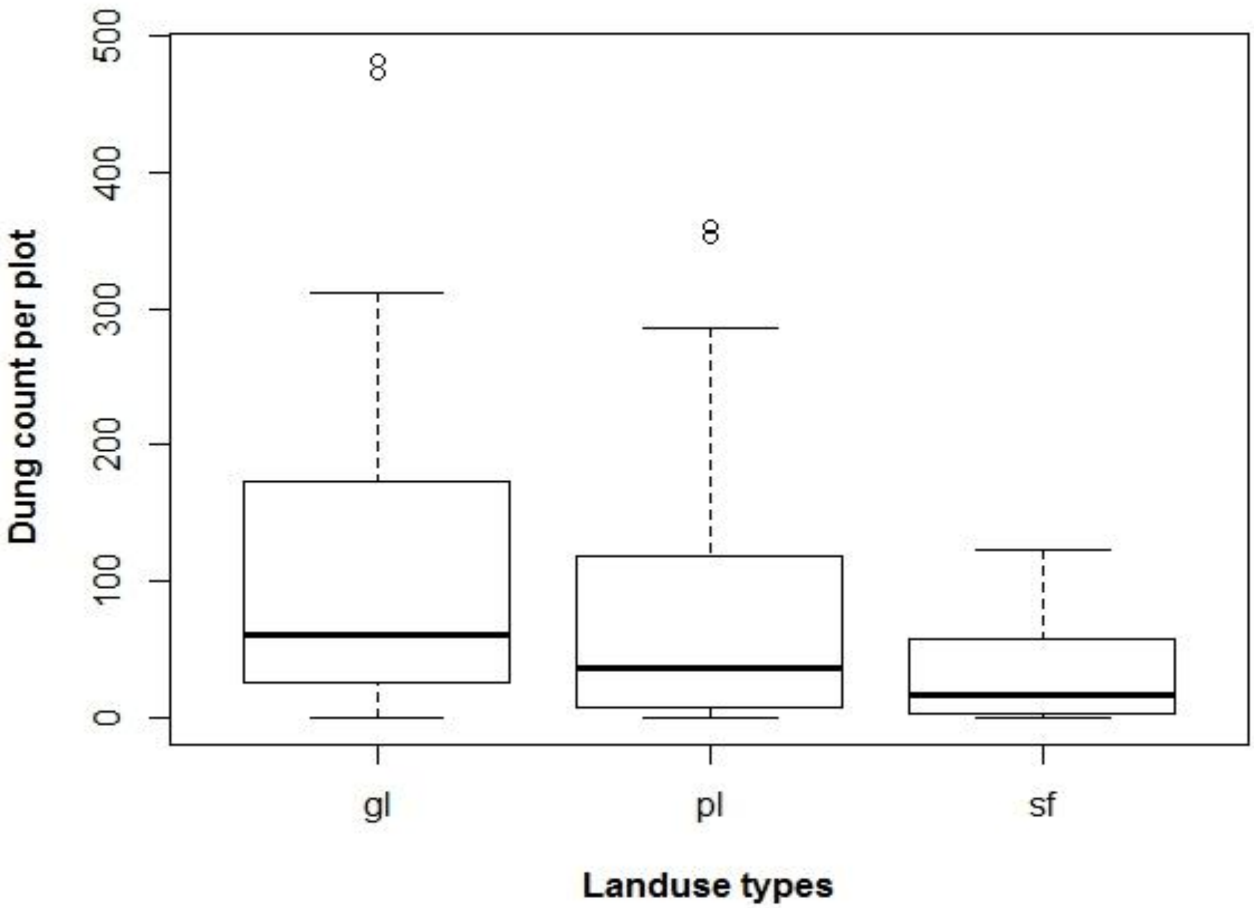

Figure 4: Box plots of dung counts in the three land use types (gl-grassland, pl-plantation, sf-shola forest) during the wet season. Grassland and shola forest ($p<0.000163$ ***); plantation and shola forest ($p<0.0034$ **); grassland and plantation ($p<0.636$)

Habitat variables

Shola forest has a higher mean vegetation height and percentage tree canopy cover compared to the other two land use types (Table 1). In contrast, ground vegetation cover is similar for grassland (87.8%) and plantation (86.8%), but higher than shola forest (26.6%). Grass is the dominant functional type in grassland and in the understory of plantation while the understory of shola forest is dominated by bareground. Grassland and plantation has similar and greater grass cover compared to shola forest (Figure 5). Shrub cover in grassland (5%) and understory of shola forest (5.9%) are similar while shrubs occupy only 2.9% in the understory of plantation. Bare ground and litter constitute 65% of the shola forest ground cover while it is 11.5% and 7.1% for grassland and plantation, respectively.

Table 1: Vegetation structure measurements in each land use type. Mean and standard error are represented.

Variables	Grassland mean $\pm$ se	Plantation mean $\pm$ se	Shola forest mean $\pm$ se
Mean height of grass (in cm)	23.35 $\pm$ 0.46	26.49 $\pm$ 0.52	48.3 $\pm$ 4.56
Mean height of shrub (in cm)	67.59 $\pm$ 3.87	47.89 $\pm$ 4.91	45.37 $\pm$ 13.36
Canopy cover (%)	0	19.71 $\pm$ 4.83	95.85 $\pm$ 1.05

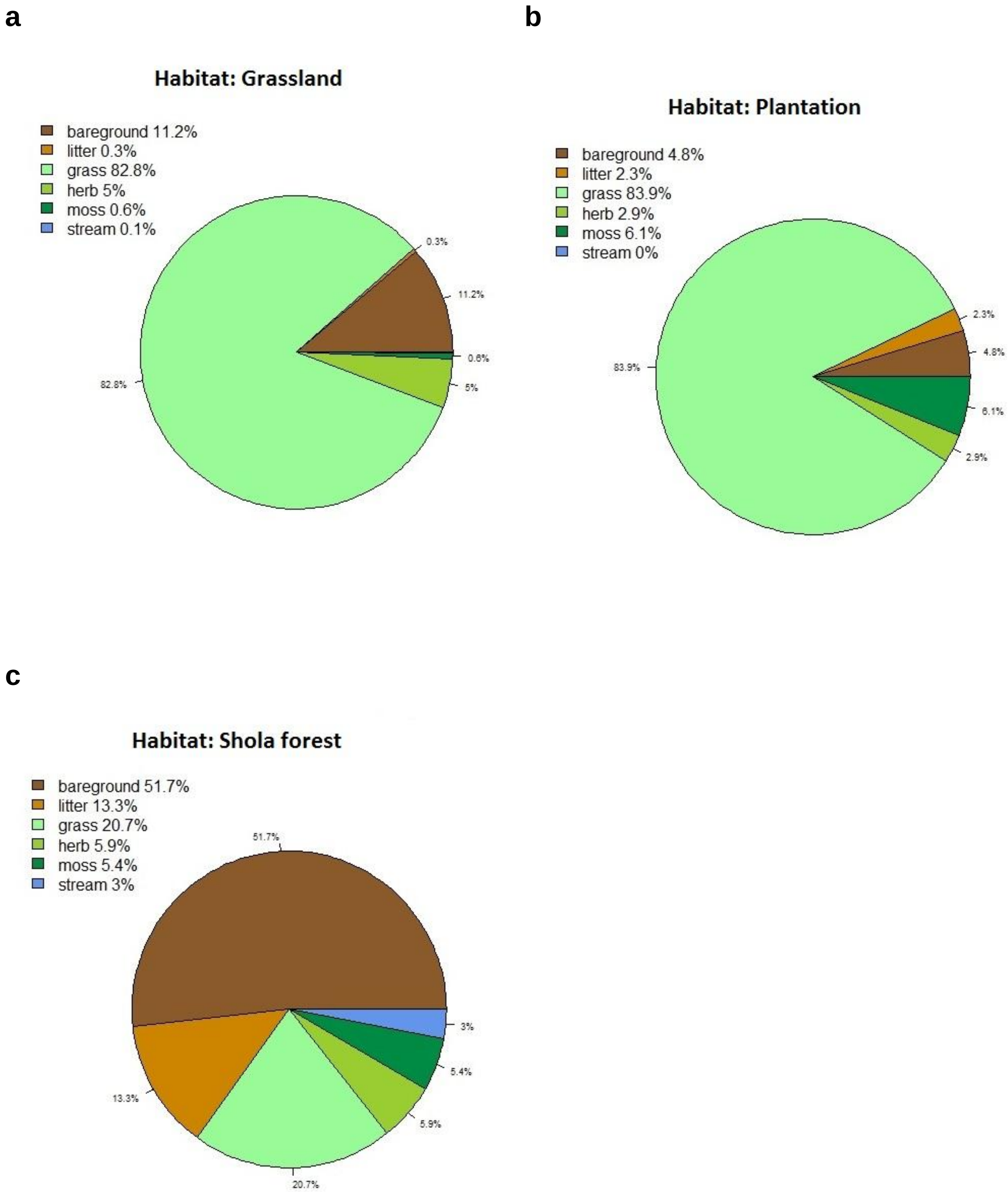

Figure 5: Percentage cover in (a) grassland, (b) plantation, (c) shola forest

Temporal variation in dung deposition rate

The pattern of use of each habitat remained the same over time but the use differed between the habitat types. The results obtained shows that dung deposition differed significantly between the habitat types. Plantation has the highest deposition rate followed by grassland and shola forest (Figure 6).

The graph represents the result obtained removing 2 outliers from the data which gave overdispersion and also a different result. The outlier values were obtained from a big shola patch. While plantation had the highest dung deposition compared to the other two land use types grassland and shola forest did not significantly differ ($p<0.19658$) in the deposition rate.

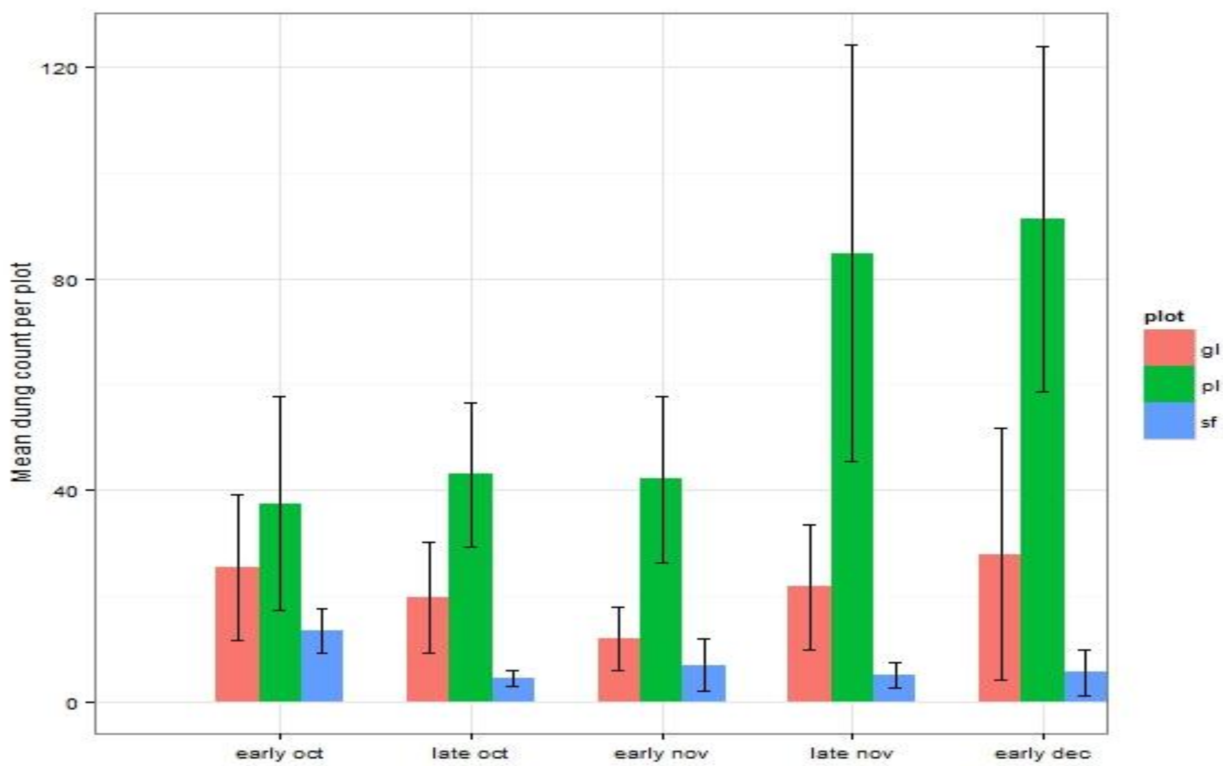

Figure 6: The bar graphs show change in the dung deposition in the three land use types (gl-grassland, pl-plantation, sf-shola forest) over time. Mean and 2SE are shown. Grassland and shola forest ($p<0.00102$ **); grassland and plantation ($p<0.00268$ **); plantation and shola forest ($p<2.99e-13$ ***)

Habitat variables

There has been no significant change in the vegetation structure or percentage cover in any of the land use types over the study period and hence the results represented are the means of the pooled data. Shola forest has a higher percentage tree canopy cover compared to the other two land use types while the mean understory vegetation height is similar for all of them (Table 2). The ground cover of grassland (98%) and plantation (97.8%) are similar, but higher than that of shola forest (3.1%). Grass is the dominant functional type in grassland and in the understory of plantation while the dominant in the shola forest is litter (Figure 7). Grassland and plantation has similar but greater grass cover compared to the shola forest (Figure 7). Bare ground and litter constitute 88.9% of the shola forest cover while it is 2% and 2.1% for grassland and plantation, respectively.

Table 2: Vegetation structure measurements in each land use type. Mean and standard error are represented.

Variables	Grassland mean ± se	Plantation mean ± se	Shola forest mean ± se
Mean height of grass (in cm)	34.65 ± 0.51	32.86 ± 0.36	38.59 ± 3.11
Mean height of shrub (in cm)	29.91 ± 6.75	23.73 ± 2.01	28.43 ± 3.91
Canopy cover (%)	0	0	99.42 ± 0.20

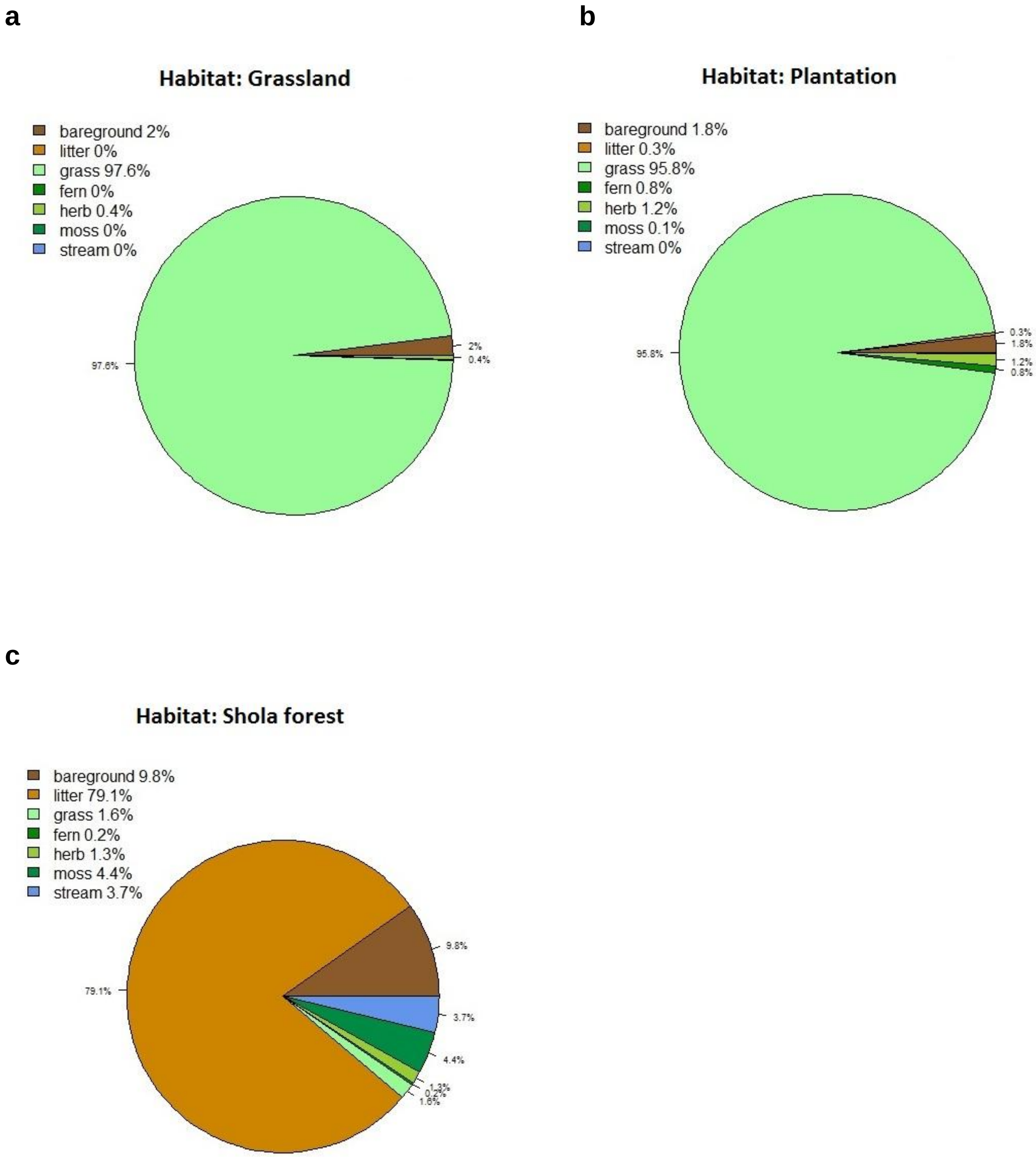

Figure 7: Percentage cover in (a) grassland, (b) plantation, (c) shola forest

Lanscape variables

None of the variables individually or in interaction with other predictor variables were able to significantly predict dung density.

Browse to grass ratio in sambar deer diet

The low $\delta^{13}C$ values indicate that sambar followed a C3 based diet (Figure 8). One way ANOVA showed that there was significant difference in the $\delta^{13}C$ values (F value =4.037, p<0.0221*). Tukey's post hoc analysis returned results to the effect that all pairs except late September and late October (p adj<0.046) were not significant. Late September and early December showed a strong C3 based diet while the other time points fell in a range where they followed a mixed diet including both the functional types.

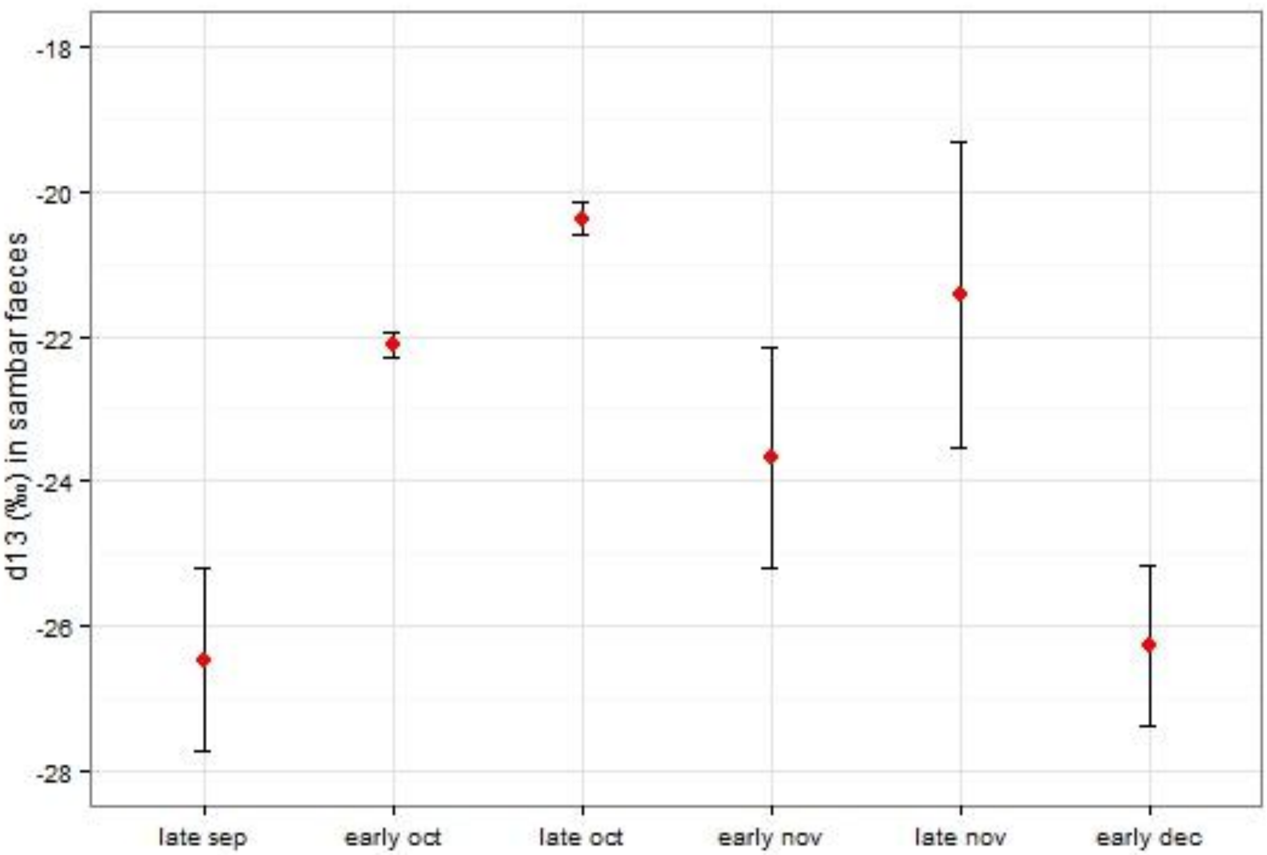

Figure 8: $\delta^{13}C$ (permil) found in the faeces of sambar in the Nilgiri south division (late September – early December, 2014). Low $\delta^{13}C$ values indicate C3 based diet. (Mean$\pm$2SE shown)

Discussion

The results obtained from both the plot based studies suggest that sambar deer use wattle plantation more followed by grassland and then shola forest. Although seasonal plots show that grassland and wattle are being used similarly, variation in the dung deposition rate over the time examined gives a reliable indication of habitat use by sambar as seasonal plots could be affected by variable decomposition rates. The pattern of habitat use and the diet followed remained same over time. The prediction that sambar could be using shola forest more compared to the other two land use types wasn't observed.

In terms of vegetation, grassland and plantation have higher ground vegetation cover compared to shola forest. The most abundant secondary vegetation in the wattle plantations is grass. The shola forest has very sparse understory vegetation compared to the grassland and wattle plantation, with mostly litter and bare ground.

Deer dung density was associated with low canopy cover which means that they preferred open habitat types. This is in support with studies that have shown that herbivores use open habitats as an anti-predator behaviour (Valeix et al., 2009).

The diet showed a mixed signature with both C3 and C4. However the C3 signal was stronger. The forbs, fern, herbs and shrubs are C3 functional type and most of the grass species in the study area are C4 functional type except for *Isachne kunthiana*, a species seen in grassland and also abundantly present inside the wattle plantation. From the density estimates, sambar deer did not spend a lot of time in the sholas, therefore most of the C3 signature could be either from the wattle plantation i.e. wattle and/or the C3 secondary growth (Ismail and Jiwan, 2015) or the selective foraging on herbs and forbs in grasslands. This study does not have the kind of data to identify the exact reason for the C3 signature. It's difficult to conclude at this point that they consume grass from grassland alone as wattle plantation was also found to have similar grass cover. Shola with its low forage quantity was not preferred over the other two land use types. A more focused study with behavioural components is required to understand this system.

The wattle plantations with densely packed vegetation have low visibility and might provide a refuge to these herbivores from humans and predators. Also, plantations can be good resting areas as wattle provides shade due to the packing. As wattle provides both food and shelter, it could be used extensively by these animals. But they do forage in the open grasslands as shown by the high dung density.

The plots were established during late wet season and were monitored till early dry season aiming to measure deposition rate as well as capture shift in use. It could be that the time period of the study (September to December, 2014) was too short to observe any change. If the study was conducted for a longer time period, any shift could have been detected. No shift in use could also be the result of the extended monsoon during the study period.

The landscape features like elevation, distance to water, road, forest patch and wattle plantation did not seem to limit the sambar deer distribution in the landscape. Studies have shown a positive correlation of herbivore density with distance to the water source (Bailey et al., 1996; Stewart et al., 2002) but this correlation is pronounced during dry season as herbivores are shown to restrict their movement and concentrate near the water sources (Omphile and Powell, 2002). A possible reason that the study did not detect a similar pattern is that it was done during wet season when sambar is not limited by water.

Distance to roads and elevation also seem to be insignificant predictors that explain sambar deer distribution contrary to previous studies (Yen et al., 2013). The reason why elevation wasn't a significant predictor could be because of the fact that the scale (2000m-2500m) looked was too small to detect a pattern. Some of the roads within the study area are not intensively used and hence may not be affecting the movement of the herbivore.

Distances to forest patch and wattle plantation were also non significant predictors to explain the distribution pattern. The vegetation map available for the study was quite old (2008). The vegetation map of the system, that is being degraded and invaded at a fast pace, needs to be revised periodically.

Future directions

The distribution and abundance of herbivores has been shown to depend largely on maximum forage intake and minimum predation pressure (Ben-Shahar and Skinner, 1988; Bjørneraas and Herfindal, 2012; Brashares and Arcese, 2002). The study clearly shows a positive association of deer dung density with available forage, for which vegetation cover was used as a proxy, in the land use types. Behavioural observations on sambar deer could possibly give reliable insights and better understandings on what these habitats are being used for.

The study was mostly done during the wet season due to the influence of both south west and north east monsoon. The results presented cannot be considered as general habitat use pattern by sambar deer as the dry season could influence the pattern.

The study indicates that sambar receives some benefits from wattle but the impacts of the presence of this ungulate in this land use type cannot be drawn from this study. At this point, it is difficult to conclude if the effect of herbivore on the expansion of wattle in the landscape is positive, negative or zero. Controlled experiments may give more information on the impacts of herbivores on the wattle plantation.

The study also points to the fact that an invasive like wattle has got well integrated into the system and a lot of species are now dependent on them and their services. In this study it was found that sambar deer use the wattle plantation more than other land use types. Sambar is one of the major large prey species to predators like tiger (Joseph et al., 2007; Kumaraguru et al., 2010). The change in population of prey will have a direct influence on the predator population (Karanth et al., 2011) or it can also lead to conflicts with humans due to lack of prey in the wild. A sudden and large scale removal of these exotics can leave an impact on the present system which can even cause the system to degrade faster. Hence if the removal of invaders and restoration to the ‘original’ form is not done scientifically and systematically, it can lead to ecological imbalances. More studies need to be done in order to draw a conclusion regarding the activity patterns in this invaded ecosystem.

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