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Ecology and Conservation of Shrubland Bird Communities in the Eastern Ghats of Indi

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Ecology and Conservation of Shrubland Bird Community in the Eastern Ghats of India

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ABSTRACT

Anthropogenic disturbance, in its multiple facets represents a major threat to biodiversity and habitat quality. Consequently, extensive research is guided towards understanding anthropogenic disturbance and their effects on wildlife for development of wildlife management plans. However, for development of effective wildlife management plans it is imperative that we understand the habitat use and preference by local fauna along with effects of anthropogenic presence. In this dissertation, I studied the habitat usage and preferences of Shrubland birds in the Eastern Ghats of India during the pre-monsoon and post monsoon seasons. Eastern Ghats show a marked difference from pre-monsoon season to post-monsoon season thereby affecting the habitat use by birds depending upon various vegetational charachterstics identified in this study. I also studied the dependence of local community on the forest products, impact of goats and sheep on forest structure. When juxtaposed with Land Use and Land Change (LULC) patterns these changes in habitat usage, anthropogenic effects it will help in predicting future habitat usage patterns in the face of climate change. This dissertation answers the following questions: 1) Do birds select a habitat based on vegetational structure or floral composition? 2) Is there any association between plant species and bird assemblages? 3) What is the structural preference of a bird assemblages? 4)How has LULC changed over five years owing to drought? 5)Effect of anthropogenic presence on habitat structure.

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Introduction

EASTERN GHATS, INDIA

Anthropogenic changes have caused the Earth to enter into a new human-dominated geological epoch called the Anthropocene (Lewis & Maslin 2015). Our activities have induced land surface transformation and changes in the composition of the atmosphere (Lewis & Maslin 2015). These changes in the past 500 years have triggered a wave of extinctions, threats, and local population declines (Dirzo et al. 2014). In North America alone, bird populations have declined by 29% (Rosenberg et al. 2019). In the wake of these widespread anthropogenic changes, it is even more critical to understand habitat use by birds and to use that information to develop wildlife management plans for conservation.

When it comes to studying ecology, not all places have received equal attention. The Eastern Ghats, despite being among the oldest geological structures on earth and being listed as one of the nine floristic zones in India, have been largely neglected by the scientific community and conservation biologists. The Eastern Ghats of India are a discontinuous mountain range running along the eastern coast of India, located between 16° to 19°N latitude and 80° to 85°E longitude. They are approximately 1690 km in length, and the width varies from 100 to 200 km on average. Because they have existed since there was a supercontinent Pangea, they have been subjected to various environmental pressures (Katz 1989). The four major rivers that cut across to the Bay of Bengal provided fertile soils for the people in southern India, and hence a majority of them settled on the eastern coast as compared to the western coast of India. This sizeable human settlement has had its costs, and the flora-fauna of the Eastern Ghats had come under tremendous human pressure. Within the Eastern Ghats, Chittoor district, agriculture (Figure 2) and goat herding (Figure 3) are the major occupations.

ANTHROPOGENIC DISTURBANCE

There are numerous anthropogenic disturbances in this region that have both positive and negative effects on wildlife. For instance, agriculture is a cause of forest fragmentation but increases water availability and pollinator populations (Paul 2012). Similarly, goat herding leads to wide-spread changes in habitat composition through direct effects and indirect effects. Plant species richness and composition is affected by foraging activity of goats. The goat herders during the summer season set fires to the grazing grounds in reserve forests. The immediate result of the fire is that the locked-up nutrients in the dry plants are released, and various species of grasses begin sprouting, and are then consumed by the goats. Fires generally happen during the dry season, thus coinciding with the nesting phenology of many scrubland birds and can consequently affect nest survival rates of birds (Deshwal, *unpubl. data*).

SITE DESCRIPTION

The rate at which people exploit tropical forests is increasing annually (Myers 1979). This combination of high anthropogenic disturbance and fewer ecological studies was the reason the Chittoor district in the Eastern Ghats was selected as the study site (Figure 4). Table 1 describes the land use pattern in the Chittoor district. Land use is often dependent upon the environmental and climatic conditions of the region (Diamond 1999). Chittoor has a semi-arid climate (Figure 5); it receives rain twice a year, first from the southwest monsoon (approx. 600 mm) during the summers and second from the northeast monsoon (approx. 300 mm) during winters. The temperature in the summer varies from around 20 $^{\circ}$C to around 40 $^{\circ}$C, whereas in the winter, it can drop to 5-6 $^{\circ}$C. The soil type of the Chittoor district is mainly of three types—red soils (57%), red dandy soils (34%), and black cotton + gummy red soils (9%). Red soil has comparatively weak water holding capacity as compared to black cotton soil. The red soil has its color due to the presence of the ferrous oxide. The red soil is deficient in lime, magnesia, phosphate, nitrogen, humus, and potash. The red soil has approximately 1.0% organic matter and 0.08% nitrogen. The percentage distribution of the three soil types and their composition has a significant impact on the associated vegetation type. The vegetation of the Chittoor district is a mixture of southern thorn forest and dry deciduous scrub forests (Champion & Seth 1968).

The forests in the Eastern Ghats have three layers—canopy layer, scrub layer, and herbaceous layer. The canopy cover consists largely of *Wrightia tinctoria, Dalbergia latifolia, Dolichandrone atrovirens, Vitex altissima, Diospyros montana, Albizzia amara, Schefflera stellata, Shorea talura, Sterculia urens,* and *Soymida febrifuga.* The tree species in the Eastern Ghats are shorter and have a smaller DBH (Diameter of stem at height of 1.5 m) as compared to the same species occurring in the Western Ghats. The main reason for this is that the soil in the Eastern Ghats is deficient in nitrogen and potassium. In the scrub layer, the common species found in the reserve forests of Chittoor district are *Erythroxylon monogynum, Chomelia asiatica, Dichrostachys cinerea, Securinega leucopyrus, Randia dumetorum, Plectronia parviflora, Dodonea viscosa,* and *Cassia sophera.* An exposed rock surface characterizes the forests of Chittoor. Since there is patchy canopy cover, lichens form an appreciable portion of the herbaceous layer. *Cymbopogon* sp. is the most common taxon in grass balds.

PURPOSE OF RESEARCH

Vegetation is an important component of habitat preference for birds, but the question as to whether or not the bird selects the habitat based on vegetational structure or floristic composition is a question that continues to remain unanswered. The factors that contribute to a birds' choice as to a precise location within which to feed, roost, and nest relate to characteristics. These include intrinsic factors such as food type or abundance, perch characteristics, and branch configurations (Hutto 1985). It is clear that the structure of the vegetation required by any particular bird species is quite specific (Dumas1950, Marshall 1957, Oelke 1966, James 1970). Although it is challenging to know whether a bird selects a specific area because of its structure, independently of other qualities, ornithologists have often assumed this to be the case (James 1970, Lack 1933, 1937, Lack and Venables 1939, Svärdson 1949, Tinbergen 1951). The assumption often made is that species-specific psychological preferences exist for certain visual combinations of structures of the environment (James 1970). There is much stronger evidence that food distribution is non-randomly distributed in space on a local level, and the use of space by birds corresponds to the availability of food (Cody and Walter 1976, Hutto 1985, Smith and Dawkins 1971, Gradwohl and Greenberg 1980, Smith and Sweatman 1974).

The habitat associations of birds are often used to predict the consequences of habitat change on conservation and management practices (Nick 2000). The history of a particular site is often ignored when developing a model for habitat associations. Habitat at any point is a function of landscape, history, the magnitude of change at multiple spatial and temporal scales (Southwood 1977, Allen and Starr 1982, Holling, 1992, Levin, 1992, Rosenzweig 1995). Hence, there is a need to study the previous extent of the scrub forest and compare it to the present extent of the scrub forest in the Chittoor district as a way of helping us to understand the components of habitat change and species response.

Many early successional species of scrubland birds are declining at an alarming rate (Hagan 1993, Askins 1993, Jennelle 2000). Hence the need for studying the vegetational structure for understanding the foraging preferences in sympatric and congeneric species. This information will help in the conservation planning of various vulnerable species, such as the yellow-throated bulbul (*Pycnonotus xantholaemus*). Sampling of the vegetational structure has often ignored finer details, emphasizing instead on the overall characteristics of vegetation (MacArthur and MacArthur 1962, James 1992). Due to the uneven characteristics of scrubland vegetation produced by mosaic patterns of alternate patches of grasses and shrubs, the task of measuring vegetational structure in this habitat becomes challenging (James 1992).

Within the Chittoor district, approximately 218 species of birds have been recorded, out of which approximately 115 species are common in thorny scrub. The Chittoor district has 1756 species of flowering plants (2500 for the state of Andhra Pradesh) which belong to 879 genera and 176 families.

I proposed to study the ecology of the bird communities in the thorny scrub hill forests to help develop potential conservation approaches to mitigate effects of LULC. The bird species chosen for this research are the 15 most common species found in scrub forests of Madanapalle. These include three species in the family Pycnonotidae: *Pycnonotus cafer* (Red-vented Bulbul) (Figure 6), *P. jocosus* (Red-whiskered Bulbul) (Figure 7), and *P. luteolus* (White-browed Bulbul) (Figure 8); four species in the family Timallidae: *Turdoides affinis* (Yellow-billed Babbler) (Figure 9) and *T. caudata* (Common Babbler) (Figure 10), *Chrysomma sinense* (Yellow-eyed Babbler) (Figure 11), *Dumetia hyperythra* (Tawny-bellied Babbler) (Figure 12);two species in the family Nectariniidae: *Cinnyris asiaticus* (Purple Sunbird) (Figure 13), *Leptocoma zeylonica* (Purple-rumped Sunbird) (Figure 14); two species in the family Cisticolidae: *Prinia inornata* (Plain Prinia) (Figure 15) and *P. sylvatica* (Jungle Prinia) (Figure 16). *Saxicoloides fulicatus* (Indian Robin) (Figure 17), *Spilopelia senegalensis* (Laughing Dove) (Figure 18), *Merops orientalis* (Green Bee-Eater) (Figure 19), and *Acrocephalus dumetorum* (Blyth's Reed Warbler) (Figure 20). *Acrocephalus dumetorum* was the only winter migrant considered in this study.

These common bird species were used as a representative group for the scrubland birds of Madanapalle. Despite being common birds, very little is known about their ecology. Most comprehensive knowledge of their ecology thus far comes from the handbook of birds of India and Pakistan together with those of Nepal, Sikkim, Bhutan, and Ceylon (Ali & Ripley 1980). The book provides detailed information regarding the natural history of these birds, which was useful in understanding their habitat preferences. The following are a few excerpts from Ali and Ripley (1980) regarding these birds: The Yellow-billed Babbler prefers to feed in a group on the ground with one bird (sentry) on the lookout by sitting on top of the shrub. The Tawny Bellied-Babbler moves among the tall grass, undergrowth, or on the ground, skulking in nature. The Common Babbler was compared to a rat scuttling under sparse vegetation while foraging. The Common Babbler prefers to hop around searching for food and loathe flying. The Yellow-eyed Babbler is a shy and elusive bird. It is reported that they have similar habitat preferences as *Prinia* but the author did not specify the species of *Prinia* or in which season. The White-browed Bulbul is shy and skulks. The Red-vented Bulbul and the Red-whiskered Bulbul have similar habitat preferences, but it was not specified if this is true for both the wet or the dry season. The Blyth's Reed Warbler is secretive and shy, hopping in shrubs and bushes. The Jungle Prinia hops jerkily in grass and thorn scrub, climbing to the top and then diving down in thicket in alarm. The Indian Robin prefers to feed on or close to the ground. The Laughing Dove prefers to feed on seeds or on the ground.

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APPENDIX

Figures and Tables –

Table 1. Land use pattern based on patch density, a comparable estimate of landscape structure (Paul 2012).

Land Use	Patch Density per 100 hectares
Agriculture	8.646
Open/Barren/Rock Exposure	5.569
Fallow Land	3.750
Scrub	7.476
Thorn Forest	14.34
Mixed Dry Deciduous Forest	15.967
Settlement	0.271
Dry Deciduous Forest	4.175
Water	0.322
Dry Evergreen Forest	0.424
Sandy Bed	0.087

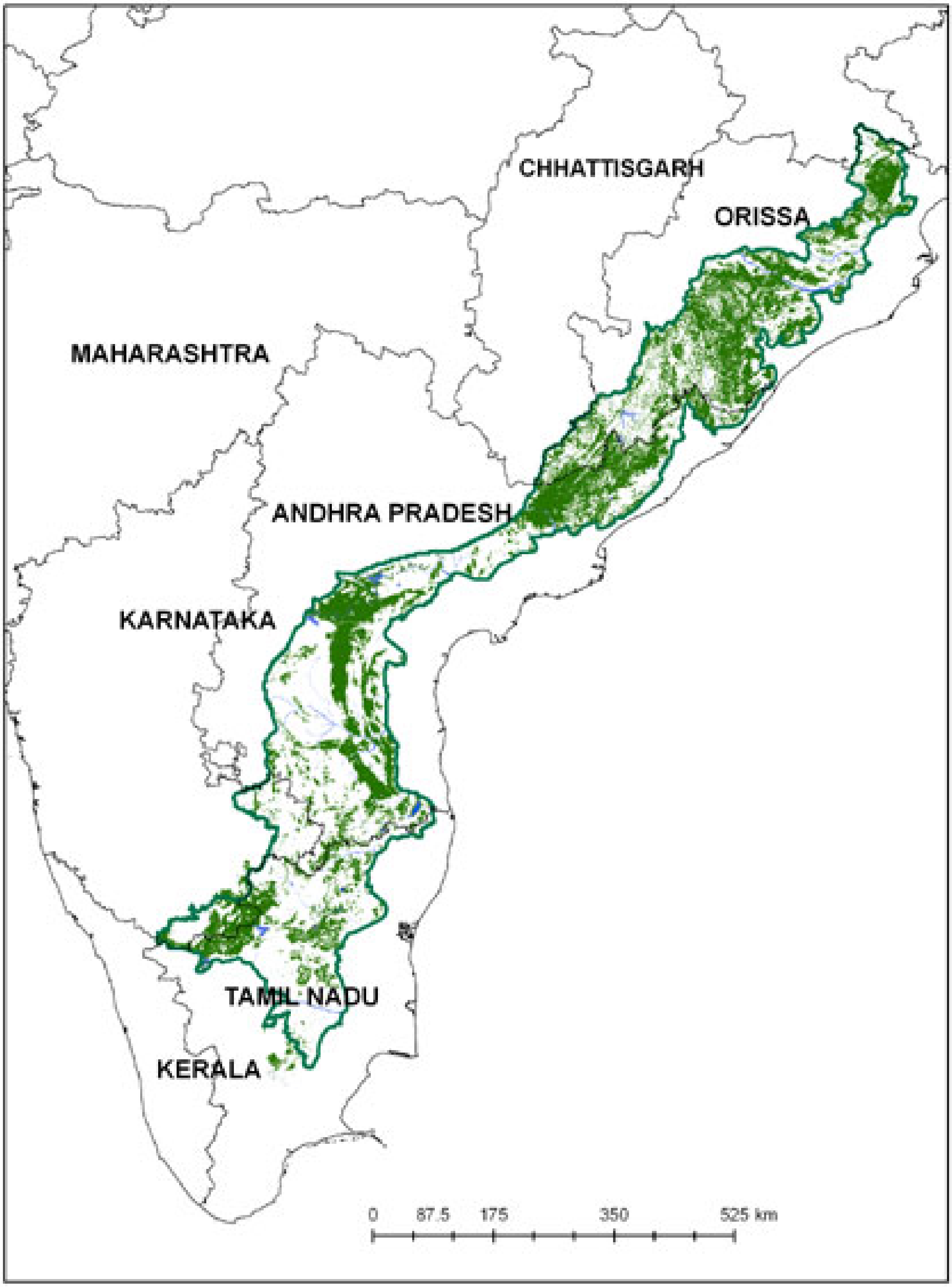

Fig.1 Eastern Ghats, southern India (Graceindia.info)

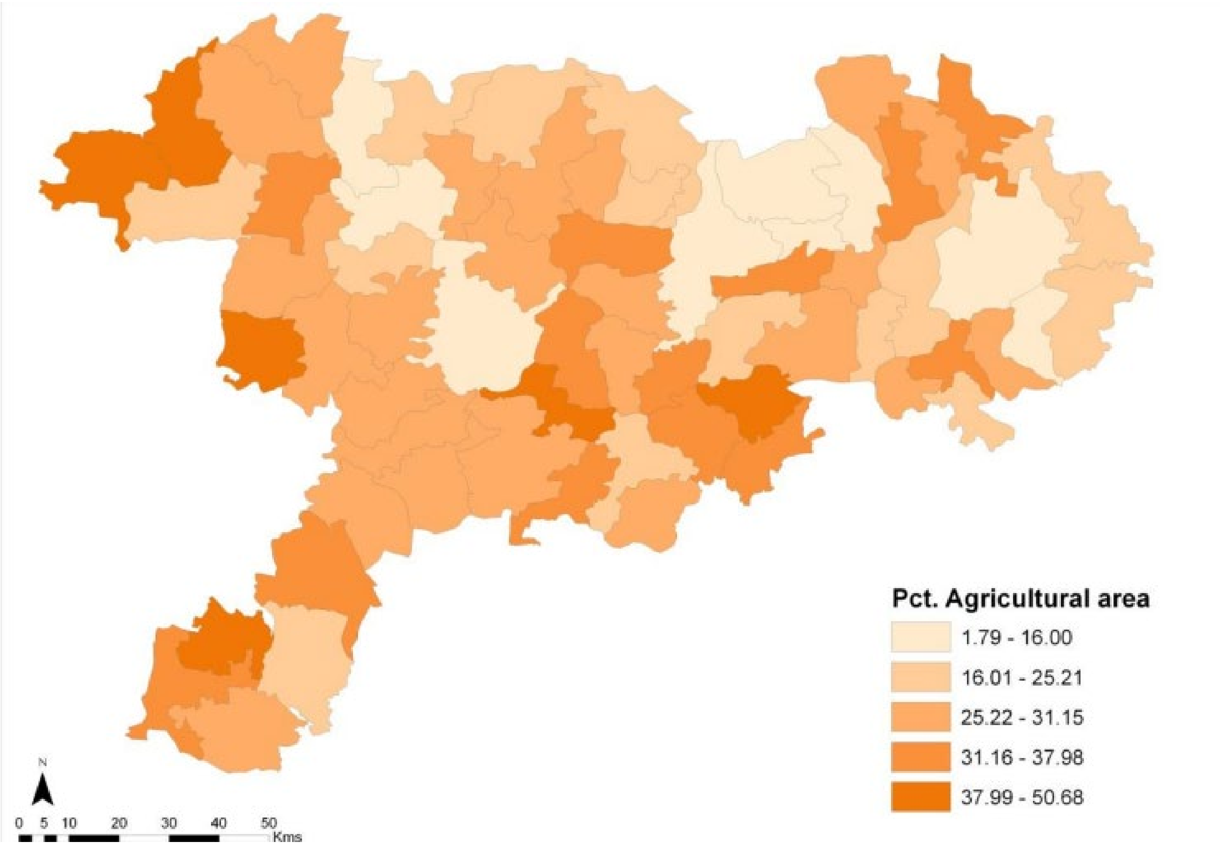

Fig. 2 Percentage agricultural cover in Chittoor (Paul 2012).

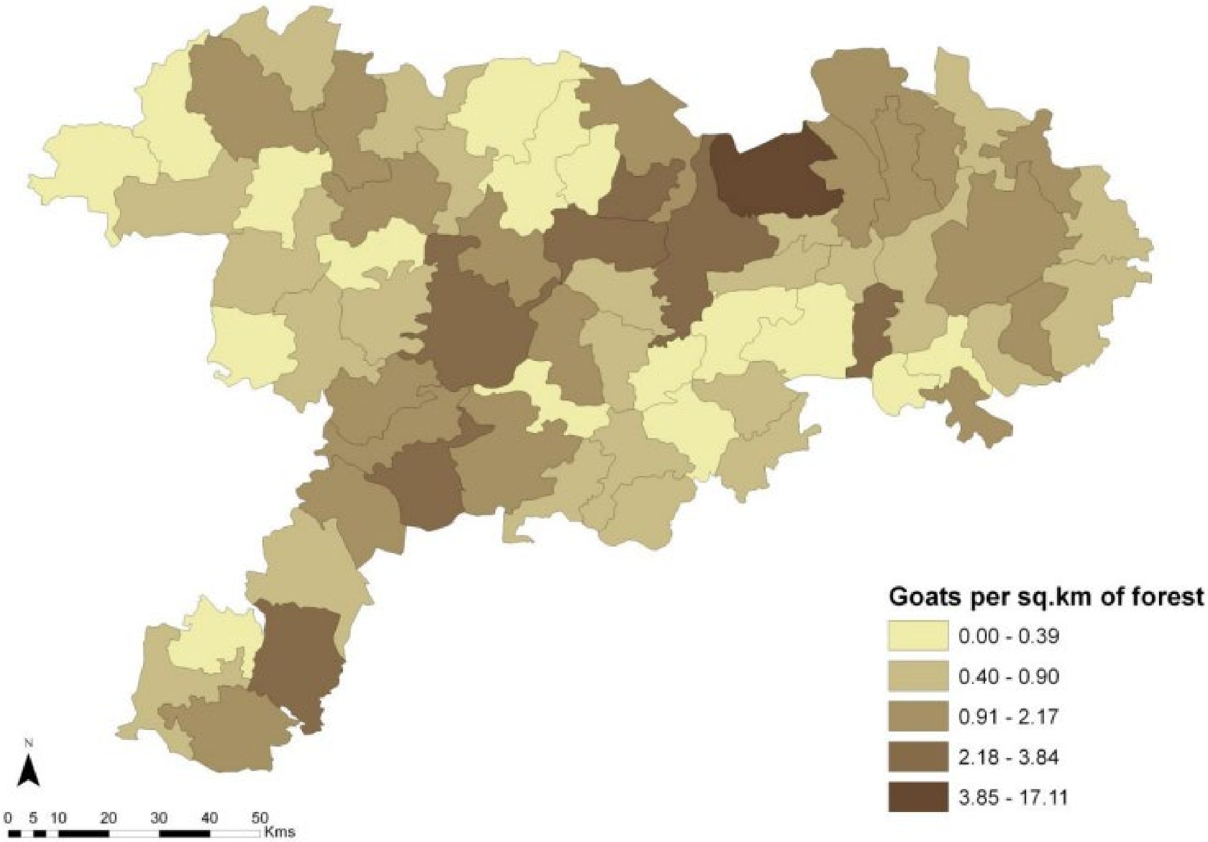

Fig 3 Goats per square kilometer in the Chittoor district (Paul 2012).

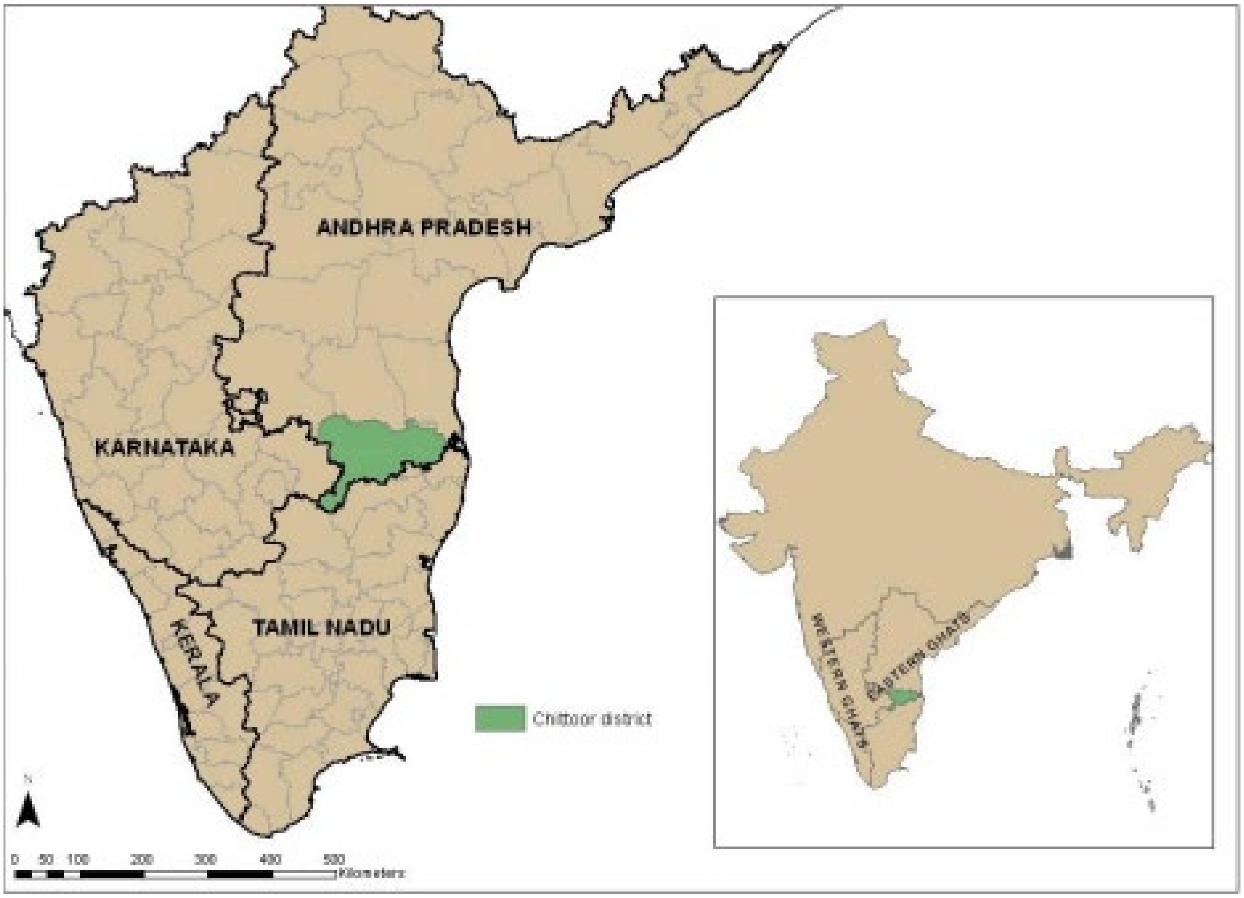

Fig. 4 Location of the study site (Paul 2012)

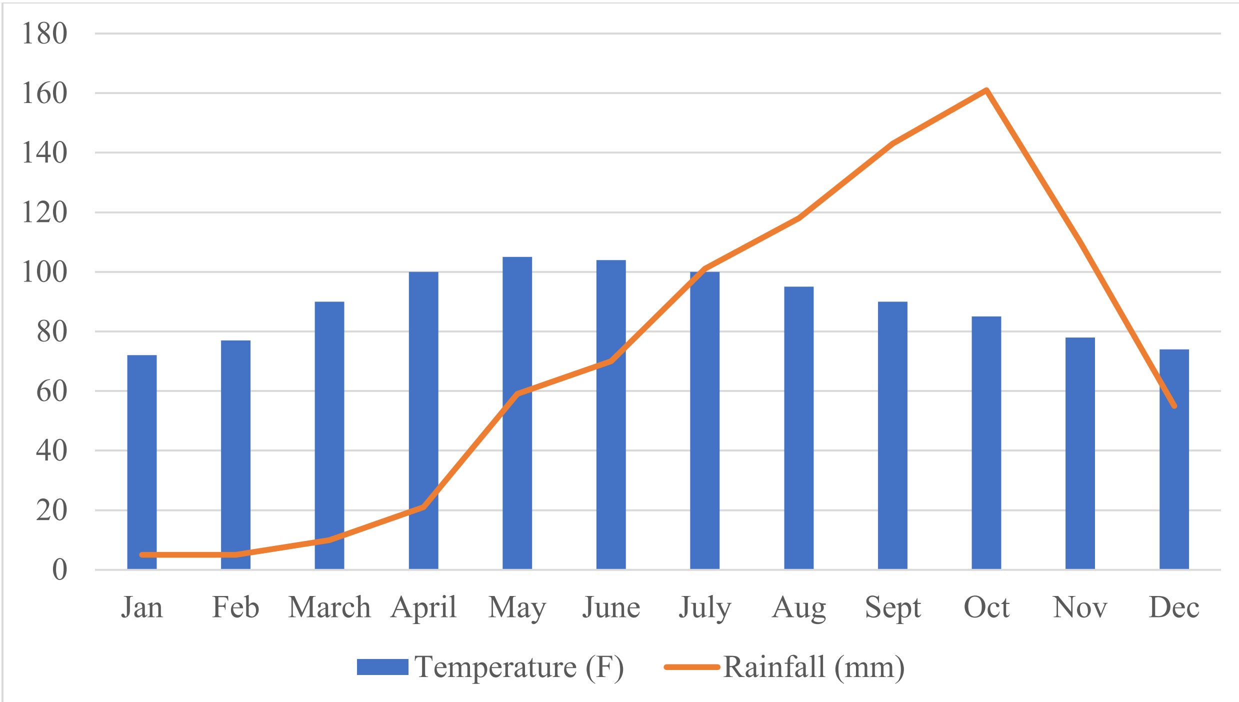

Fig. 5 Climate graph of Chittoor (source: climate data by Anant Deshwal).


Figure 6: Red-vented Bulbul (Image by Anant Deshwal)

Figure 7: Red-whiskered Bulbul (Image by Anant Deshwal)


Figure 8: White-browed Bulbul (Image from ebird.org)

Figure 9: Yellow-billed Babbler (Image by Anant Deshwal)

Figure 10: Common Babbler (Image by Anant Deshwal)

Figure 11: Yellow-eyed Babbler (Image from ebird.org)

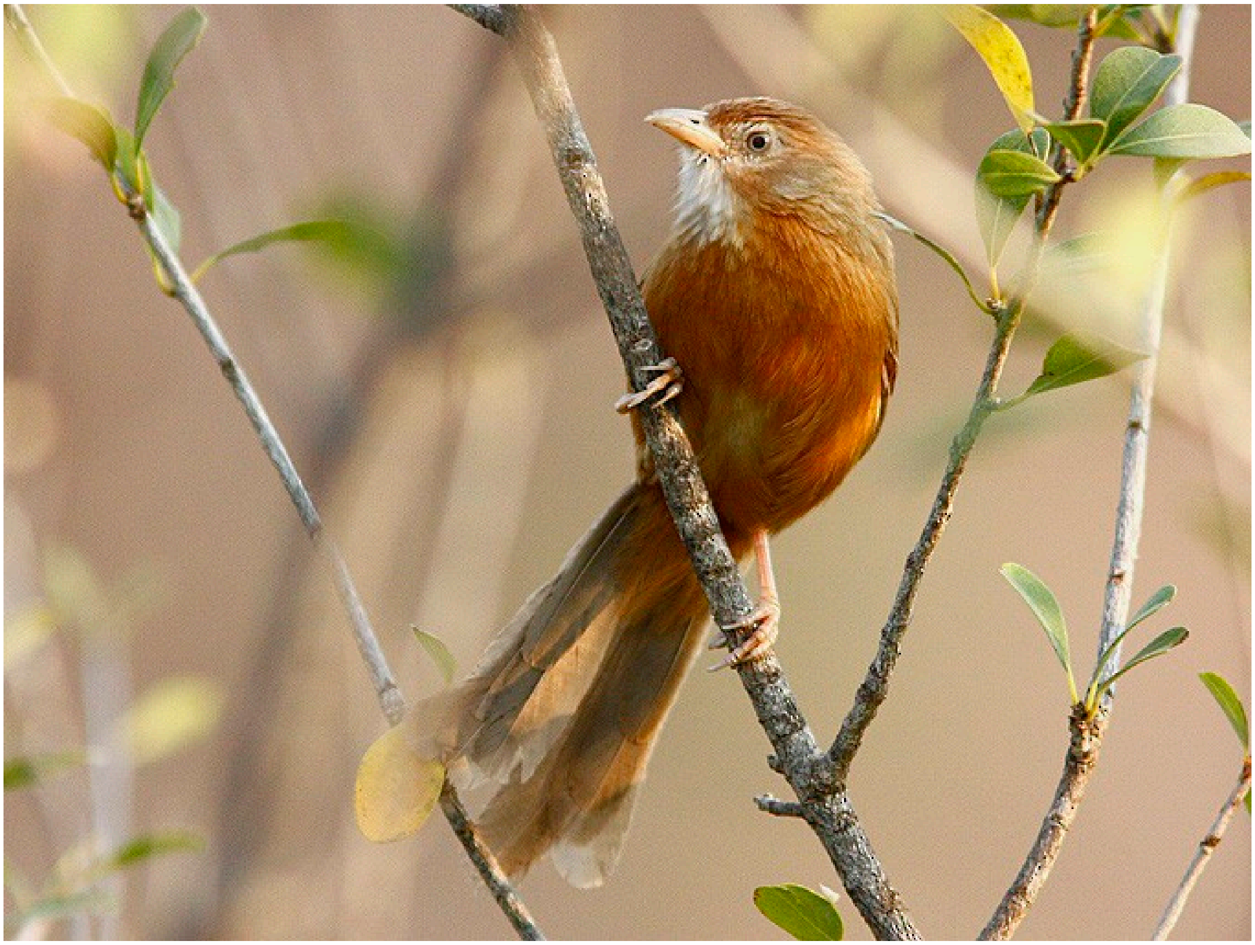
Figure 12: Tawny-bellied Babbler (ebird.org)


Figure 13: Purple Sunbird (Image by Anant Deshwal)

Figure 14: Purple-rumped Sunbird (Image by Anant Deshwal)


Figure 15: Plain Prinia (Image from ebird.org)


Figure 16: Jungle Prinia (Image from ebird.org)

Figure 17: Indian Robin (Image by Anant Deshwal)


Figure 18: Laughing Dove (Image by Anant Deshwal)


Figure 19: Green Bee-eater (Image by Anant Deshwal)


Figure 20: Blyth's Reed Warbler (Image from ebird.org)

Chapter 1: The Dilemma of avian habitat preference during the dry season: floristic composition or vegetational structure?

ABSTRACT

Climate change and pronounced drought conditions have been documented to cause changes in ecosystem structure and resource use across a great diversity of organisms. A shift in ecosystem structure due to drought would affect the avian community depending by changing vegetation structure and/or floristic composition. There is no consensus if the habitat selection by birds is based on vegetational structure or floristic composition. Floristic composition is defined as assemblage of plant species. Vegetational structure is defined as the structural arrangement of branches and leaves in plants. In this study, we investigated habitat selection by shrubland birds in the drought-hit Eastern Ghats of India to determine if the former is based on vegetational structure, floristic composition, or both during dry season. I split 15 species of shrubland birds in three groups: 60% of the avian species had selected habitat based on vegetational structure, 13.3% of avian species had habitat preference based on floristic composition, and 26.7% of the avian species had habitat preference based on both vegetational structure and floristic composition. The cues being used by birds for habitat selection play an important role in the population trends of these birds.

INTRODUCTION

The effects of climate change on biota has been a focus of many studies (e.g., Hampe and Petit 2005, Lovejoy 2006, Araujo and Rahbek 2006, Thuiller 2007, Bellard et al. 2012). The trend in mean conditions (temperature and precipitation) is important, but it is the frequency of extreme events that has far-reaching implications (Jentsch et al. 2007, Albright et al. 2010). Globally, regions experiencing drought are predicted to increase in size due to climate change

(Pachauri and Reisinger 2007). Extreme droughts can drastically shift ecosystem structure by inducing widespread vegetation die-off, thus affecting the avian community (Parmesan and Yohe 2003, Breshears et al. 2005, Both et al. 2006, Albright et al. 2010). Precipitation is the major driver of primary productivity, flower, fruit and seed production, and insect abundance (Albright et al. 2010), and hence it affects habitat use by the avian community. Sensitivity and response to drought will vary among avian assemblages depending upon the life history and behavioral characteristics of the bird species that compromise the community (Albright et al. 2010).

In arid shrublands, the dry season can affect the avian community by limiting available resources such as arthropod abundance (Seely and Louw 1980) or through changes in vegetation coverage and physiognomy (Weaver and Albertson 1956, Vijayan 1975, George et al. 1992). George et al. (1992) termed the effects of the extreme variability of climatic conditions on avian community as "ecological crunches". Forest fires can further limit resource availability by limiting habitat available to birds (Deshwal *unpubl. data*). During the dry season, a bird's choices for suitable habitat are constrained by limited available habitat and resources. The cues used by the birds to select foraging habitat can be used to determine the level of adversity of the effects of drought on avian communities in arid environments.

There are two schools of thought regarding habitat usage by birds. One says that birds use floristic composition as the proximal cue for habitat selection (Balda 1969, Lovejoy 1974, Power 1975, Tomoff 1974a, Rotenberry and Wiens 1980, Wiens and Rotenberry 1981, Rotenberry 1985). A significant source of variation among plants to which birds are likely to respond is the provision of food (Rotenberry 1985). Food is non-randomly distributed in space on a local level and the use of space by birds corresponds to the availability of food (Smithand Dawkins 1971, Smith and Sweatman 1974, Cody and Walter 1976, Gradwohl and Greenberg 1980, Hutto 1985), thus supporting the theory that floristic composition is used as a cue by members of the avian community.

The second school of thought says that vegetation structure plays an important role in habitat selection by birds (e.g., MacArthur and MacArthur 1961, MacArthur et al. 1962, Hildén 1965, Ficken and Ficken 1966, Cody, Martin L. 1968, Wiens 1969, Orians 1971, Zimmerman 1971, Anderson and Shugart Jr 1974, Tomoff 1974b, Smith, K. G. 1977). Wiens (1973) summarized this viewpoint by stating that vegetational structure is important to birds in many ways such as by providing display perches, shelter, nest sites and suitable foraging habitat. Although diets may be opportunistic in shrubland bird species, foraging methods may be different among species (Cody. 1985). These different foraging methods may be affected by vegetational structure. In tall and dense shrubland, slower searching methods are necessary as compared to open regions where a variety of methods can be practiced (Cody 1985). In a temperate grassland avian community, species associated with tall grassland were more responsive to structural cues than species associated with short grassland species (Cody 1985).

Only few studies have examined vegetation structure and habitat selection in birds outside of temperate forests (Pulliam 1973, Rubenstein et al. 1977, Folse 1982, Cody 1985, Ford and Paton 1985, Terborgh 1985, James, D. A. 1998). Even fewer studies have focused on avian habitat use in tropical India, and no studies have been conducted in the Eastern Ghats of India. Understanding habitat use by avian assemblages is critical in Eastern Ghats as they are prone to climate change induced recurrent drought conditions (Paul 2012, Kumar et al. 2019). Most of the studies carried out on avian ecology or habitat usage on the Indian Subcontinent have been at a broad spatial scale, correlating either point count or line transect data to satellite spectral images for evaluating habitat usage (Beehler et al. 1987, Javed and Rahmani 1998, Bhatt and Kumar

2001, Joshi and Shrivastava 2012, Jayprakash 2014, Tiwary and Urfi 2016, Das et al. 2017, Wickramasinghe et al. 2017). These studies at best inform us about the presence of a particular organism in the region. The finer details of habitat usage, preference for vegetation structure or floristic composition are overlooked in such studies. This broad scale approach gives us only partial insights into habitat usage, especially for the regions that show high seasonal variability. Habitat selection by birds based on structural cues or the floristic composition of the habitat in which they occur is important for management practices. If birds are using various aspects of vegetational structure as cues for habitat selection then those cues will be lost as vegetational structure changes due to climate change-induced drought (Farooq et al. 2009, Anjum et al. 2011). In this study, we examined the habitat use of 15 common bird species in the Eastern Ghats to explicitly test if these species select habitat based on vegetation structure or the floristic composition of the vegetation.

MATERIALS AND METHODS

Study area –

The Eastern Ghats of India are a discontinuous mountain range running along the eastern coast of India, located between 16^0 to 19^0 N latitude and 80^0 to 85^0 E longitude. Our study sites were located near the town of Madanapalle (Chittoor District) in Andhra Pradesh, which is nested in the southern Eastern Ghats. The elevation of the area ranges from 500 to 1200 m above mean sea level. The study site is described as semi-arid with distinct dry and wet seasons. The average annual rainfall is 700 mm. Vegetation is a mix of southern thorn forests and dry deciduous scrub forests (Champion and Seth 1968) .

Bird species −

For a representative avian community, we had selected a community of 15 sympatric species that were most common at the study site (Table 1). These species were regarded as most common species based on point count done by the senior author before the start of this study. Out of these 15 species, *Acrocephalus dumetorum* was the only winter migrant considered.

Sampling −

I collected data during the dry season (February-May) in 2015 and 2016. The study area was 6 km^2. The entire study site was divided into a grid with the cell size being 11 x 11 m. Grid size was selected to be 11 x 11 m because of topographical constraints. Every morning, we scanned 8 new cells from 5 am to 8 am for foraging birds and all locations where birds were seen foraging were marked. Keeping marked foraging location as the center, we collected vegetational data for each species of birds using 20 individual circular plots, 11 m in radius (James and Shugart Jr 1970, James1971, James 1998, James and Kannan 2009, Patterson and James 2009). Each plot represented a unique individual. To avoid marking multiple plots for same individual, we covered a particular grid cell only once. For species foraging in groups, a randomly selected an individual to represent the group.

Along with the species of plants on which the bird was feeding, we collected data on 24 vegetational factors within these plots with each transect length being equal to 11 m(Table 2). The first transect was established by following the direction indicated by a random twirl of a compass dial, and measurements were taken at random positions in each of the four transects (Smith 1977, James1992, Mudappa and Kannan 1997, James 1998, Kannan and James 2008).

We collected the same vegetational data for 50 randomly selected plots to determine the nature of the overall vegetation available for comparison with habitats occupied by birds. We selected the control plots by assigning a unique number to each cell within the grid. Using a random number generator, we selected the cell to be sampled (James 1992) .

Analysis –

To assess difference in vegetation between bird foraging locations and randomly selected locations, I analyzed the data using Principal Component Analysis (PCA) followed by Linear Discriminant Analysis (LDA) and ANOVA. We subjected twenty-four habitat factors for all species to PCA to discover the variables responsible for maximum variance among species (Mudappa and Kannan 1997, James and Kannan 2007, James and Kannan 2009). Through PCA we were able to establish a gradient of preference by avian species based on habitat characteristics. As the gradient is not sharply defined, we needed to remove the extraneous variables to isolate only the habitat preference and associated avian response (James 1971, Smith 1977). This can be accomplished by maximizing the differences that exist between vegetational characteristics using LDA. The resulting ordination reflects the pure effect of the vegetation gradient because forest habitat samples are strongly biased towards establishing this environmental axis. If this ordination closely matches one based on the actual habitat occupied by birds as depicted by PCA, it can be concluded that this avian community is primarily structured by the variables short-listed for LDA. If not, it is assumed that other habitat factors also have a role in determining the community composition and spatial patterns.

We used LDA on the subset of variables that maximized distance between species (James 1971, Smith 1977). We then multiplied all the habitat data for all avian plots by discriminant weights obtained for each factor, and the products were summed to obtain one discriminant score for each plot. We subjected these discriminant scores to ANOVA followed by

Tukey HSD to assess the significance of the mean score distribution along discriminant axis (Smith 1977).

To determine associations between plant and bird species, we conducted an association test between focal plant species and avian community. If the value of standardized residuals is greater than equal to two, then there is a significant association between plant and bird species. For all statistical analysis, we used the software R (R Core Team 2017).

RESULTS

By combining all avian species data in one PCA, we identified the important vegetational characteristics for the avian community in shrub forests (Table 3). Only the first two principal components were selected because after first two principal components the scree plot smoothed out and explained 35% of the variance. Variables positively correlated to principal component 1 were ground cover, fine evenness, and leaves at heights of 0 – 0.6 m and 0.6 – 1.2 m. These variables represent the uniformity and intensity of vegetation at lower heights. The variable negatively correlated to principal component 1 was dry grass. The variable positively correlated to the second principal component was shrub density. An ordination of distribution of the principal component scores for the individual plots for each species indicated that this interaction between uniformity of vegetation and shrub density clearly separate the species (Figure 1). The Common Babbler, Laughing Dove, and Yellow-billed Babbler showed a preference for lower ground cover and higher patchy vegetation, whereas the Red-whiskered Bulbul, White-browed bulbul, and Purple-rumped Sunbird prefer higher ground cover and uniform vegetation. The Green Bee-eater, Plain Prinia, Red-vented Bulbul, Purple Sunbird, and Yellow-eyed Babbler prefer an intermediate position.

In the second principal component, ordering of the species changes. The Common Babbler prefers higher shrub density compared to the Laughing Dove, Yellow-billed Babbler, Green Bee-eater, Purple-rumped Sunbird, and Blyth's Reed Warbler. Other species show no affinity to either extreme.

Distribution along ground cover and uniformity of vegetation distribution gradient −

In the ordination based on LDA (Figure 2), the y-axis represents the discriminant axis with patchy vegetation at one extreme ($\bar{x}$ = -0.724) and overall uniform vegetation at the other extreme ($\bar{x}$ = 0.769). Means of all avian species show a greater tendency for uniform vegetation cover than suspected from the ordination based on avian habitat samples alone (Figure 1). The ordering of the avian species in Figure 2 closely matches the ordination of the actual habitat occupied by birds. Hence, it can be concluded that this avian community is primarily structured by the ground cover and overall uniformity of the vegetation.

A significant difference between avian scores was indicated by one-way analysis of variance, and the various groups generated by a Tukey HSD test (at $\alpha = 0.05$) are highlighted by the color coding in Figure 4. Any two groups having same letter assigned to them are not significantly different. The Red-whiskered Bulbul was significantly different from the Plain Prinia, Yellow-billed Babbler, Laughing Dove, and Common Babbler. The Red-whiskered Bulbul, White-browed Bulbul, Purple-rumped Sunbird, Tawny-bellied Babbler, and Jungle Prinia were significantly different from the Yellow-billed Babbler, Laughing Dove, and Common Babbler. The Group "abc" consisting of Blyth's Reed Warbler, Purple Sunbird, Yellow-eyed Babbler, and Red-vented Bulbul were able to utilize most of the forest gradient.

Association between plant and bird species –

We plotted the result of the association test a using mosaic plot (Figure 3). The thickness of the box represents variance for the plant species, and the length of the box represents the variance of particular bird species. Each box represents the degree of association between each plant and bird species. The White-browed Bulbul and Purple-rumped Sunbird were not associated with any plant species. The Red-vented Bulbul, Red-whiskered Bulbul, Laughing Dove, all of which are frugivorous birds, were associated with *Santalum album, Cassia fistula,* and *Pongomia pinnata* and *Dalbergia paniculata,* respectively. The Tawny-bellied Babbler, Common Babbler, Yellow-eyed Babbler, Yellow billed Babbler, Plain Prinia, Jungle Prinia, Green Bee-eater, Indian Robin, Blyth's Reed Warbler, which are all insectivorous birds, were associated with *Lantana camera* and *Premna tomentosa, Mundelia suberosa* and *P. tomentosa, Flacourtia sepiaria* and *Dodonea viscosa, Leucas aspera, Cymbopogan citrus* and *D. panniculata, F. sepiaria* and *D. viscosa, Cassia auriculata* and *L. aspera, Randia dumetorium* and *Plectronia parviflora,* and *C. auriculata* and *Cassia sophera,* respectively. The Nectivorous Purple Sunbird was associated with *M. suberosa.*

DISCUSSION

Assessment of habitat preference based on vegetation structure or floristic composition yielded a mixed bag; it was not dependent upon genus, family or feeding guild of the bird. Our data were able to split different species of birds in three groups: 60% of the avian species had selected the habitat based on vegetational structure, 13% of avian species had a habitat preference based on floristic composition, and 27% of the avian species had a habitat preference based on both vegetational structure and floristic composition.

Habitat selection based on vegetational structure –

The Yellow-billed Babbler, Tawny-bellied Babbler, and Common Babbler, White-browed Bulbul, Jungle Prinia, Purple-rumped Sunbird, Purple Sunbird, Indian Robin, and Laughing Dove selected their foraging habitat based on vegetational structure.

There are various factors that can cause birds to select a habitat based on vegetational structure. Examples include behavior, plant phenology, and the diet of birds. The Yellow-billed Babbler and Jungle Prinia select habitat based on their behavioral preferences. Ali and Ripley (1980a) reported that the Yellow-billed Babbler prefers to feed in groups on the ground with one bird (sentry) on lookout while sitting at the top of the shrub. The Yellow-billed Babbler was associated with *Leucas aspera,* a tall tree with many branches and thorns, which is used by the sentry bird in the flock for lookout. This suggests that the Yellow-billed Babbler uses the structural advantage provided by *L. aspera*. The Jungle Prinia, being a shy bird (Ali and Ripley 1980b), preferred high shrub density with a uniform distribution of vegetation and high ground cover. This provides them with ample hiding spots. The Jungle Prinia is associated with *F. sepiaria* and *D. viscosa* as both plants have the vegetational structure preferred by the species. *Dodonea viscosa* does not shed leaves during the dry season, providing the Jungle Prinia additional cover.

The Tawny-bellied Babbler, Common Babbler, and Indian Robin were each associated with two plants species. Though the plants were in different genus, both reflected same structural configurations as preferred by the birds. For example, the Tawny-bellied Babbler were associated with *L. camera* and *P. tomentosa,* which reflects their structural preference for high, uniform vegetation density and high ground cover, with leaves up to 1.2 m. The White-browed

Bulbul and Purple-rumped Sunbird did not have any strong association with any plant species but had preferences for vegetational structure.

It was plant phenology along with structural advantages that were used as cues by some species such as the Laughing dove, which prefer to feed on seeds or on the ground (Ali and Ripley 1980b), which explains their choice for patchy vegetation with low shrub density. The preferred structure is provided by both of the plant species (*P. pinnata* and *D. paniculate*) with which they tend to be associated. *Pongomia pinnata* starts fruiting by mid-March and hence provides the necessary seeds for Laughing dove.

Habitat preference based on floristic composition –

The Yellow-eyed Babbler and Plain Prinia did not show any strong vegetational structure preference but were associated with specific plant species suggesting that an association with floristic composition is more important than structural cues. The weak preference by the Yellow-eyed Babbler for high shrub density in statistical analysis probably relates to the fact that they were associated with *Dodonea viscosa* and *Flacourtia sepiaria*, both small shrub with dense branches.

Habitat preference based on both presence of plants species and vegetational structures –

Avian species that used a particular habitat based upon the presence of certain plants and suitable vegetational structure were the Red-whiskered Bulbul, Red-vented Bulbul, Green Bee-eater, and Blyth's Reed Warbler. The Green Bee-eater and Blyth's Reed Warbler are both associated with *Cassia auriculate,* a plant that stays green throughout the year with fruits and flowers without any dependence on rain, which may facilitate higher insect presence within these plants. *Cassia auriculate* is structurally similar to the type preferred by both these birds. The Green Bee-eater and Red-vented Bulbul's association with *Leucas aspera* and *Santalum album* has no relationship with structural preference, thus suggesting that all three species are selecting their habitat based on both floristic composition and structural cues.

The observation that birds respond to both floristic composition or structural configuration has important implications for conservation and management practices. Although the bird species selected for this study are classified as of least concern by IUCN (BirdLife International 2018), certain species such as the Red-whiskered Bulbul (BirdLife International 2018), Tawny-bellied Babbler (BirdLife International 2018) and Jungle Prinia (BirdLife International 2018) show a decreasing trend in their populations. All three species select suitable habitat based on structural cues. Drought conditions alter the vegetational structure by disrupting the structural development of plants (Farooq et al. 2009, Anjum et al. 2011). The fact that our study site is drought prone (Kumar et al. 2019) increases the vulnerability risk for avian species using vegetational structure as a cue for habitat selection. The Red-vented Bulbul (BirdLife International 2018), Green Bee-eater (BirdLife International 2018), and Blyth's Reed-warbler (BirdLife International 2018) are increasing in population size. All three species select their habitat based on structural cues or floristic composition, giving them more flexibility than species selecting habitat on the basis of structural cues alone. Even though a habitat may seem suitable for a species on a broader level, it is the subtle cues that the birds use for habitat utilization. This has an important implication for efforts related to their conservation. Understanding the cues (vegetational structure or floristic composition) used by birds for selecting habitat is the first step for developing effective conservation and management plans.

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APPENDIX

Figures and Tables –

Table 1: Bird species used in this study

Scientific Name	Common Name	Code used in this study
Turdoides caudata	Common Babbler	CB
Turdoides affinis	Yellow-billed Babbler	YBB
Chrysomma sinense	Yellow-eyed Babbler	YEB
Dumetia hyperythra	Tawny-bellied Babbler	TBB
Pycnonotus cafer	Red-vented Bulbul	RVB
Pycnonotus jocosus	Red-whiskered Bulbul	RWB
Pycnonotus luteolus	White-browed Bulbul	WBB
Prinia inornata	Plain Prinia	PP
Prinia sylvatica	Jungle Prinia	JP
Leptocoma zeylonica	Purple-rumped Sunbird	PRS
Cinnyris asiaticus	Purple Sunbird	PS
Spilopelia senegalensis	Laughing Dove	LD
Saxicoloides fulicatus	Indian Robin	IR
Merops orientalis	Green Bee-eater	GBE
Acrocephalus dumetorum	Blyth’s Reed Warbler	Warb

Table 2: Variables used to quantify vegetational structure for shrubland avian community in the Eastern Ghats of India

Variable Name	Description
Slope	Ground incline within the plot
Focal Shrub Height	Height of the shrub on which bird was foraging
DBH	Diameter at breast height
Rock Cover	Percentage of large rock boulders in the plot
Barren Ground	Percentage of land with no vegetation or rock boulders in the plot
Shrub Density	Measured by counting the number of stems (Diameter at Breast Height (DBH) < 7.5 cm) touching the meter stick held horizontally at waist height (ca 1 m) along each transect.
Ground Cover	We obtained percentages of ground cover by using a sighting tube, pointing the tube vertically downwards, counted number of times cross hairs at the end of the tube intersected the vegetation at 44 random points along four transects
Dry Grass	We obtained percentages of dry grass cover by using a sighting tube, pointing the tube vertically downwards, counted number of times cross hairs at the end of the tube intersected the dry grass at 44 random points along four transects
Grass Height	Height of grass measured at 44 random points along four transects
Distance to Tallest Tree	Distance from the tallest tree/shrub in the plot to the focal shrub
Canopy Height	Average height of vegetation within the plot.
Stem Evenness	Pattern of shrubiness. High values show even distribution of woody vegetation
Stem Variability	Amount of shrubiness between sectors in a plot

Table 2 contd.

Variable Name	Description
Number of leaves at 0.6 m interval from 0 – 4.8 m	The leaves were counted using a calibrated pole, 3.0 m long and 10 mm in diameter and marked off into 0.6 m intervals, accentuated using different colored paints. We positioned the pole vertically from the ground and counted the total number of leaves touching it at each of 0.6 m intervals up to 4.8 m at 40 randomly distributed measurements along four orthogonal line transects originating at the center of the plot.
Foliage Vertical Evenness	High values associated with diverse and evenly spread leaves
Coarse Evenness	Measure relating to spread of vegetation sector to sector in a plot. Low values suggesting patchy vegetation
Fine Evenness	Measure relating to spread of vegetation, sector to sector in a plot and within each sector. Low values suggesting patchy vegetation

Table 3: First principal component (PC1 and PC2) between 24 habitat factors and combined avian species. Correlations in bold highlight important relationships.

Habitat Factors	PC1	PC2
Slope	0.183	0.096
Focal Shrub Height	0.125	0.419
DBH	-0.016	0.175
Rock Cover	0.353	-0.086
Barren Ground	-0.254	-0.048
Shrub Density	0.258	**0.758**
Ground Cover	**0.829**	-0.383
Dry Grass	**-0.722**	0.472
Grass Height	0.005	0.305
Distance to Tallest Tree	-0.180	-0.098
Stem Evenness	0.408	0.510
Stem Variability	0.105	0.476
Foliage Vertical Evenness	0.362	0.575
Coarse Evenness	0.583	0.153
Fine Evenness	**0.793**	0.149
Leaf up to 0.6m	**0.725**	-0.252
Leaf from 0.6 m – 1.2 m	**0.756**	0.100
Leaf from 1.2 m – 1.8 m	0.549	0.333
Leaf from 1.8 m – 2.4 m	0.313	0.297
Leaf from 2.4 m – 3.0 m	0.230	0.178
Leaf from 3.0 m – 3.6 m	0.007	0.256
Leaf from 3.6 m – 4.2 m	0.002	0.242
Leaf from 4.2 m – 4.8 m	0.001	0.199
Canopy Height	0.302	0.612

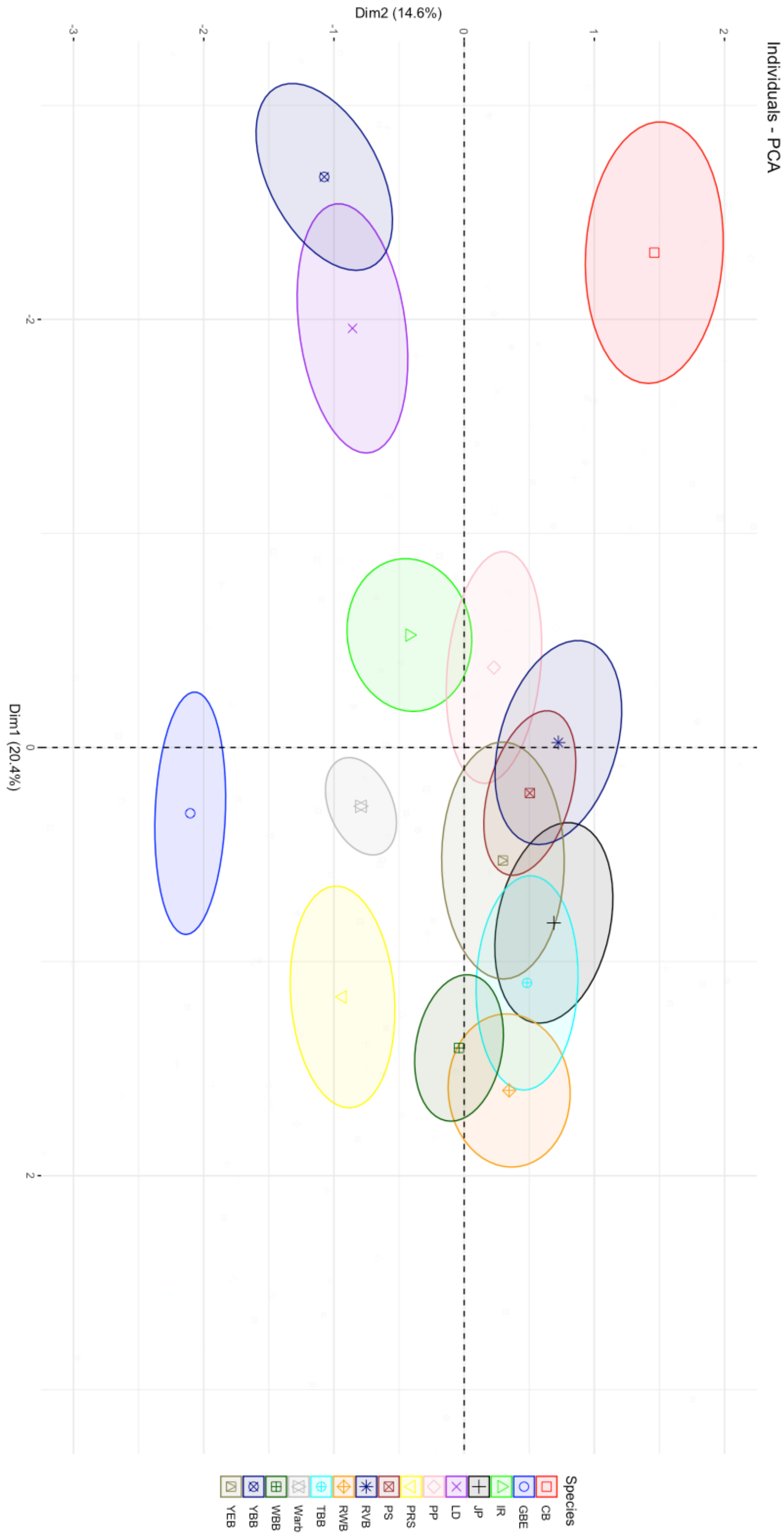

Figure 1: Ordination of avian habitat utilization for the dry season obtained from a PCA of combined avian species.

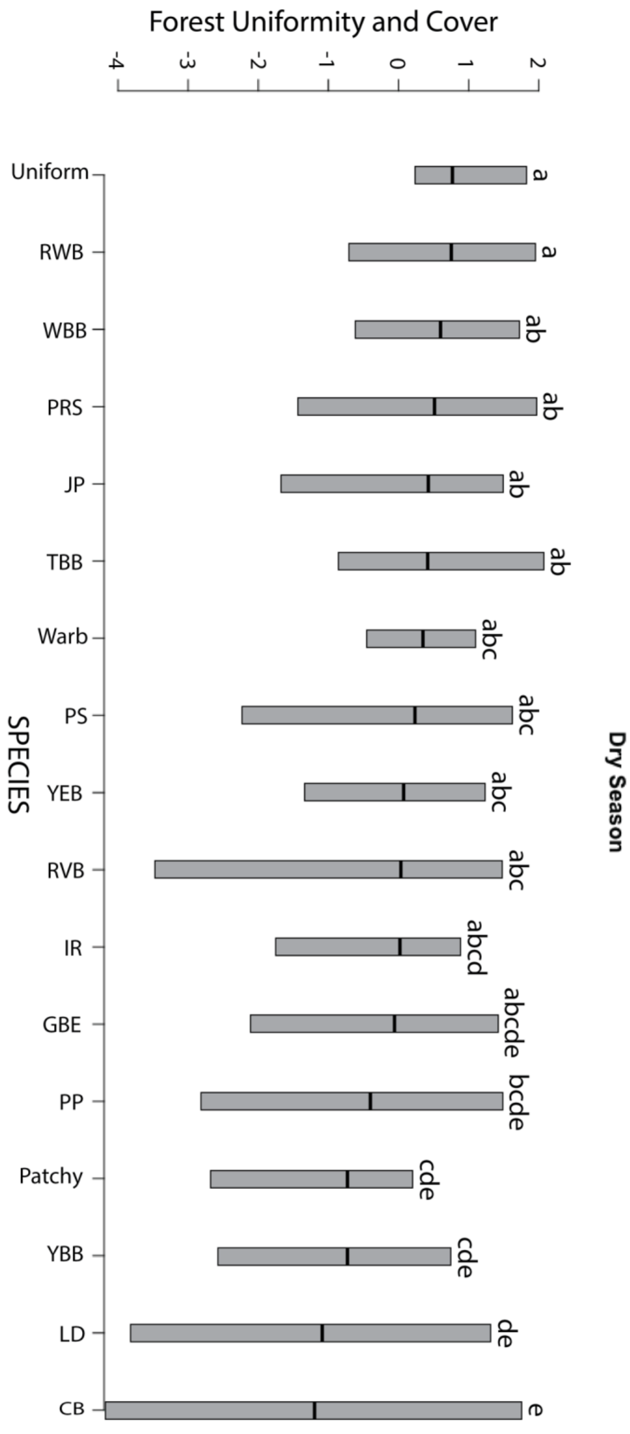

Figure 2: Arrangement of the avian species along the gradient of vegetation cover and its uniformity. The variables used for creating this gradient had high correlation with dimension 1. The groups were generated by TukeyHSD and groups having same letters are not statistically different. For example, group “a”, “ab”, “abc”, “abcd”, “abcde” are not statistically different but group “a” is different from group “bcde” etc.

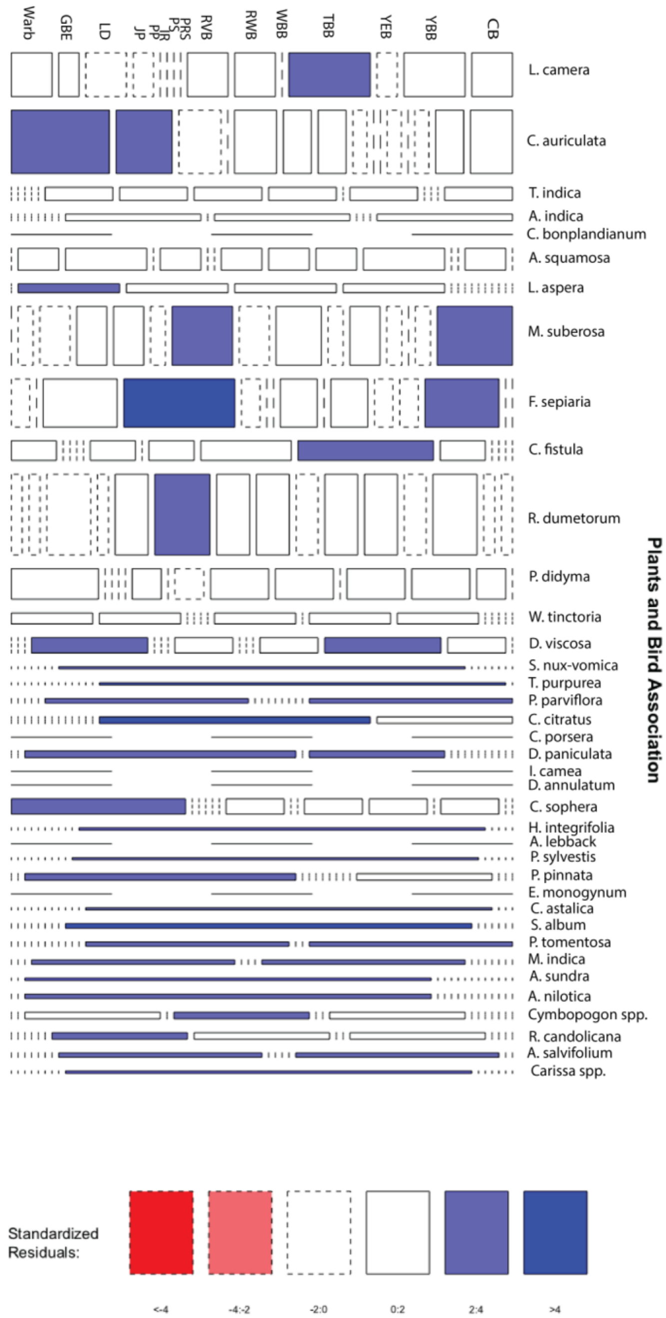

Figure 3: Association between bird species and plant species. The thickness of each box represents variance for the plant species and length of the box represents variance of bird species. Each box represents the degree of association between each plant and bird species. If the value of standardized residuals is greater than equal to two, then there is a significant association between plant and bird species.

Chapter 2: Cues used by Avian Assemblages for Habitat Use Post-monsoon: floristic composition or vegetational structure?

ABSTRACT

Whether habitat use by avian communities is dependent on floral composition or vegetational structure has often been a topic of debate. In this study, we attempted to determine if the habitat usage by the avian community in the scrub forest of Eastern Ghats of India is dependent upon floral composition or on vegetational structure. Our data indicated that there is no single answer to this question. The cues being used by birds for habitat selection were independent of feeding guild or genus, with 14.2% of the avian species using structural configuration, 42.8% of avian species using floral composition and 35.7% of the avian species using both structural configuration and floral composition as cues for habitat selection.

INTRODUCTION

As a result of being extremely mobile and wide-ranging, birds possess and presumably do exercise the potential for habitat selection. The selected foraging habitat plays an important role in survival and fecundity of birds (Cody1985), with subsequent implications for population dynamics. There are several ultimate and proximate factors involved in bird choice of habitat selection that Hildén (1965) distinguished and summarized.

There are two schools of thought regarding habitat usage by birds. One suggests that birds use floristic composition as the proximal cue for habitat selection (Balda 1969, Lovejoy 1974, Power 1975, Tomoff 1974a, Rotenberry and Wiens 1980, Wiens and Rotenberry 1981, Rotenberry 1985). A significant source of variation among the plants to which birds are likely to respond is the provisioning of food (Rotenberry 1985). Food is non-randomly distributed in space at a local level and the use of space by birds corresponds to the availability of food (Smith and Dawkins 1971, Smith and Sweatman 1974, Cody and Walter 1976, Gradwohl and Greenberg 1980, Hutto 1985), thus supporting the theory that floristic composition is used as a cue by members of the avian community.

The second school of thought suggests that vegetation structure plays an important role in habitat selection by birds as discussed in chapter 1. There is a major shift in habitat structure from dry to wet season. The major changes in habitat structure is due to increased foliage, shrub density, ground and canopy cover. With the onset of monsoons, there is an increase in number of fruits, flowers and insects. This increase in resources help in reducing the competition between bird species. Changes in structural complexity of the forest leads to modification in hunting methods being used by birds (Cody 1985).

Most of the habitat association studies have focused on single season to draw their conclusion regarding habitat use by birds. Most of those studies have focused on temperate forests with except for Pulliam (1973), Rubenstein et al. (1977), Folse (1982), Cody (1985), Ford & Paton (1985), Terborgh (1985), James (1998). There are no studies that address the habitat use by birds in regions such as Eastern Ghats that are susceptible to climate change and recurrent droughts (Paul 2012, Kumar et al. 2019). Understanding microhabitat use by birds as a response to change in season is critical to formulating wildlife management decisions for conservation.

MATERIALS AND METHODS

Study area −

The Eastern Ghats of India are a discontinuous mountain range running along the eastern coast of India, located between 16° to 19° N latitude and 80° to 85° E longitude. Our study sites were located near the town of Madanapalle (Chittoor District) in Andhra Pradesh, which is in the southern portion of the Eastern Ghats. The elevation ranges from 500 to 1200 m above mean sea level. The study site is described as semi-arid with distinct dry and wet seasons. The average annual rainfall is 700 mm. The vegetation is a mixture of southern thorn forests and dry deciduous scrub forests (Champion and Seth 1968) .

Bird species −

For a representative avian community, we selected a community of 14 sympatric species that were most common at the study site (Table 1). These species were regarded as the most common species based on a point count done by the senior author before the start of this study.

Sampling −

We collected data during the dry season June - November in 2016. The entire study site was divided into a grid with the cell size being 11 x 11 m. Every morning, we scanned 8 new cells from 5 am to 8 am for foraging birds and all locations where birds were seen foraging were marked. With the marked foraging location as center, we collected vegetational data for each species using 20 circular plots (James and Shugart Jr 1970, James 1971, James 1998, James and Kannan 2009, Patterson and James 2009). Within each plot we measured vegetational characteristics relating to a unique individual. To avoid marking multiple plots for same individual, we covered a particular grid cell only once. For species foraging in groups, a randomly selected individual represented the group.

Along with the species of plants on which the bird was feeding, we collected data on 24 vegetational factors within these plots (Table 2). The first transect was established by following the direction indicated by a random twirl of a compass dial, and measurements were taken at random positions in each of the four orthogonal transects (Smith 1977, James 1992, Mudappa and Kannan 1997, James 1998, Kannan and James 2008).

We collected the same vegetational data for 50 randomly located control plots to determine the nature of the overall vegetation available for comparison with habitats occupied by birds. We selected the control plots by assigning a unique number to each cell within the grid. Using a random number generator, we selected the cell to be sampled (James 1992) .

Analysis –

We analyzed the data using Principal Component Analysis (PCA) followed by Linear Discriminant Analysis (LDA) and ANOVA. We subjected twenty-four habitat factors for all species to PCA to discover the variables responsible for maximum variance among species (Mudappa and Kannan 1997, James and Kannan 2007, James and Kannan 2009). Through PCA we were able to establish a gradient of preference by avian species based on habitat characteristics. As the gradient is not sharply defined, we needed to remove the extraneous variables to isolate only the habitat preference and associated avian response (James 1971, Smith 1977). This was accomplished by maximizing the differences that exist between vegetational characteristics using LDA. The resulting ordination reflects the pure effect of the vegetation gradient because forest habitat samples are strongly biased towards establishing this environmental axis. If this ordination closely matches one based on the actual habitat occupied by birds as depicted by PCA, it can be concluded that this avian community is primarily structured by the variables short-listed for LDA. If not, it is assumed that other habitat factors also have a role in determining the community composition and spatial patterns.

We used LDA on the subset of variables that maximized distance between species (James 1971, Smith 1977). We then multiplied all the habitat data for all avian plots by discriminant weights obtained for each factor, and the products were summed to obtain one discriminant score for each plot. We subjected these discriminant scores to ANOVA followed by

Tukey HSD to assess the significance of the mean score distribution along discriminant axis (Smith 1977).

To determine associations between plant and bird species, we conducted an association test between focal plant species and members of the avian community. We plotted the result of the association test using a mosaic plot (Figure 3). The thickness of the box represents variance for the plant species, and the length of the box represents the variance of particular bird species. Each box represents the degree of association between each plant and bird species. If the value of standardized residuals is greater than or equal to two, then there is a significant association between plant and bird species. For all statistical analysis, we used the software R (R Core Team 2017).

RESULTS

By combining all avian species data in one PCA, we identified the important vegetational characteristics for the avian community in shrub forests (Table 3). Only the first two principal components were selected because after first two principal components the scree plot smoothens out and explained 33% variance. Variables positively correlated to principal component 1(PC1) were shrub density, foliage vertical evenness, and leaves at height 0.6 – 1.2 m, thus characterizing how dense and even the vertical leaf distribution is in the shrub forest. The Green Bee-eater, Laughing Dove, and Yellow-billed Babbler were negatively correlated to PC1, whereas the White-browed Bulbul, Jungle Prinia, and Tawny-bellied Babbler were positively correlated.

The variable positively correlated with the second principal component (PC2) was foliage coarse-grained horizontal evenness, which characterized the patchiness of vegetation across the plot. The Green Bee-eater, Yellow-billed Babbler, and Purple-rumped Sunbird were negatively correlated to PC2 as compared to the Yellow-eyed Babbler and Tawny-bellied Babbler, which were positively correlated. Other species formed an intermediate group showing no affinity for either extreme. An ordination of distribution of the principal component scores for the individual plots for each species showed that this interaction between the shrub density, uniformity of vertical leaf distribution, and patchy vegetation distribution separate out the species quite well (Figure 1).

Distribution along ground cover and uniformity of vegetation distribution gradient −

In the ordination based on LDA (Figure 2), the y-axis represents the discriminant axis with open and uneven vertical foliage at one extreme ($\bar{x}$ = -1.287) and dense and uniform vertical foliage at the other ($\bar{x}$ = 1.383). All avian means show a greater tendency for vegetational density and vertical uniformity than suspected from the ordination based on avian habitat samples alone (Figure 1). The grouping of species through the LDA is similar to PCA, but the affinity within the groups for dense forest with uniform vertical foliage is different from the PCA ordination (Figure 1). Because the ordering of the avian species along the axis is slightly different from the arrangement in the principal component analysis ordination (Figure 1), the species do not appear to be reacting solely to the actual forest density and vertical foliage uniformity. As the discriminant function maximizes the cline and then stresses the patchy and uniform ends of the cline and then stresses those factors in establishing the gradient, the resulting ordination (Figure 2) is much more informative than the principal component ordination (Figure 1).

A significant difference between avian scores was indicated by one-way analysis of variance and the various groups generated by a Tukey HSD test (at $\alpha = 0.05$) as highlighted by the color coding provided in Figure 2. Any two groups having same letter of the alphabet assigned to them are not significantly different. For example, the Tawny-bellied Babbler is statistically different from all other species except for the White-browed Bulbul, Yellow-eyed Babbler, Purple Sunbird, Jungle Prinia, and Red-vented Bulbul. The habitat preference of the Red-whiskered Bulbul significantly differs from either extreme of the shrub forest (i.e., dense or open shrub forest). The habitat preference of the Green Bee-eater is significantly similar to the open shrub forest.

Association between plant and avian species –

The results of the association test were plotted using a mosaic plot (Figure 3). The White-browed Bulbul and Red-vented Bulbul were not associated with any plant species. Both the frugivorous birds, the Red-whiskered Bulbul and the Laughing Dove, were associated with *Cassia fistula* and *Croton bonplandianum* respectively. The Tawny-bellied Babbler, Common Babbler, Yellow-eyed Babbler, Yellow billed Babbler, Plain Prinia, Jungle Prinia, Green Bee-eater, and Indian Robin, all of which are insectivorous birds, were associated with *Mundelia suberosa, Cymbopogan spp, Wrightia tinctoria* and *Randia dumetorium, Cassia sophera* and *Tephrosia purpurea, Cassia auriculata* and *Cymbopogan citratus, C. fistula* and *R. dumetorium, C. auriculata,* and *Plectronia parviflora, respectively.* The Nectivorous Purple Sunbird and Purple-rumped Sunbird were associated with *Lantana camara* and *Terminalia chebula, L. camara, Annona reticulata* and *Pongamia pinnata.*

DISCUSSION

The data generated in the present study were able to split the different species of birds in three groups, with 14.2% of the avian species having a habitat preference based on vegetational structure, 42.8% of the avian species having a habitat preference based on plant species, and 35.7% of the avian species having a habitat preference based on both vegetational structure and plant species. The Red-vented Bulbul did not select habitat based on either structural configuration or plant species. Moreover, habitat selection based on vegetational structure and/or plant species was not dependent upon family or genus.

Habitat selection based on vegetational structure –

The Yellow-eyed Babbler and White-browed Bulbul selected their foraging habitat based on structural configuration. Ali and Ripley (1980) reported that it is a shy and elusive bird which can be seen in its habitat choice of dense and uniform vegetational configuration. The floristic association of the Yellow-eyed Babbler does not provide any information about the habitat choice, since *Randia dumetorium* has a dense structural configuration and *Wrightia tinctoria* has an open configuration. The White-browed Bulbul was not associated with any plant species but preferred high shrub density and vertical foliage evenness.

Habitat selection based on plant species availability –

Avian species that used a particular habitat depending upon the presence of certain plants were the Common Babbler, Red-whiskered Bulbul, Purple Sunbird, Indian Robin, Plain Prinia, and Laughing Dove. The Common Babbler, Red-whiskered Bulbul, Purple Sunbird, Indian Robin, and Plain Prinia did not display a preference for structural configuration but were associated with certain plant species, thus indicating that they selected their habitat based on floristic composition. The Laughing Dove was associated with *Croton bonplandianum* and often was observed feeding on the seeds of this plant by the senior author. *C. bonplandianum* is a short that grows 30 cm in height. Ali and Ripley (1980) reported that the Plain Prinia and Yellow-eyed Babbler were similar in their habitat preference. However, as seen in Figure 2, they differ significantly in their habitat preference. The Plain Prinia prefers more open habitat than does the Yellow-eyed Babbler.

Habitat selection based on both plant species availability and structural configuration –

Avian species that selected habitat based on both structural and floristic composition as cues were the Yellow-billed Babbler, Tawny-bellied Babbler, Purple-rumped Sunbird, Jungle Prinia, and Green Bee-eater. The structural configuration of the plants with which these birds were associated was similar to the structural configuration preferred by the birds (e.g., the Tawny-bellied Babbler associated with *Mundelia suberosa)*. The latter is a shrub with a high density of branches providing a uniform vegetational cover as preferred by the Tawny-bellied Babbler. The Red-vented Bulbul did not show any preference for structural configurations or floristic composition and apparently selected habitat based on factors not considered in this study.

Although the bird species selected for this study are classified as of least concern by IUCN (BirdLife International 2018), certain species such as the Red-whiskered Bulbul (BirdLife International 2018), Tawny-bellied Babbler (BirdLife International 2018) and Jungle Prinia (BirdLife International 2018) show a decreasing trend in population. By having a comprehensive understanding of seasonal habitat utilization by these birds coupled with effective wildlife management plans, it should be possible to prevent the decline of these species.

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APPENDIX

Figures and Tables –

Table 1: Bird species used in the present study

Scientific name	Common name	Code used herein
Turdoides caudata	Common Babbler	CB
Turdoides affinis	Yellow-billed Babbler	YBB
Chrysomma sinense	Yellow-eyed Babbler	YEB
Dumetia hyperythra	Tawny-bellied Babbler	TBB
Pycnonotus cafer	Red-vented Bulbul	RVB
Pycnonotus jocosus	Red-whiskered Bulbul	RWB
Pycnonotus luteolus	White-browed Bulbul	WBB
Prinia inornata	Plain Prinia	PP
Prinia sylvatica	Jungle Prinia	JP
Leptocoma zeylonica	Purple-rumped Sunbird	PRS
Cinnyris asiaticus	Purple Sunbird	PS
Spilopelia senegalensis	Laughing Dove	LD
Saxicoloides fulicatus	Indian Robin	IR
Merops orientalis	Green Bee-eater	GBE
Acrocephalus dumetorum	Blyth's Reed Warbler	Warb

Table 2: Variables used to quantify vegetational structure for shrubland avian community in the Eastern Ghats of southern India.

Variable name	Description
Slope	Ground incline within the plot
Focal Shrub Height	Height of the shrub on which bird was foraging
DBH	Diameter at breast height
Rock Cover	Percentage of large rock boulders in the plot
Barren Ground	Percentage of land with no vegetation or rock boulders in the plot
Shrub Density	Measured by counting the number of stems (Diameter at Breast Height (DBH) < 7.5 cm) touching the meter stick held horizontally at waist height (ca 1 m) along each transect.
Ground Cover	We obtained percentages of ground cover by using a sighting tube, pointing the tube vertically downwards, counted number of times cross hairs at the end of the tube intersected the vegetation at 44 random points along four transects
Dry Grass	We obtained percentages of dry grass cover by using a sighting tube, pointing the tube vertically downwards, counted number of times cross hairs at the end of the tube intersected the dry grass at 44 random points along four transects
Grass Height	Height of grass measured at 44 random points along four transects
Distance to Tallest Tree	Distance from the tallest tree/shrub in the plot to the focal shrub
Canopy Height	Average height of vegetation within the plot.
Stem Evenness	Pattern of shrubiness. High values show even distribution of woody vegetation
Stem Variability	Amount of shrubiness between sectors in a plot

Table 2 contd.

Variable Name	Description
Number of leaves at 0.6 m interval from 0 – 4.8 m	7The leaves were counted using a calibrated pole, 3.0 m long and 10 mm in diameter and marked off into 0.6 m intervals, accentuated using different colored paints. We positioned the pole vertically from the ground and counted the total number of leaves touching it at each of 0.6 m intervals up to 4.8 m at 40 randomly distributed measurements along four orthogonal line transects originating at the center of the plot.
Foliage Vertical Evenness	High values associated with diverse and evenly spread leaves
Coarse Evenness	Measure relating to spread of vegetation sector to sector in a plot. Low values suggesting patchy vegetation
Fine Evenness	Measure relating to spread of vegetation, sector to sector in a plot and within each sector. Low values suggesting patchy vegetation

Table 3: First and second principal components (Dimensions) between 24 habitat factors and combined species for both dry and wet seasons (PCA was performed separately for each season). Correlations in bold highlight important relationships.

Habitat factors	Wet Season	
	Correlation to Dimension 1	Correlation to Dimension 2
Slope	-0.05581851	-0.008801465
Focal shrub height	0.65342832	-0.268139770
DBH	0.48603582	-0.315163101
Rock cover	0.20906637	0.378964422
Barren Ground	-0.34337196	-0.108991955
Shrub Density	**0.72874364**	0.442799467
Ground Cover	0.21209387	0.185825884
Dry Grass	-0.17688913	0.009599117
Grass Height	0.21209387	0.185825884
Distance to Tallest Tree	-0.17932913	0.157304251
Stem Evenness	0.41987196	0.467680068
Stem Variability	0.56496881	0.275698135
Foliage Vertical Evenness	**0.80199891**	-0.325842276
Coarse Evenness	-0.01833438	**0.607353938**
Fine Evenness	0.67255812	0.436544643
Leaf up to 0.6m	0.10748407	0.439020496
Leaf from 0.6 m – 1.2 m	**0.72384293**	0.403802646
Leaf from 1.2 m – 1.8 m	0.61707409	-0.011867207
Leaf from 1.8 m – 2.4 m	0.57630606	-0.261580147
Leaf from 2.4 m – 3.0 m	0.49908786	-0.527211396
Leaf from 3.0 m – 3.6 m	0.51080457	-0.517768130
Leaf from 3.6 m – 4.2 m	0.30091772	-0.363485007
Leaf from 4.2 m – 4.8 m	0.11673998	-0.337009039
Canopy Height	0.35882120	0.009808996

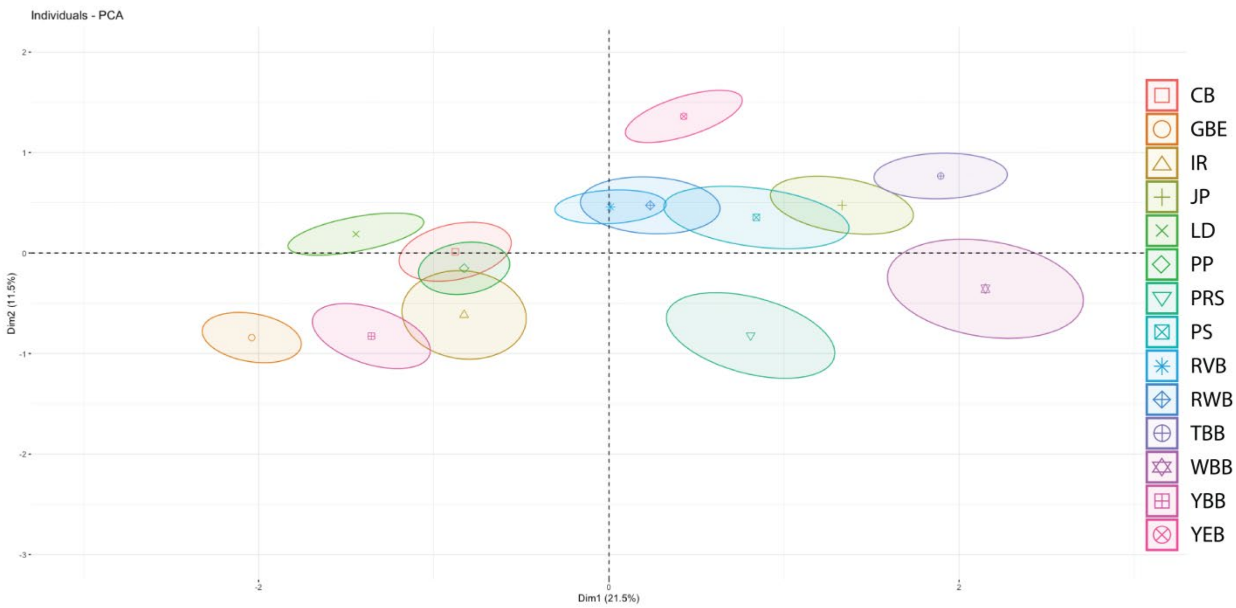

Figure 1: Ordination of avian habitat utilization for wet season, obtained from PCA of combined avian species: Common Babbler (CB), Yellow-billed Babbler (YBB), Yellow-eyed Babbler (YEB), Tawny-bellied Babbler (TBB), Red-vented Bulbul (RVB), Red-whiskered Bulbul (RWB), White-browed Bulbul (WBB), Plain Prinia (PP) and Jungle Prinia (JP), Purple-rumped Sunbird (PRS) and Purple Sunbird (PS), Laughing Dove (LD), Indian Robin (IR), Green Bee-eater (GBE), and Blyth's Reed Warbler (Warb). Dimension 1 is comprised of shrub density, foliage vertical evenness, and leaves from 0.6-1.2m. Dimension 2 is comprised of Coarse Evenness.

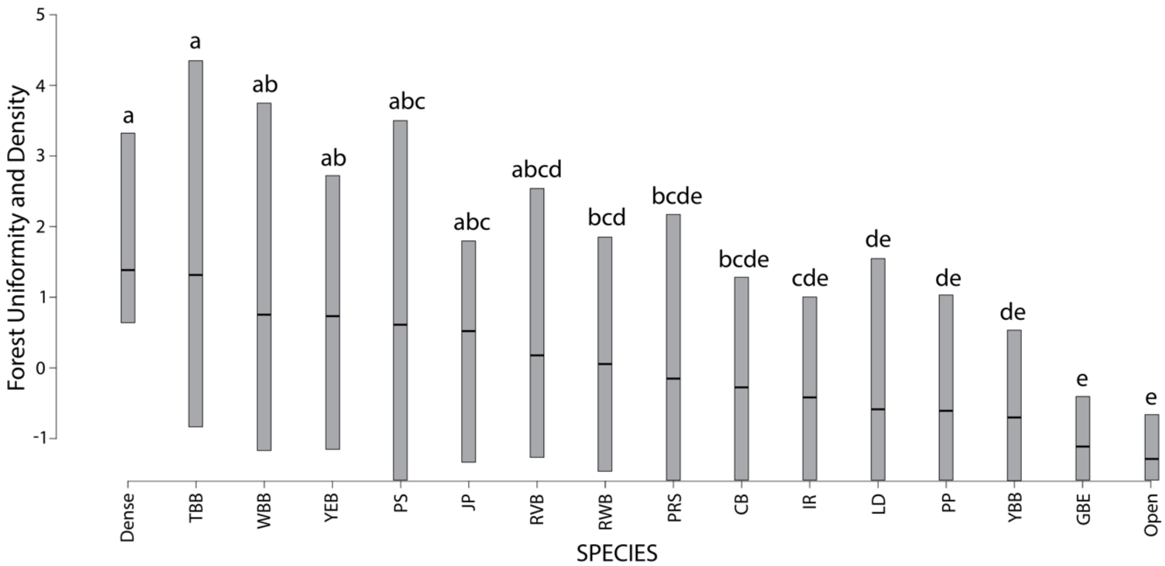

Figure 2: During wet season, arrangement of the avian species {Common Babbler (CB), Yellow-billed Babbler (YBB), Yellow-eyed Babbler (YEB), Tawny-bellied Babbler (TBB), Red-vented Bulbul (RVB), Red-whiskered Bulbul (RWB), White-browed Bulbul (WBB), Plain Prinia (PP) and Jungle Prinia (JP), Purple-rumped Sunbird (PRS) and Purple Sunbird (PS), Laughing Dove (LD), Indian Robin (IR), Green Bee-eater (GBE)} along the gradient of vegetation cover and its uniformity. The variables used for creating this gradient had high correlation with dimension 1. The groups were generated by TukeyHSD and groups having same letters of the alphabets are not statistically different (for example, group “a”, “ab”, “abc”, “abcd”, “abcde” are not statistically different but group “a” is different from group “bcde”)

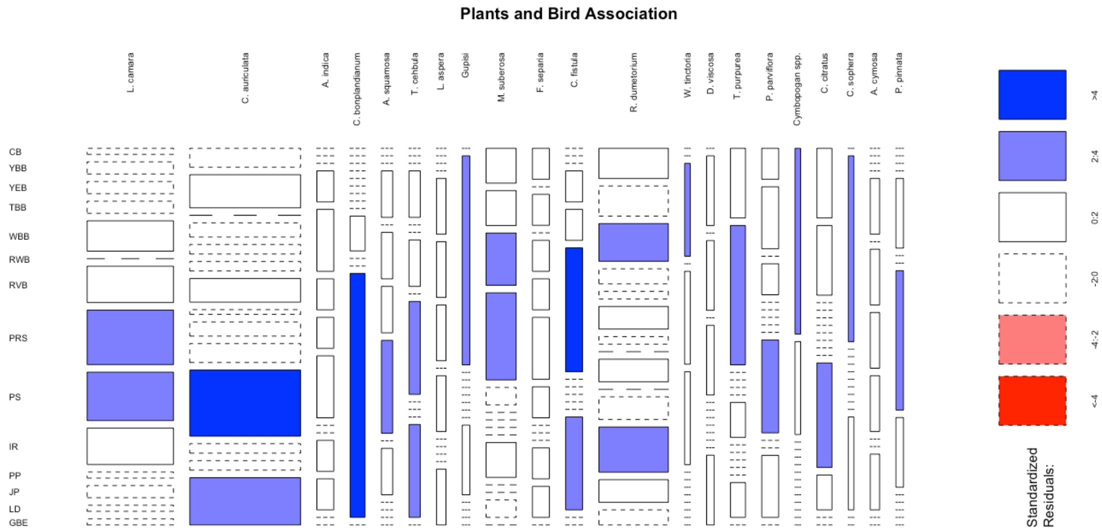

Figure 3: Association between bird species and plant species. The thickness of each box represents variance for the plant species and length of the box represents variance of bird species. Each box represents the degree of association between each plant and bird species. If the value of standardized residuals is greater than equal to two, then there is a significant association between plant and bird species.

Chapter 3: Land Use and Land Cover Change in the Eastern Ghats of Southern India

ABSTRACT

Anthropogenic disturbance either as the result of urbanization or climate change is one of the major threats to wildlife and natural habitats. Rapid human population growth is a major cause for urbanization and thus the destruction of forests. In the current study, changes in Land Use and Land Cover (LULC) patterns in the Eastern Ghats were investigated to understand the factors responsible for the loss of shrub forests and waterbodies. Shrub forests and waterbodies had the most appreciable declines among all categories considered. Waterbodies declined largely due to climate change-induced drought. In contrast, shrub forests declined due to combination of climate change-induced drought and the rise in population.

INTRODUCTION

Urbanization is one of the most widespread anthropogenic causes of the loss of arable land (Lopez et al. 2001), habitat destruction (Aphan 2003), and decline in natural vegetation cover. The conversation of rural areas and land under forest cover to urban areas is happening at an unprecedented rate in recent human history and has a marked influence on the natural functioning of ecosystems (Turner 1994). Anthropogenic changes in land use and land cover are increasingly being recognized as critical factors in influencing global change (Nagendra et al. 2003). It is because of this global influence on changes in land cover that studies related to Land Use and Land Cover (LULC) have become increasingly important (Stow & Chen 2002). LULC studies help us understand the various impacts of human activity on the overall ecological condition and functioning of ecosystems (Yeh & Li 1999, Hansen et al. 2001, Assessment 2005, Fischlin et al. 2007).

For countries with high population density and high population growth rate, understanding changes in LULC becomes critical. The population of India grew by 17.7% from 2001 to 2011, with 12.3% rural population growth and 31.8% urban population growth (Census India 2011). LULC analysis done in India (Amin 2102, Pooja et al 2012, Mehta et al. 2012, Rawat et al. 2013a, Rawat et al. 2013b, Rawat et al. 2013c, Rawat et al. 2013d, Rawat et al. 2014) has effectively indicated a sharp rise in urbanization at the cost of agricultural lands and forest cover. A rapid rise in population coupled with climate change will magnify the effect of land use patterns, including such examples as the town of Madanapalle in Chittoor district, which is a drought prone region (Kumar et al. 2019). In villages surrounding Madanapalle, the farmers are often forced to leave their existing agricultural lands fallow for a decade or more while they encroach upon scrub forest for viable agricultural lands (*personal obs*.). This dynamic land use pattern needs to be investigated to quantify the changes that occur with respect to land cover patterns. In this study, the results of land use and land cover changes in Madanapalle are described.

MATERIALS AND METHODS

Study area –

The project described herein was carried out in the Chittoor district in the Southern Eastern Ghats of India. The Eastern Ghats are a discontinuous mountain range running along the eastern coast of India, located between 16° to 19° N latitude and 80° to 85° E longitude. The actual study site lies between 191850.355- 275511.772m E and 1475895.399 - 15429519.933m N. The total area of the field site is 4500.207 km^2. The elevation varies from 405 m to 1365 m. The region is characterized by red soil with numerous rocks. The study site is described as semi-arid with distinct dry and wet seasons. The average annual rainfall is 700 mm. The predominant vegetation is a mixture of southern thorn forests and dry deciduous scrub forests (Champion and Seth 1968). The entire region has been drought prone and is often affected by drought.

Data Source –

For this project data were collected from the USGS Earth explorer website. Landsat TM images for the month of December in 2011 and 2016, from Landsat 5 data for the path 143 and row 051 were used. Month of December was selected as there was comparatively less seasonal change within this month. Pixel size for the Landsat imagery was 30 m for both thermal and reflective types. The images were projected to the WGS 1984 UTM 44N coordinate system. Data from bands1-5 and 7 were used because 2011 images did not have band 6, it was left out from the 2016 data for the sake of uniformity.

Methodology –

ArcMap 10.5.1 was used to perform land use/cover classification on the Landsat images. A total of eight land classes were identified for this study. These were water bodies, deciduous forest, abandoned agricultural fields, agricultural fields, barren ground/rock cover, shrub forest, human habitation, and roads (Table 1). Supervised classification was performed for this study using 20 polygons for each class. To assess the accuracy of supervised classification using a confusion matric, the "Create accurate assessment points tool" was used to generate 210 random stratified points. These points were updated with ground truth values obtained from Google Earth Pro.

The Land Change Modeler module within the TerrSet was used to analyze changes in land cover from 2011 to 2016 and to predict probable land cover and land use in 2030. The basic principle behind this module was to evaluate the trend of change from one land use category to other and finally predict the land use pattern based on the previous trend (Mishra et al. 2014).

The Land Change Modeler was used since it creates more accurate change potential maps, and the multiple neural networks output is able to express the simultaneous change potential to various land cover types more adequately (Pérez-Vega, Mas and Ligmann-Zielinska 2012). All land cover units used were 1 square km. The Change Analysis tab was used to understand the interaction between different land cover types and how they have changed. The Transition potential was calculated by developing two main submodels based on the main drivers of the change—Climate Change and Direct Human Impact. The variables were added to the models as static. Each submodel had nine transition sub-models as Multiple-Neural Networks can work on maximum of nine submodels. The models were verified for the explanatory power of the variables using Cramer's V test. The latter indicates the degree to which the variable is associated with the distribution of land cover categories (Clark 2009). Run Transition sub models were used to create transition potential maps for each submodel using 10,000 iterations. These transition potential maps were then used to create a predictive map for 2030 using the Markov Chains method. The Markov Chain analyzes a pair of land cover images and outputs a transition probability matrix, a transition areas matrix, and a set of conditional probability images. The transition probability matrix is a text file that records the probability that each land cover category will change to every other category. The transition areas matrix is a text file that records the number of pixels that are expected to change from each land cover type to each other land cover type over the specified number of time units. In both of these files, the rows represent the older land cover categories and the columns represent the newer categories.

RESULTS

For both of the Landsat images, classified using ARCMAP for both 2011(Figure 1) and 2016 (Figure 2), the area for each class (Table 1) was calculated using Area Module in TerrSet.

The supervised classification had a kappa value of 0.7015 calculated from 210 random stratified points. Water bodies and deciduous forest had highest accuracy (100%), whereas barren grounds/rocks had lowest accuracy (48%) (Figure 3). Since pixel size for the Landsat images was 30 m, it becomes problematic to identify rock boulders greater than 30 m in size and hence bringing the overall accuracy of this class down.

Water bodies showed greatest percentage loss among all classes and agriculture showed greatest gain among all classes (Figure 4). Human habitation and agriculture were the biggest contributors to the loss of water bodies (Figure 5), roads and barren grounds were largest contributors to the loss of abandoned agriculture fields. Shrubs gained from abandoned agriculture land and water bodies, with agriculture lands and barren grounds/rocks being major contributors to loss of shrub land (Figure 5). Agriculture gained mainly from shrub forest and water bodies, but ~15% of agriculture land was converted to barren grounds (Figure 5). Transition potential for the conversion of the different classes is presened in Table 3. Markov Chains were used to predict the land cover for 2030 using the transition images generated from the Transition submodel, where the transition model for each class and its probability of conversion to every other class was calculated using 10000 iterations per sub-model. The accuracy rate of the Transition submodel was 50.19%.

The predicted map for 2030 (Figure 6) using Markov Chains shows agriculture will dominate the landscape. All classes showed a drop in total area except for agriculture, which grew by 14.83%.

DISCUSSION

LULC changes in Madanapalle region are governed by a combination of factors such as climate change-induced drought and direct impact from anthropogenic activities. The human population of Madanapalle grew by 22% from 2001 to 2011, with 67.7% growth in urbanization and a decline in rural areas by 36.2%. Although population growth is the primary source of rapid urbanization, there are socio-economic factors that need to be considered along with climatic conditions for a more complete understanding the changes in LULC.

One of the major causes of decline in rural areas is the region being highly prone to drought (Kumar et al. 2019). The Chittoor district has been hit by drought for nearly two decades. The water table has dropped from 90 m to 300 m in past 10 years (*unpubl. data*). Since agriculture is the main source of income in the region, the drop in the water table and poor rainfall has caused many people to abandon their agriculture lands (*unpubl. data*). Abandoned agricultural lands are left fallow for up to a decade some of which turn into barren grounds. Owing to secondary succession, a small part of the abandoned agriculture fields begins turning into shrub forests, given water availability. Six percent of abandoned agricultural land had converted to shrub forest. However, a major portion of the agricultural land turned into barren lands. When the agriculture lands are left barren, they are often poor in soil nutrients, and with low soil moisture the probability of them turning to barren lands increases.

The category with sharpest drop was waterbodies. Reduced rainfall in the past decade, coupled with higher demand for water due to rise in population, has hastened the rate at which water bodies have dried up. The area covered by water bodies dropped from 101 km^2 to 10 km^2 from 2011 to 2016. Dried up water bodies are very lucrative for farming as they have fertile soil and the water table is comparatively closer to the surface. The dried-up water bodies inaccessible for farming or development either turn into shrub forest or barren land based on the prevailing topography.

Although the overall trend is for a decline in shrub forests, there are a few regions where shrub forests have recovered. These are habitation, abandoned agricultural fields, and dried up water bodies. The rise of urbanization has led to a few settlements being abandoned, thus allowing shrub forests to regrow. At the same time climate change-induced drought is one of the biggest causes of concern for shrub forests, as most of the shrub forests have turned into barren ground in the absence of rainfall.

Agriculture, despite being under strain from drought conditions, has gained from all other categories except barren grounds. Agriculture has gained from dried up water bodies and shrub forests. Loss of both shrub forests and water bodies is bound to have an adverse effect on the local fauna that is dependent on these forests. Shrubland bird communities are dependent on these shrub forests, either based on their unique structural configuration or their floristic composition (Deshwal et al., *in press*), and loss of these forests will cause population declines for these birds.

Understanding the trend of changes in land cover and land use is instrumental in designing the correct methodology for forest management and habitat conservation. The results obtained in the present study should help to develop a greater understanding of the causes and factors affecting shrub forests in the Chittoor district and therefore in developing effective conservation measures.

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APPENDIX

Figures and Tables –

Table 1: Classes used in the classification of Landsat images and their description.

CLASS	DESCRIPTION
Water Bodies	Any non-covered region that may be natural or man-made for storing water.
Deciduous Forests	Hardwood trees or vegetative growth form with a DBH> 7 inches and height above 2 m
Abandoned Agricultural Fields	Agricultural fields that have been left fallow for more than 10 years
Barren Ground/Rock	Mostly rock cover or regions that have no major vegetative growth such as shrubs, trees or native grasses
Human Habitations	Regions where humans are living either villages or towns
Shrubs	Shrubby vegetation such as examples dominated by *Acacia*
Agricultural Fields	Active agricultural fields that have been used in past 10 years
Roads	Both paved and dirt roads

Table 2: Area under different classes for both the years 2011 and 2016 along with the percent change for each class.

Categories	2011. Area (km^2)	2016. Area (km^2)
Not Categorized	390.5937	403.7436
Water Bodies	101.3166	10.044
Deciduous Forests	441.9054	388.3149
Abandoned Agricultural Fields	824.6997	441.2844
Barren Grounds/Rocks	205.3656	517.1715
Human Habitations	90.4815	78.2658
Shrubs	1058.6583	735.7086
Agricultural Fields	1126.0296	1628.9730
Roads	250.6176	286.1622

Table 3: Mean probability of a particular class changing to another class as derived from the Transition submodel tab in LCM.

Original Class	Potential Class in Future	Mean Probability of Conversion
Abandoned Agriculture Fields	Shrubs	0.5
Abandoned Agriculture Fields	Barren Ground/Rock	0.07
Abandoned Agriculture Fields	Agricultural Fields	0.24
Agricultural Fields	Barren Ground/Rocks	0.000055
Shrubs	Barren Ground/Rocks	0.12
Shrubs	Habitations	0.25
Shrubs	Agricultural Fields	0.25
Barren Ground/Rocks	Agricultural Fields	0.30

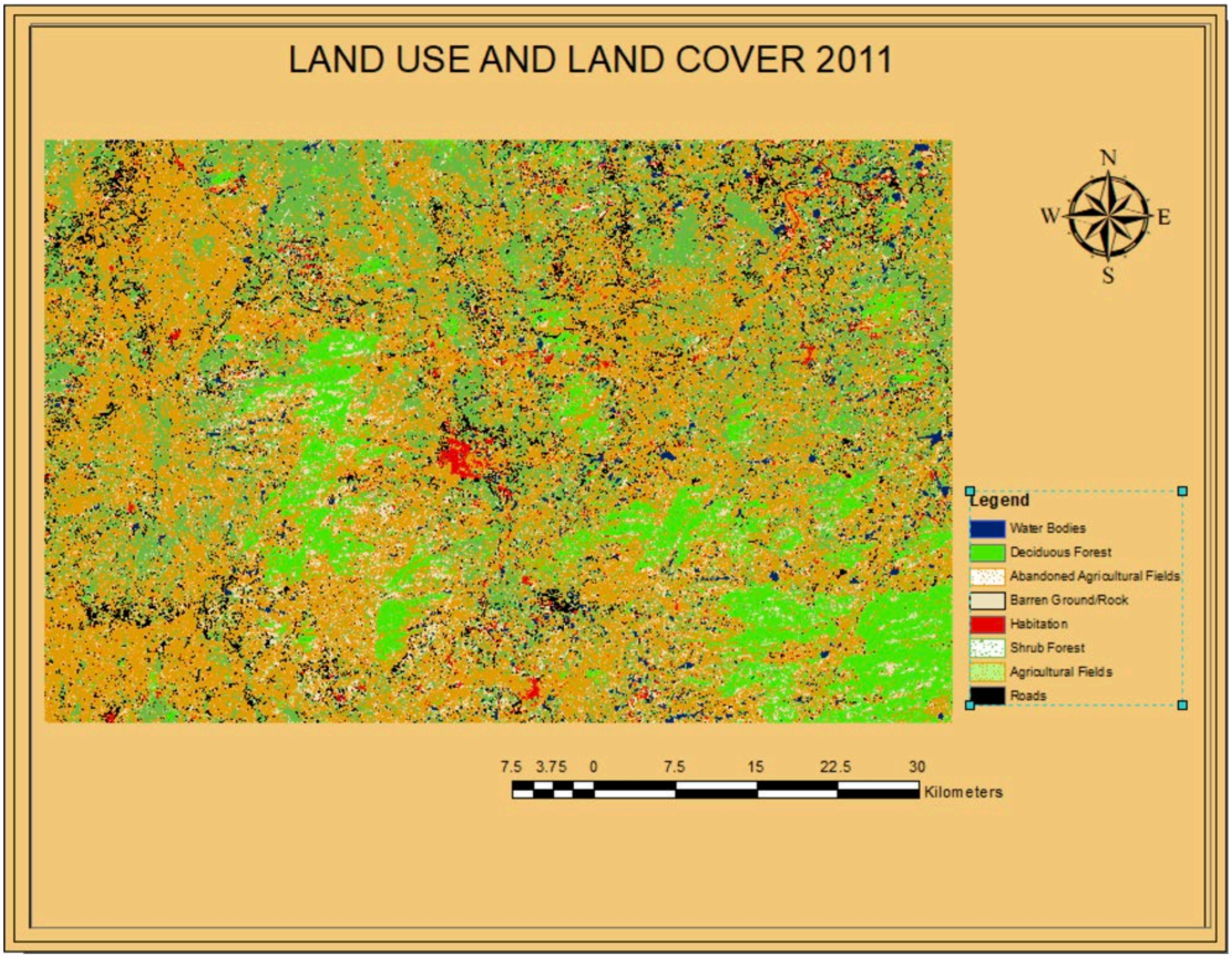

Figure 1: Classified image of the Chittoor district for the year 2011.

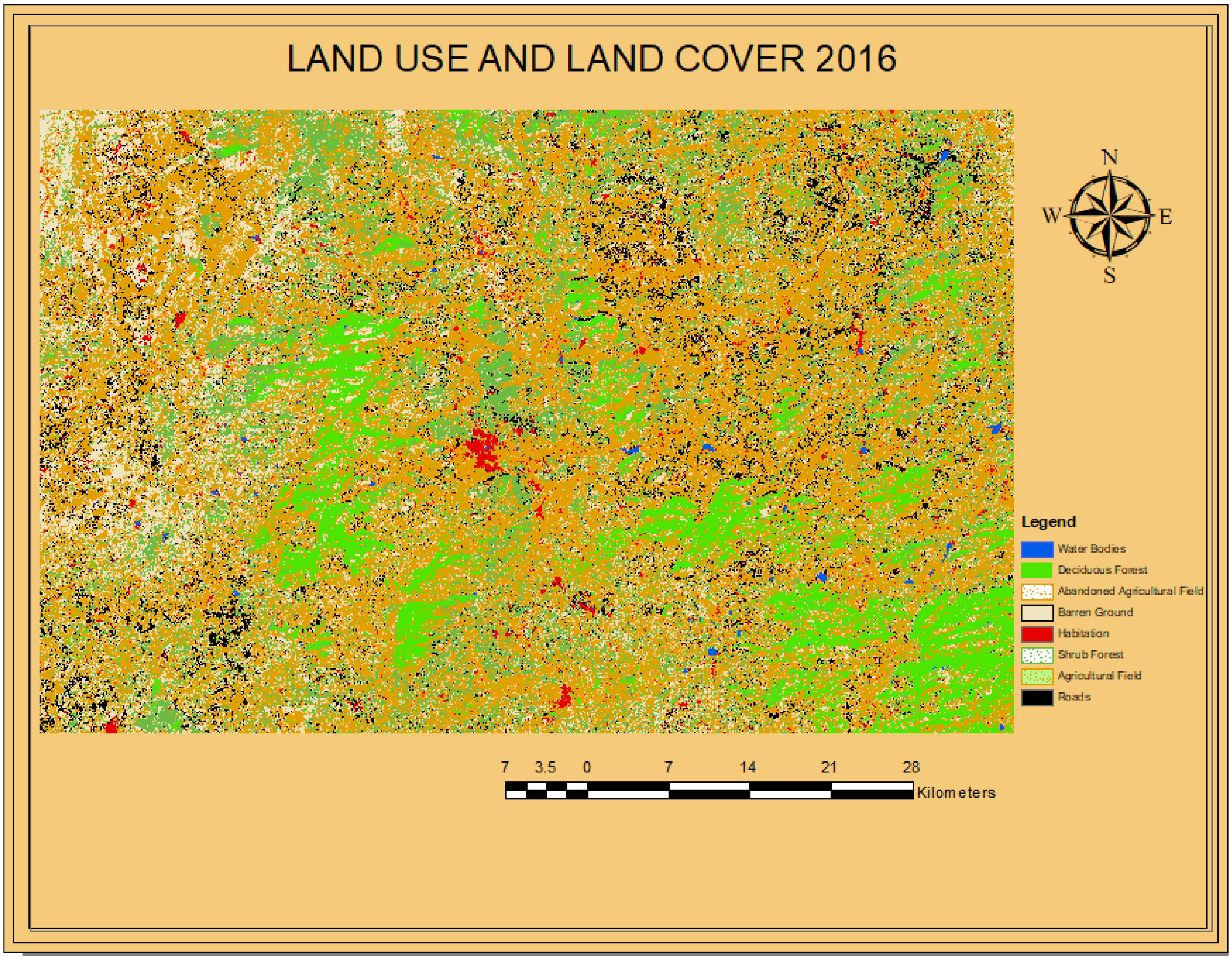

Figure 2: Classified image of the Chittoor district for the year 2016.

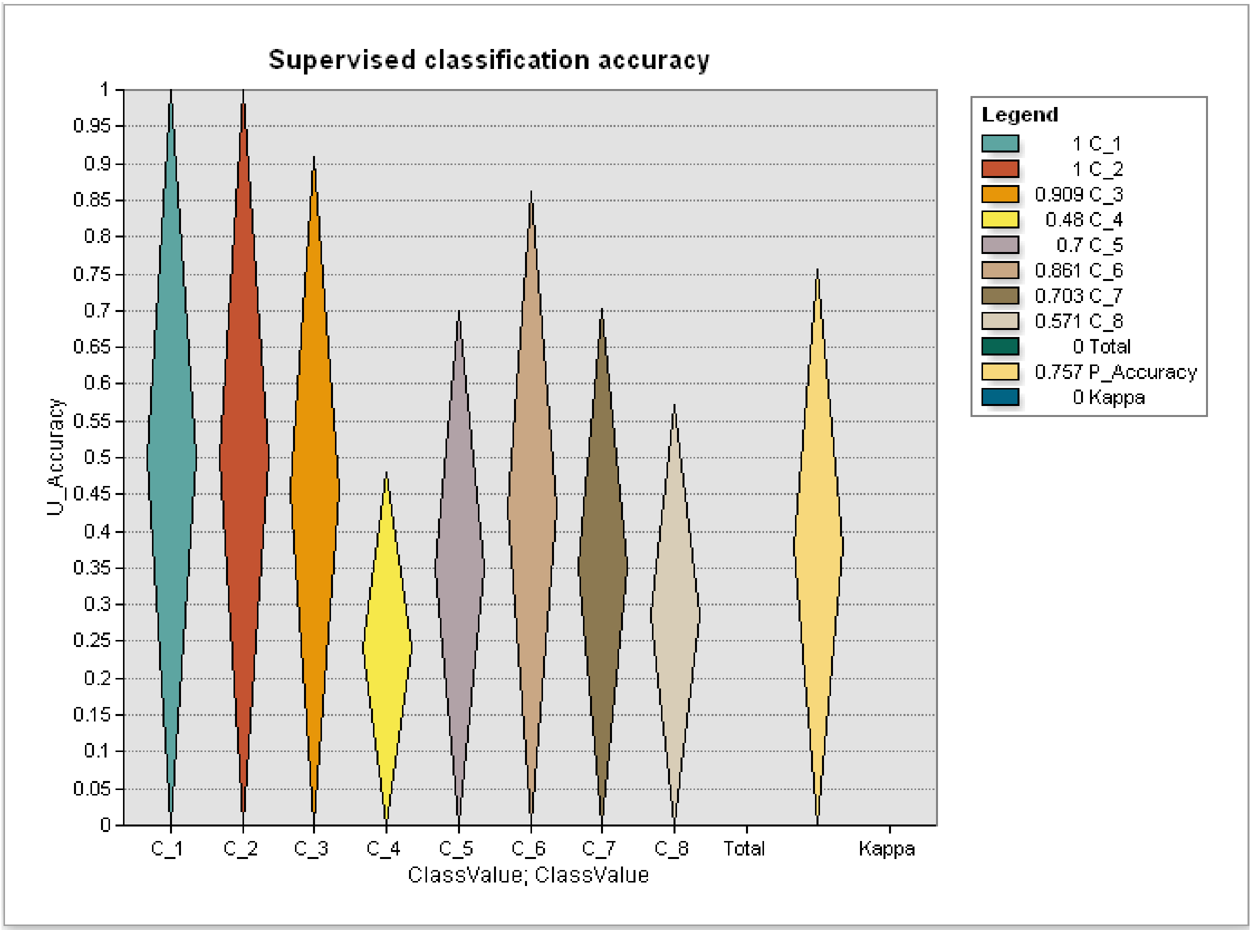

Figure 3: Accuracy for different classes under supervised classification. In the legend C_1 = Water Bodies, C_2 = Deciduous Forests, C_3 = Abandoned Agriculture Lands, C_4 = Barren Ground/Rocks, C_5 = Human Habitations, C_6 = Shrubs, C-7 = Active Agriculture Fields, C_8 = Roads.

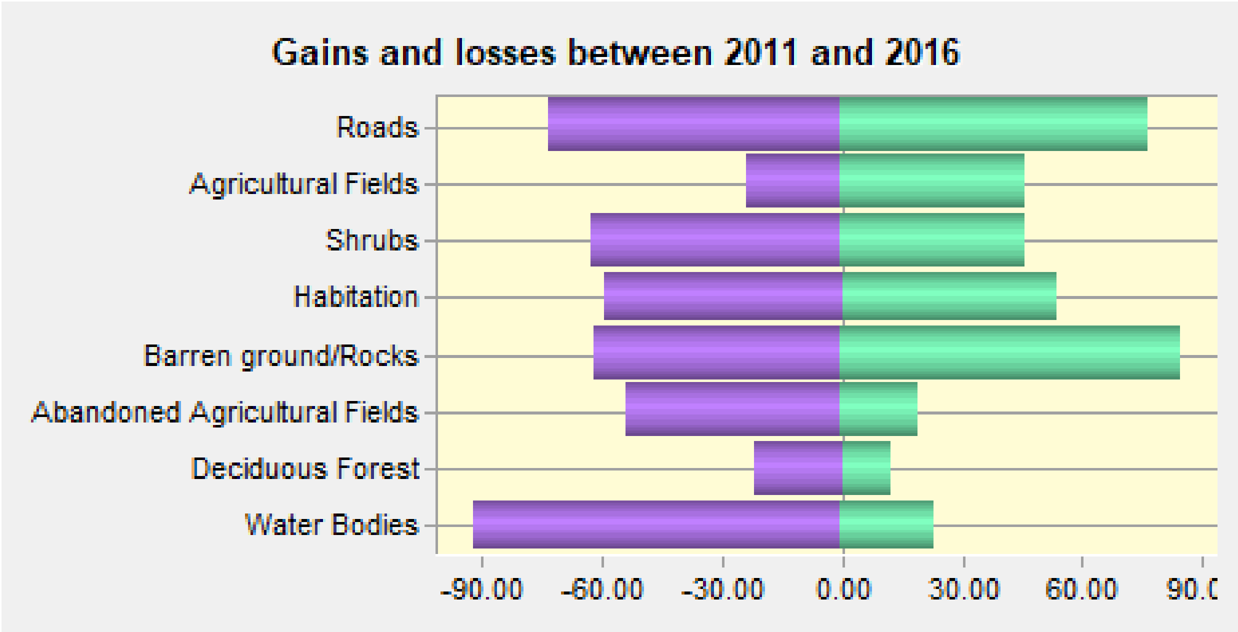

Figure 4: This graph shows the percentage change in different classes from 2011 to 2016. The green colored bars represent growth, and the purple colored bars represent decline.

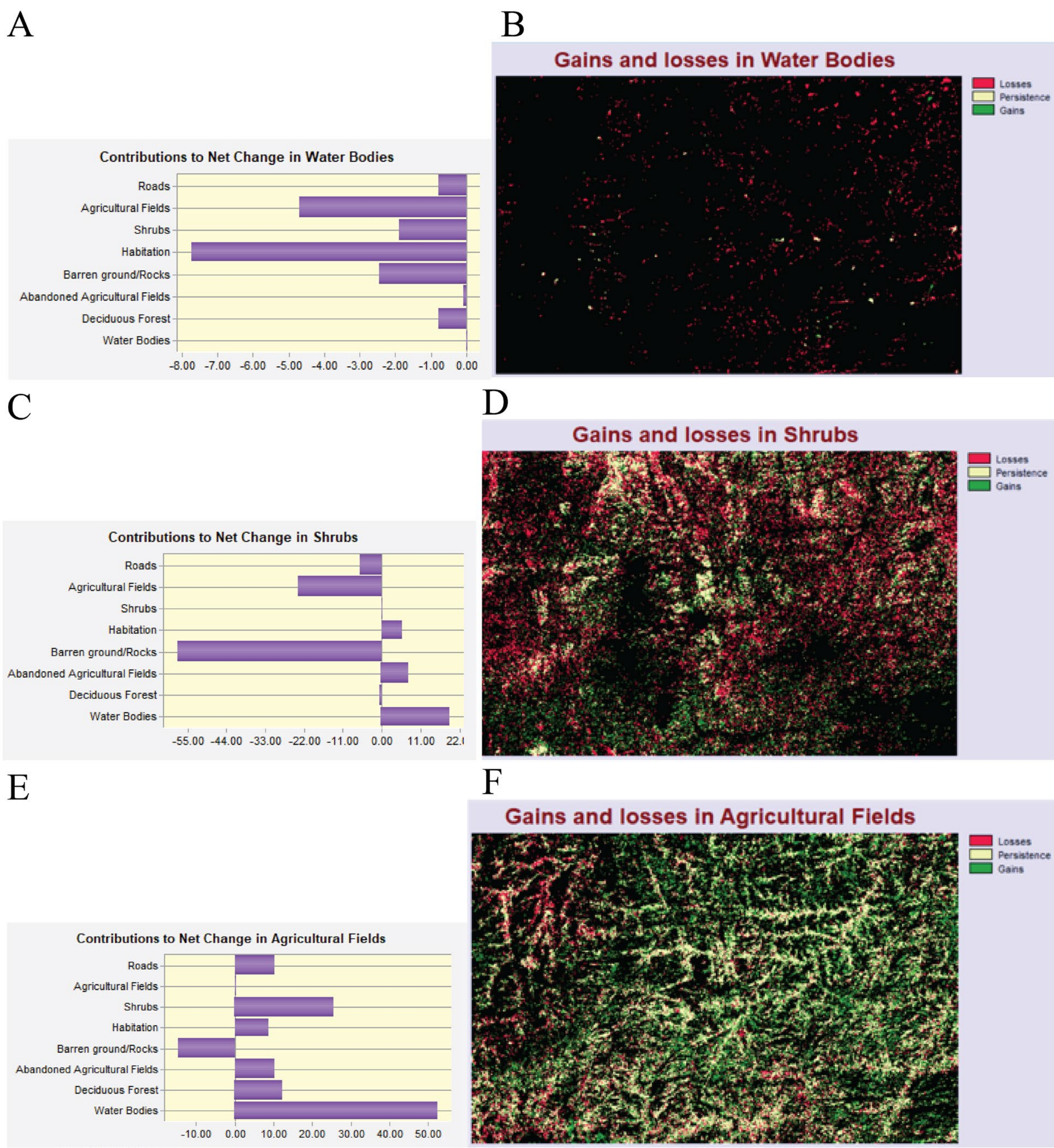

Figure 5: A, C, E represent percent changes in water bodies, shrub forests, and agricultural fields in the study site, whereas B, D, F represent regions on the map where the category of concern has changed from 2011 to 2016.

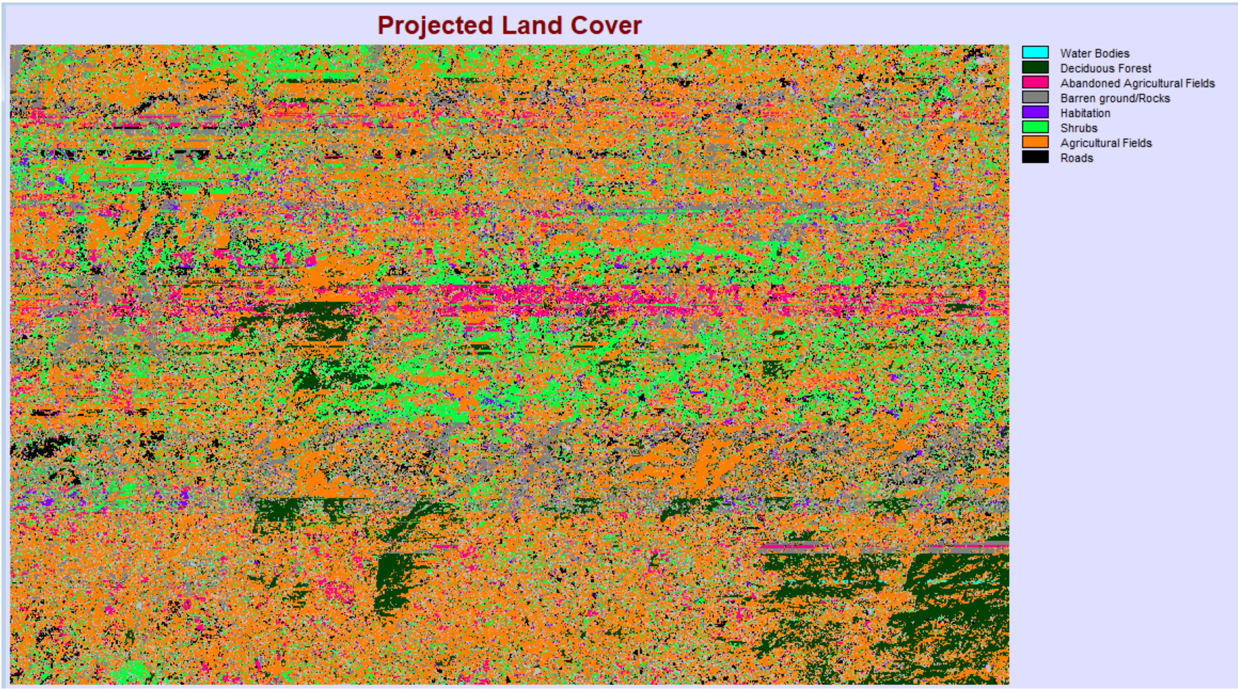

Figure 6: Land Cover Land Use predicted map for 2030, generated using the Markov Chain.

Chapter 4: Anthropogenic Dependence on the Scrub Forests of the Eastern Ghats of India

ABSTRACT

The Chittoor district has been under immense anthropogenic pressure in the form of land use and land cover changes and the recurrent drought has increased the economic stress. Recurrent drought has forced the people to abandon their agricultural lands and encroach the shrub forests for agricultural purposes. Some farmers have increased their dependence on goats and sheep as a secondary source of income. I quantified the effect of anthropogenic presence on habitat characteristics. To do so, I quantified changes in agricultural land cover, change in dependence on forest products through semi-structured interviews, effect of goats and sheep on forest structure and composition by comparing non-grazed areas with grazed areas. My results indicated that the community was highly aware of their impact on the forests. The use of forest products did not change in the past decade. However, the plant species they used for firewood was the same species that many birds preferred. The goat browsing pattern was in direct conflict with the preferred habitat structure of birds. The browsing height of goats was similar to that preferred height of birds. Plant species composition and structural configuration was affected by grazing and browsing, but browsing did not have an effect on species richness.

INTRODUCTION

Anthropogenic changes have caused the Earth to enter into a new human-dominated geological epoch called the Anthropocene. Our activities have resulted in land surface transformation and changes in the composition of the atmosphere (Lewis & Maslin 2015). These changes in the past 500 years have triggered a wave of extinctions, threats, and local population declines (Dirzo et al. 2014). Owing to anthropogenic changes in North America alone, since 1970 bird populations have declined by 29% (Rosenberg et al. 2019). Anthropogenic disturbance can take many forms such as changes to land use and land cover patterns, introduction of invasive species, extraction of forest products, grazing, and browsing.

In order to formulate effective management plans, it is important to understand the relationship between land and man. The relationship between man and land gets strained in regions experiencing rapid human population growth and urbanization. Socio-economic conditions and relationship to land for such regions needs to be investigated, such as Chittoor district within Eastern Ghats, which are experiencing rapid population growth (Paul 2012). Agriculture along with goat and sheep grazing/browsing is the main occupation of the people in the Chittoor district (Paul 2012). The Chittoor district is a semi-arid landscape which is prone to drought conditions (Kumar et al. 2019) and is nested within Eastern Ghats of India. The Chittoor district which has a high percentage of land under agriculture (Paul 2012) and has been under economic stress due to recurrent droughts (Paul 2012, Kumar et al. 2019).

In villages surrounding Madanapalle (a town, within the Chittoor district), some farmers have been forced to leave their existing agricultural lands fallow for a decade or more while they encroach upon scrub forest for viable agricultural lands (*pers. observe*). Others have ended up becoming more dependent upon goat and sheep grazing/browsing to earn their livelihood.

Within the Chittoor district, a strong positive correlation exists between goats and cattle per square kilometer and forest area (Paul 2012). Goat grazing in open patches affects the herbaceous community (Gabay et al. 2011). The direct effect of herbivory on vegetation includes modifications to plant growth, reproduction and structure (Torrano et al. 2004). Increased presence of goats in shrub forests increases the competition for resources between goats and shrubland birds. Goats present a potential threat to plant communities given the large number of plant species that are palatable to them and their ability to browse and graze in inaccessible areas such as in trees or in dense thickets (Squires 1980; Parkes et al. 1996).

As the relationship between man and the forest changes, it has an impact on the bird community. Shrubland birds are known to select habitat by using structural or floristic composition as cues. Conversion of shrub forest to agricultural land and increased grazing will have an impact on structural configuration of plants as well as floristic composition. In this study My objective is to quantify the dependence of the local community upon the scrub forests.

MATERIALS AND METHODS

Study area –

The Eastern Ghats of India are a discontinuous mountain range running along the eastern coast of India, located between 16° to 19° N latitude and 80° to 85° E longitude. My study sites was located near the town of Madanapalle (Chittoor District) in Andhra Pradesh, which is in the southern portion of the Eastern Ghats. Elevation range from 500 to 1200 m above mean sea level. The study site is described as semi-arid with distinct dry and wet seasons. The average annual rainfall is 700 mm. The vegetation is a mixture of southern thorn forests and dry deciduous scrub forests (Champion and Seth 1968) .

Sampling –

Field work was conducted from August – December 2016. I conducted semi-structured surveys in all the 1000 households in 24 villages surrounding my study site (IRB number: 16-08-42). 1000 survey sheets were distributed and all of them were returned. The households represented both farmers and goat/sheep herders. The surveys were conducted in the evening after the farmers and goat/sheep herders had returned home. The questionnaire (Table 1) was designed to elicit information regarding current agricultural land holding and numbers of sheep, goats and cows. The questionnaire also focused on the dependence of the local community on the shrub forest in terms of firewood, grass and other products.

Impact of goat and sheep –

I used a natural experimental setup to understand the impact of grazing and browsing on plant structure. Within my study site there are existing segregated sections demarcating three zones of grazing (Zone 0 – no grazing, Zone 2 – medium level of grazing, Zone 3 – high grazing). To compare the species diversity and species composition variation between goat plots and non-goat plots, I used the line transect method. Twenty transects of 15 meter in length were laid out in each of the three grazing zones. All the plant species that touched the 15 m long tape were recorded with the frequency of their encounters and precise locations on the tape. I also recorded DBH and height of all species touching the measuring tape. The data was analyzed using ANOVA.

Foraging behavior of goats –

Goats and sheep were followed throughout the day while they were in forest foraging and the name of plant species being foraged, the various heights at which browsing took place along with the time spent at the particular height were recorded (Negi et al. 1993, Ouédraogo-koné et al. 2006). Each morning a unique goat was marked with red paint and was followed in the forest. To avoid pseudo-replication, I would follow a unique goat from a different goat herder each morning. The data was analyzed using T-tests.

<u>RESULTS</u>

The survey results reflected an 0.8% increase in total agriculture land size in the past 10 years (p-value > 0.05). This does not match the results obtained from LULC analysis done in Chapter 3, probably due to bias in survey responses. However, there was a significant (72%)

drop in the irrigated area in the past 10 years (p-value = 0.0001). Based on the survey results, there has been a significant increase in the depth of borewells used for irrigation and household purposes (p-value < 2.2 e-16), with the dropping from 400 m to 650 m. During 2016, there were 800 cows and 2000 goats and sheep present in these villages. There was no significant change in number of cattle, goats and sheep for the past ten years. However, there was a significant drop in number of native cows (p-value < 2.2 e-16) in past ten years. Villagers mainly used *Lantana camara, Dodonea viscosa, Terminalia chebula, Plectronia didyma,* and *Wrightia tinctoria* for firewood. On an average a family reported harvesting 50 kgs of firewood per week. There was no significant difference in firewood collection between 2006 and 2016 (p-value < 0.05).

Goat, sheep grazing/browsing effect –

Goats browse from ground level up to a height of 2 m of height (Figure 1). Although goats did not specifically show a high preference for any plant species, they did spend more time foraging on *Wrightia tinctoria, Randia dumetorum, Plectronia parviflora, Flacourtia sepiaria, Azadyractus indica*, Merapaganeja (Scientific name unknown), and Dusara (Scientific name unknown) (Figure 2). Goats avoided *Cymbopogan citrus,* and *Cymbopogan montana* (Figure 2). There was no significant difference in species richness among the three zones of foraging (p-value > 0.05) (Figure 3). *Randia dumetorium* and *Lantana camara* were significantly shorter in the high intensity grazing zone as compared to the medium and no grazing zones (p-value < 0.05) (Figure 4). There was a significant difference between DBH of plants in the no grazing zone, medium grazing zone and high grazing zone (p-value < 0.05) (Figure 5). Abundance of grasses such as *Cymbopogan citrus, Saccharum spontaneoum*, and Wupa (Scientific name unknown) was higher in the no grazing zone and *Cymbopogan montana* was higher in the zone with a high grazing intensity (Figure 6). *Cymbopogan montana* and Wupa were significantly different in structural configuration between the no grazing zone and high grazing zone. They both were significantly taller in the no grazing zone (Figure 7).

DISCUSSION

The Chittoor district has a high rate of poverty (Paul 2012). Recurrent droughts have only increased the financial stress on the indigenous farming community surrounding the shrub forests. However, at the same time, owing to the relationship the indigenous people have with their land, they have used their traditional ecological knowledge in reducing their impact on the forest. Despite the increased socio-economic stress, the villagers are working on reducing their dependence on the forest products. For example, they have marginally reduced the use of firewood for basic purposes such as cooking. At the same time, it is important to note that plant species that are used for firewood are also preferred by birds such as *Lantana camara* being preferred by the Tawny-bellied Babbler, Purple Sunbird, Purple-rumped Sunbird (Chapter 1 and 2). *Dodonea viscosa* and *Wrightia tinctoria* are preferred by the Yellow-eyed Babbler (Chapter 1 and 2). The Tawny-bellied Babbler selects its habitat based on structural cues (Chapter 1 and 2) and collection of firewood does affect the structural configuration of the plant, thus dependence on firewood may play a role in describing the decreasing trend in population of the species (Birdlife International 2018).

Droughts often leave the land unsuitable for cultivation, forcing the farmers to abandon their agricultural land. The farmers make an effort to ensure that they do not encroach upon scrub forest more than required for their sustenance. This is substantiated by the fact that the net change in size of the total land under agriculture has not changed substantially in the past decade (Chapter 3). The net increase in size of agricultural land based on response from survey response was 0.8%, while the Landsat imagery showed a decline of 5%. The abandoned agricultural land is allowed to grow back into shrub forest (Chapter 3), thus maintaining a healthy relationship with the land.

However, there are certain practices such as goat and sheep foraging which does have a direct impact on the ecology of the shrubland bird community. Goats and sheep forage on leaves and fruits up to a height of 2 m. Since most of the shrubland birds, except for the Red-vented Bulbul and the Red-whiskered Bulbul at the study site had a structural preference for foliage at 0.6 – 1.2 m (Deshwal et al. *in Press*), this brings the goat and sheep foraging behavior in direct conflict with the habitat preference of the birds. However, the indigenous people are careful enough to ensure that foraging by goats and sheep happens at a gradient, thus allowing the forest to recover. There are three natural gradients selected by the herding community. These are (1) a strict no foraging zone by goats and sheep followed by (2) a medium level of foraging defined by 100- 200 goats and sheep per day and finally (3) a high grazing area which has more than 200 goats and sheep per day (Figure 8).

Although foraging by goats and sheep did not affect species richness (Figure 3), it did have an effect on the structural configuration of the plants (Figure 4). Height of *Randia dumetorium* was significantly affected by the grazing intensity. *Randia dumetorium* was shortest in the heavily grazed regions and tallest in regions with no grazing. *Lantana camara* showed similar results a reduction in height, it is a defense mechanism of plants against browsing. Though species richness was same among the three levels of grazing, the data reflected that species composition was among between the three zones of grazing (Figures 5 & 6). Grasses such as *Cymbopogan citrus, Saccharum spontaneoum*, and Wupa were more abundant in the no grazing area, while the only grass more abundant in highly grazed regions was *Cymbopogan montana*. The latter was preferred by the Common Babbler (Chapter 1 and 2), but the bird was found to more abundant in areas with no or a medium level of grazing and this can be attributed to the structural configuration of this grass (*personal obs.*). *Cymbopogan montana* was taller in the no grazing zone (Figure 7), thus providing cover to birds that prefers to feed on ground. *Cymbopogan citratus* was preferred by Plain Prinia (Chapter 1 and 2) and hence it was found in areas with no to a medium grazing intensity.

It is with the combined understanding of anthropogenic presence and ecological preference of an avian community can we develop any effective management plans. Distribution of the Common Babbler and the Plain Prinia is best explained by a combination of grazing intensity, structural configuration and floristic composition. Understanding the relationship man has with land will lead to much more cost-effective and sustainable conservation efforts. Although traditional ecological knowledge was not measured in the present study, the impact of traditional ecological knowledge in conservation was apparent in the herding and farming practices of indigenous community.

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APPENDIX

Table 1: Sample Datasheet used to conduct survey in the villages.

Name of Village				
Number of adult house members				
Number of young (below 10 years age) house members (to understand how village demographic has changed in past 10 years)				
Agriculture (To understand how extent of agricultural fields have changed in past 10 years, data will be used to correlate with exent of change in scrub forests)				
Number of Borewells				
Dry borewell number				
Number of borewells 5 years ago				
Number of borewells 10 years ago				
Depth of Borewell				
Depth of Borewell 5 years ago				
Depth of Borewell 10 years ago				
Total Agricultural field (acre)				
Total Agricultural field 5 years ago				
Total Agricultural field 10 years ago				
Irrigated area				
Irrigated area 5 years ago				
Irrigated area 10 years ago				
Domestic Use of water (To understand dependency on ground water and how it has changed in past 10 years)				
Liters of water used daily				
Liters of water used daily 5 years ago				

Table 1 contd.

Liters of water used 10 years ago				
Which work requires maximum water				
Which work requires minimum water				
Drought, work was water usage most affected				
Drought, work was water usage not affected				
Livestock	Present day	5 years ago	10 years ago	
Number of bulls				
Water usage per day (liters)				
Amount of food per day (kgs)				
Number of young bulls				
Water usage per day				
Amount of food per day				
Number of adult hf/jersey cow				
Water usage per day				
Amount of food per day				
Number of young hf/jersey cow				
Water usage per day				
Amount of food per day				
Number of pregnant hf/jersey cow				
Water usage per day				
Amount of food per day				
Number of adult native cow				
Water usage per day				
Amount of food per day				
Number of young native cow				
Water usage per day				
Amount of food per day				
Number of pregnant native cow				

Table 1 contd.

Water usage per day				
Amount of food per day				
Number of female sheep adult				
Water usage per day				
Amount of food per day				
Number of male sheep				
Water usage per day				
Amount of food per day				
Number of young sheep				
Water usage per day				
Amount of food per day				
Number of pregnant sheep				
Water usage per day				
Amount of food per day				
Number of female goat adult				
Water usage per day				
Amount of food per day				
Number of male goat adult				
Water usage per day				
Amount of food per day				
Number of young goat young				
Water usage per day				
Amount of food per day				
Number of pregnant goat				
Water usage per day				
Amount of food per day				
Number of poultry				
Water usage per day				
Sheep/goat grazing area				
Cattle grazing area				
Dependence on Forest				

Table 1 contd.

Tree name of which branches are collected. (1 mop=25kgs and 1 mop consist of species mentioned in the list, it is difficult to state how much quantity of each species is collected) (To understand the dependency on scrub forests for firewood through logging and lopping)	How many bundles of branches are collected per week	How many bundles of branches are collected per week 5 years ago	How many bundles of branches are collected per week 10 years ago	
Month of branch collection and amount				
January	February	March	April	
May	June	July	August	
September	October	November	December	
Material used per day	Purpose			
Grass				
Sticks				
Gas (per month)				
Amount of grass load purchased per year				

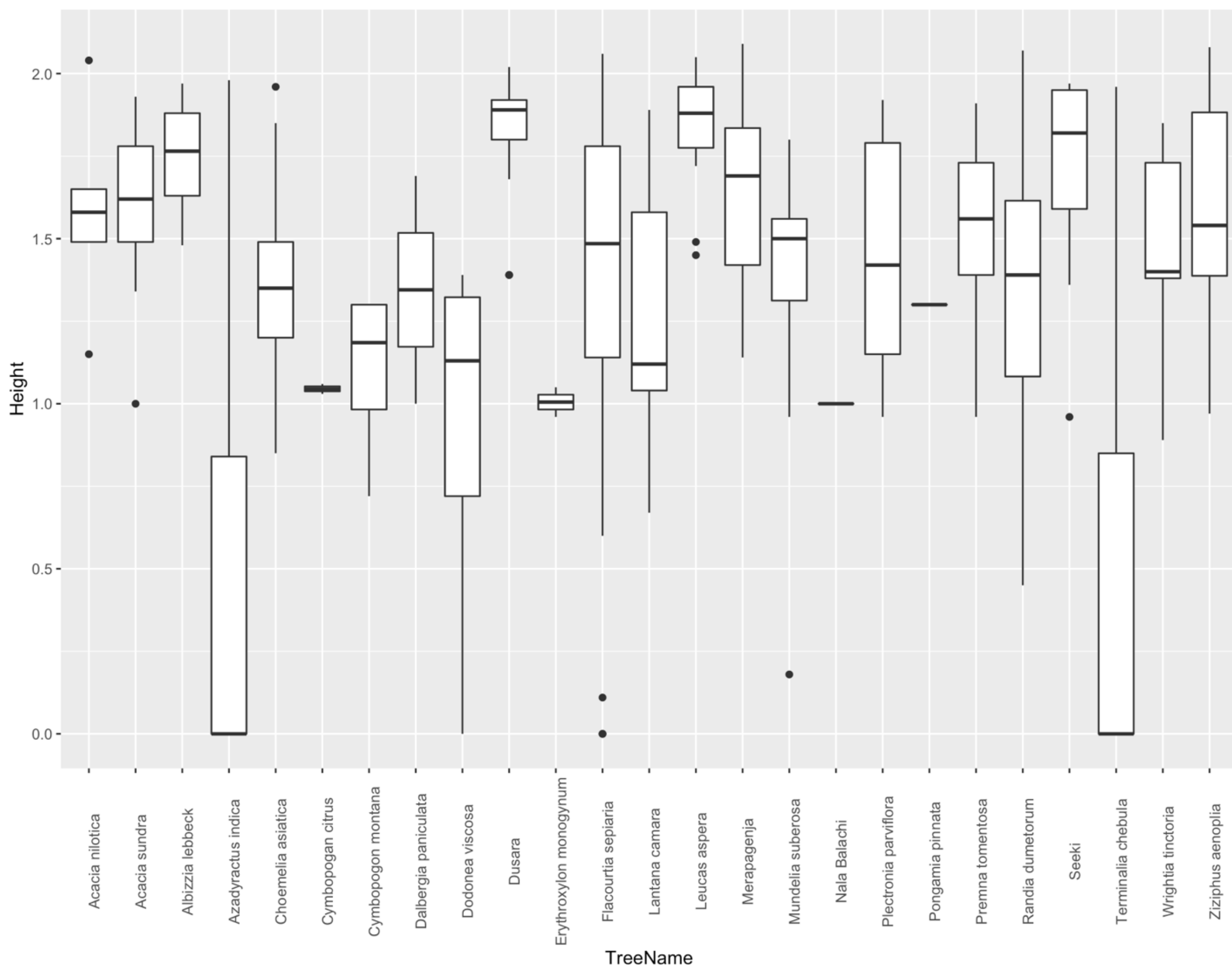

Figure 1: Browsing height of goats for each species of plant.

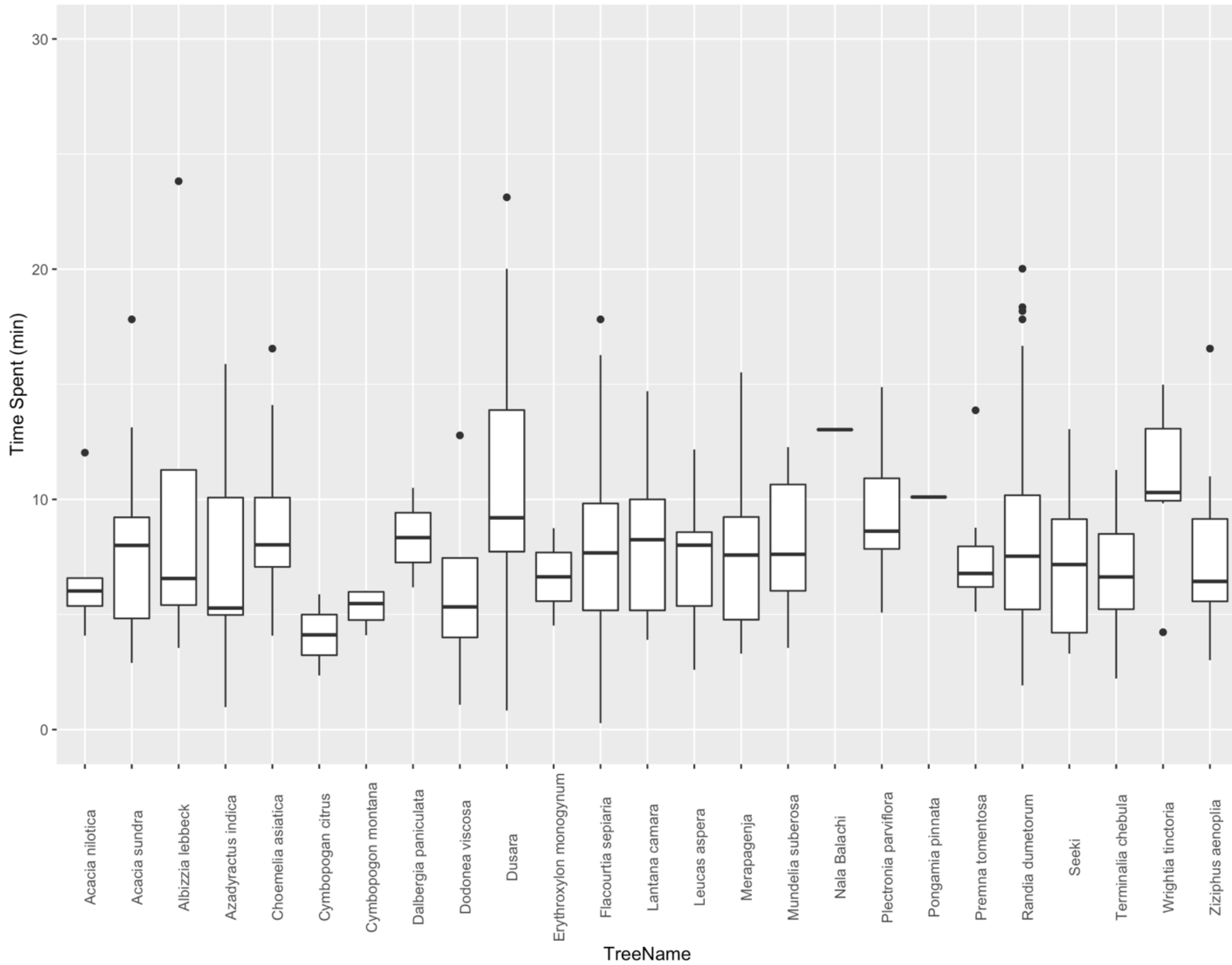

Figure 2: Time spent browsing by goats for each species of plant

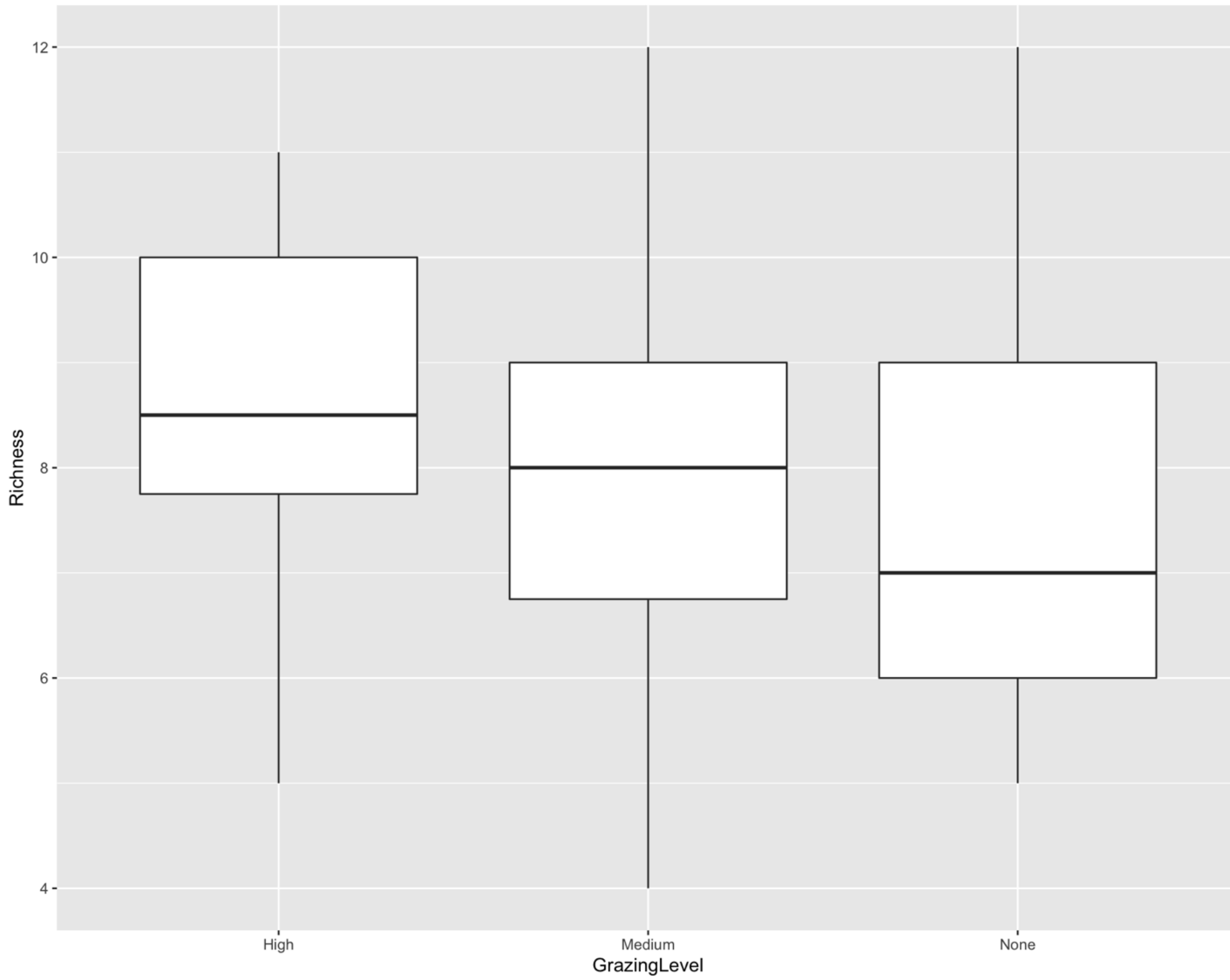

Figure 3: Comparing species richness among the three zones of grazing: No grazing, medium grazing, and high intensity of grazing.

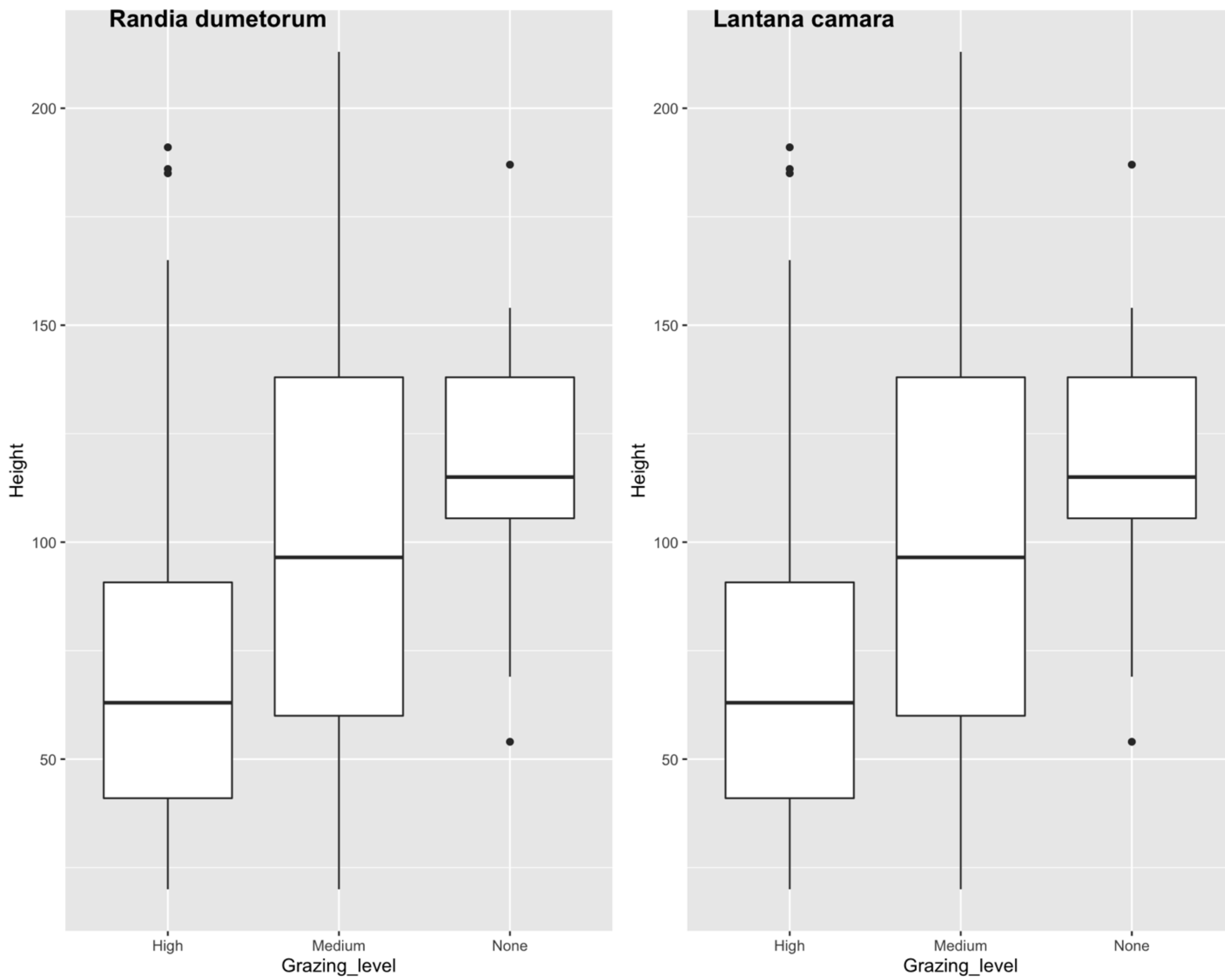

Figure 4: Structural difference in *Randia dumetorium* and *Lantana camara* as a result of grazing. The height of plants was directly correlated to intensity of browsing.

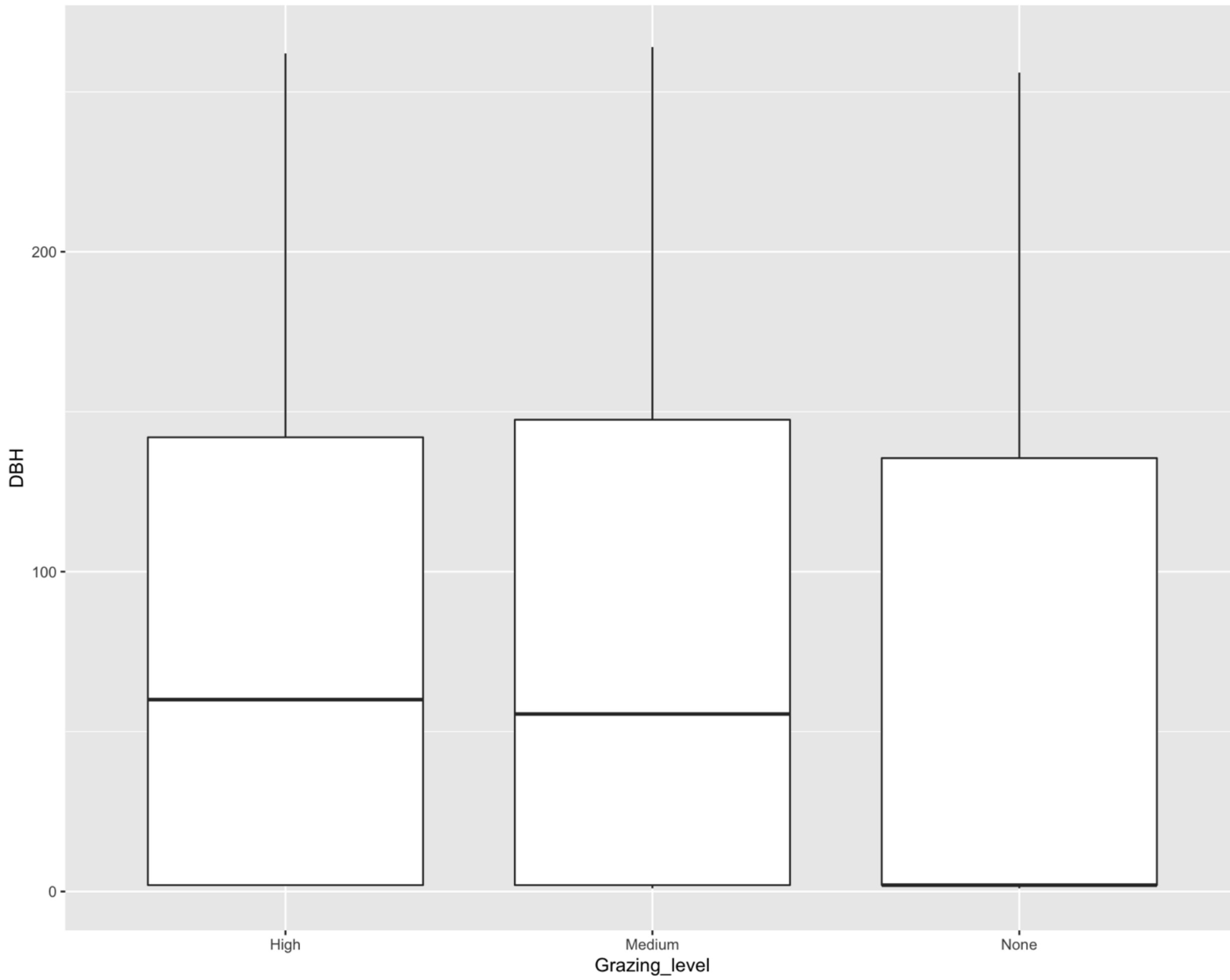

Figure 5: Maximum diameter of stem was significantly lower at no grazing site than medium or high intensity grazing sites. High abundance of grass at no grazing site is major factor for this difference in maximum stem diameter.

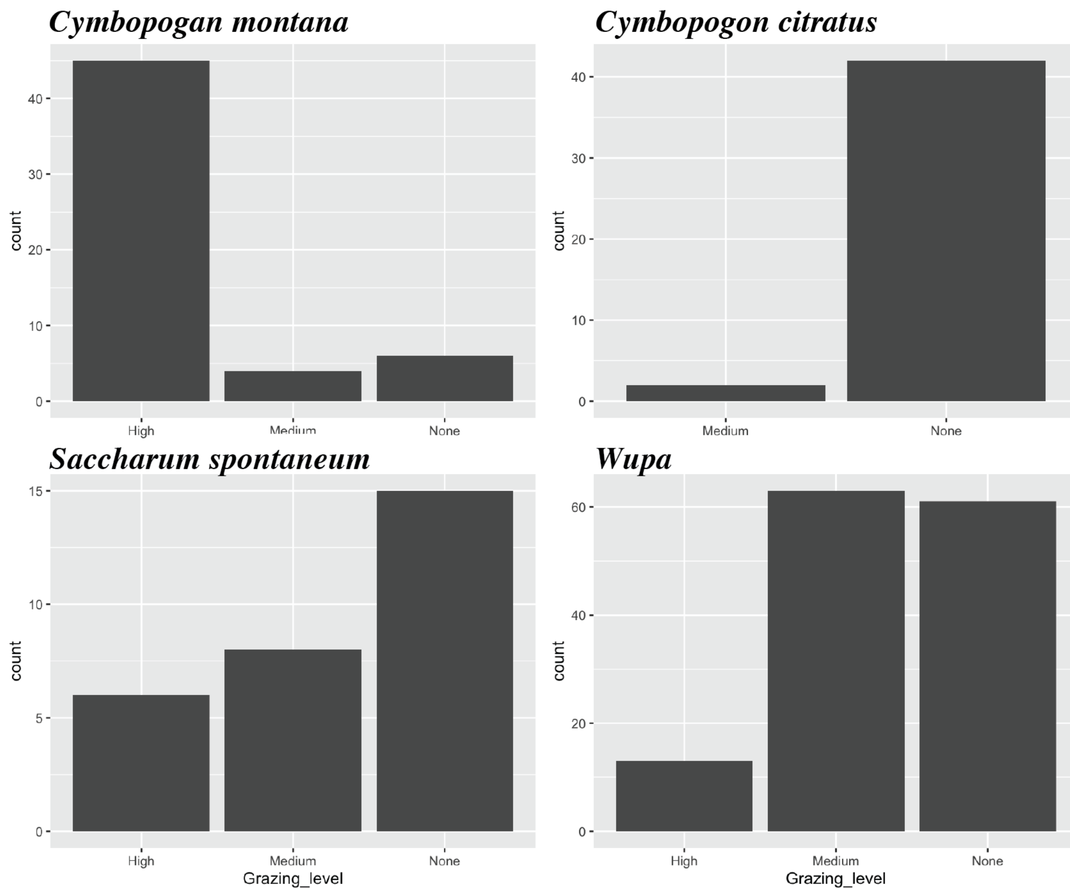

Figure 6: Lower DBH observed at the no grazing site (Figure 5) can be explained by grass species abundances in the three differential foraging zones. *Cymbopogan citrus, Saccharum spontaneoum*, and Wupa were high in the no foraging zone while *Cymbopogan montana* was high in the high grazing zone.

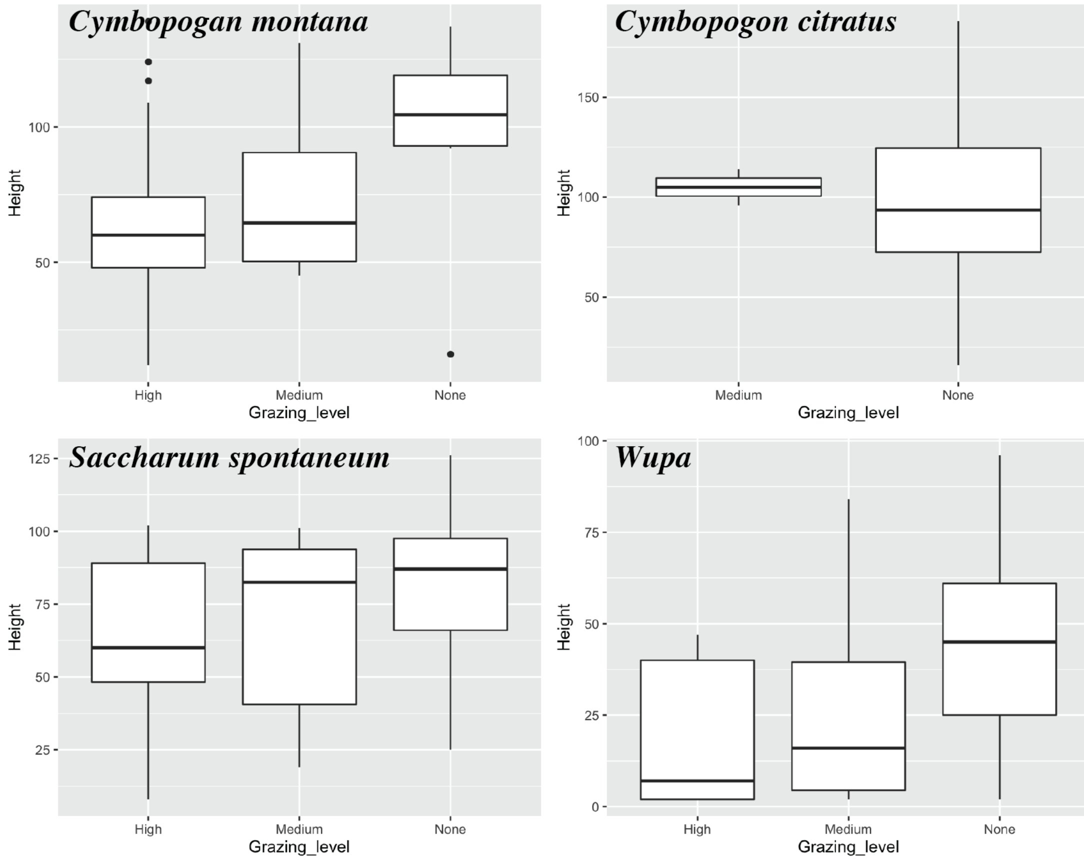

Figure 7: *Cymbopogan montana* and Wupa were significantly different in structural configuration between the no grazing zone and the high grazing zone. Both were significantly taller in the no grazing zone owing to the absence of sheep.

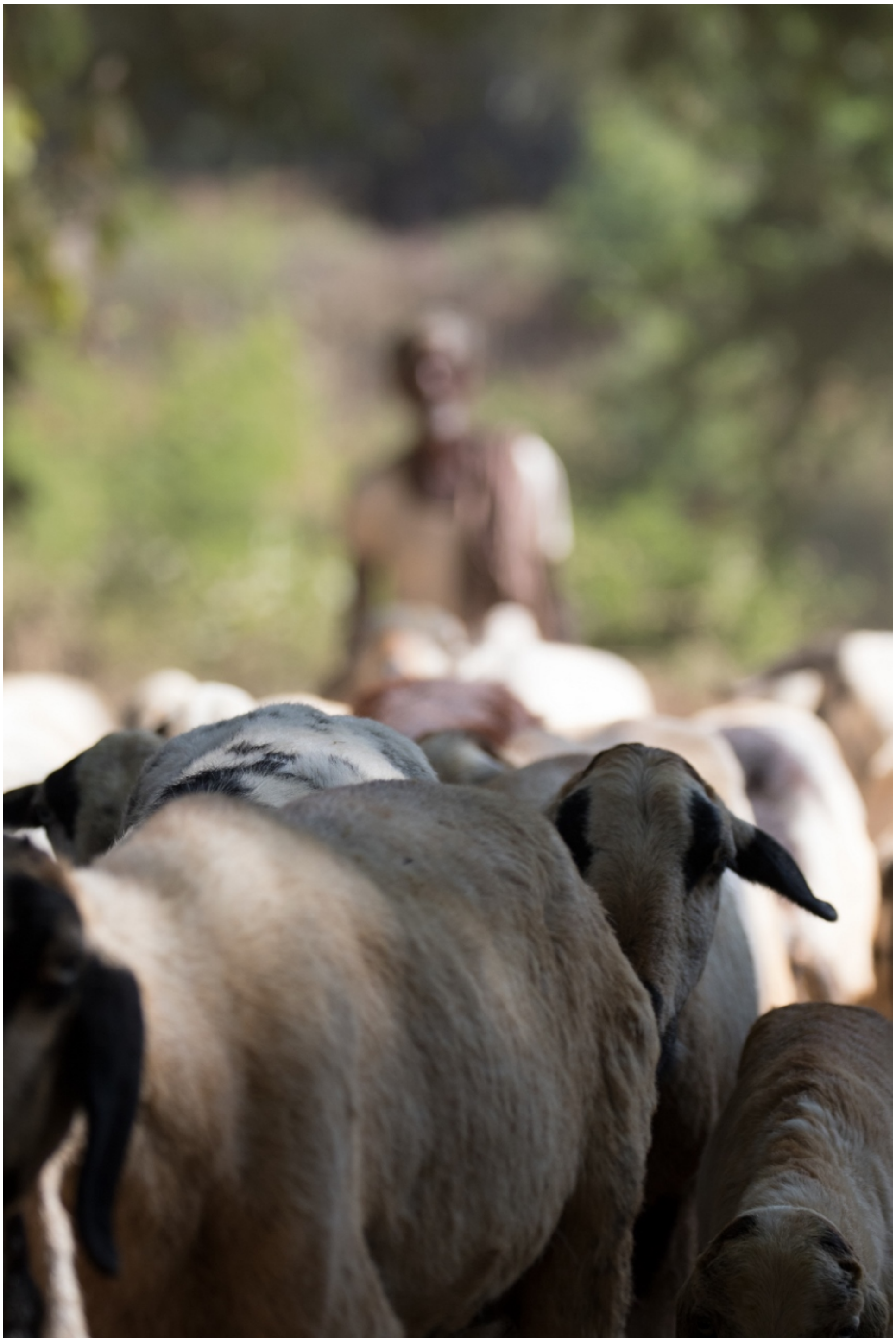
Figure 8: A herder taking his goats and sheep for foraging into the shrub forest (Image by Anant Deshwal).

CONCLUSION

Anthropogenic changes have caused the Earth to enter into a new human-dominated geological epoch called the Anthropocene (Lewis & Maslin 2015). Our activities have induced land surface transformation (Lewis & Maslin 2015). These changes in the past 500 years have triggered a wave of extinctions, threats, and local population declines (Dirzo et al. 2014). There is a myriad of studies that have been undertaken in understanding various steps that can be undertaken to understand climate change, LULC changes and their effect on wildlife community (Mapaure & Campbell 2002, Inkley et al. 2004, DeFries et al. 2007, Rahdary et al. 2008, Ndegwa & Murayama 2009, Mawdsley et al. 2009. Brodie et al. 2012). Yet, there are quite a few species that we know very little about especially with regards to habitat usage. Conservation efforts of a species without the knowledge of its habitat usage often leads to wastage of funds and other resources. What is required is a detailed understanding of habitat preference and usage by both common and rare birds. Unfortunately, detailed field-based studies to understand habitat usage are becoming increasingly uncommon.

In this dissertation, I employed detailed field-based data collection methodology and satellite imagery to answer the following questions: 1) Do birds select a habitat based on vegetational structure or floral composition? 2) Is there any association between plant species and birds? 3) What is the structural preference of a bird? 4)How has LULC changed over 5 years owing to drought?

In **Chapter 1**, I characterized the habitat usage of shrubland bird community during dry season in Eastern Ghats of India. To do so, I collected vegetational structure data and floristic compositional data for 15 sympatric shrubland birds. The species selected were most common species in the habitat so that they can act as a representative species for the habitat. Birds were from various feeding guilds, families. Vegetation structure data was analyzed using multivariate analysis. Whereas, floristic composition analysis was conducted using association tests. My results show species had higher affinity for selecting habitat based on vegetational structure than floristic composition. It is understandable as during dry season the available resources were very limited owing to plants being leafless, fruitless.

In **Chapter 2**, I characterized the habitat usage by shrubland bird community during dry season in Eastern Ghats of India. To do so, I collected vegetational structure data and floristic compositional data for 15 sympatric shrubland birds. The species selected were most common species in the habitat so that they can act as a representative species for the habitat. Birds were from various feeding guilds, families. Vegetation structure data was analyzed using multivariate analysis. Whereas, floristic composition analysis was conducted using association tests. My results show species had higher affinity for selecting habitat based on floristic composition as compared to vegetational structure. It is understandable as post monsoon season many plant species start flowering, attracting various arthropods that act as food source for many insectivores' birds. These shrubs also start fruiting thereby attracting frugivorous birds.

In **Chapter 3**, I identified the Land Use and Land Cover (LULC) change patterns. To do so, I had used Landsat imagery from 2011 and 2016. Only the color bands present in both the Satellite imagery were selected. The Landsat images were subjected to supervised classification and then compared using neural network. My results show a 90% decline in waterbodies that has an effect on shrub forest cover and agricultural lands. There was rise in agricultural lands and abandoned agricultural lands. These LULC patterns are very important in identifying the effect on existing suitable habitat for birds but also in predicting future changes in habitat structure given the current trend in LULC continues.

In **Chapter 4**, I quantified various effects of anthropogenic presence on shrub forest habitat. To do so, I had conducted semi-structured surveys with the indigenous people to elicit information regarding agricultural land usage, goats, sheep, cattle and dependence on forest products. My results show that the community was highly aware of their impact on the forests. The use of forest products did not change in past decade. However, the plant species they used to collect firewood was the same species that many birds preferred. The goat browsing pattern was in direct conflict with the preferred habitat structure with birds. The browsing height of goats was similar to preferred height by birds. Species composition and structural configuration was affected by grazing and browsing. Foraging did not have an effect on species richness.

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APPENDIX

UNIVERSITY OF ARKANSAS

Office of Research Compliance
Institutional Review Board

August 24, 2016

MEMORANDUM

TO:	Anant Deshwal Douglas Adam James
FROM:	Ro Windwalker IRB Coordinator
RE:	New Protocol Approval
IRB Protocol #:	16-08-042
Protocol Title:	*Ecology and Conservation of Bird Communities of the Thorny Hill Scrub Habitat in Peninsular India*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Approved Project Period:	Start Date: 08/24/2016 Expiration Date: 08/23/2017

Your protocol has been approved by the IRB. Protocols are approved for a maximum period of one year. If you wish to continue the project past the approved project period (see above), you must submit a request, using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. This form is available from the IRB Coordinator or on the Research Compliance website (https://vpred.uark.edu/units/rscp/index.php). As a courtesy, you will be sent a reminder two months in advance of that date. However, failure to receive a reminder does not negate your obligation to make the request in sufficient time for review and approval. Federal regulations prohibit retroactive approval of continuation. Failure to receive approval to continue the project prior to the expiration date will result in Termination of the protocol approval. The IRB Coordinator can give you guidance on submission times.

This protocol has been approved for 1,000 participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 109 MLKG Building, 5-2208, or irb@uark.edu.

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