



**EFFECT OF GRAZING ON THE COMMUNITY
STRUCTURE AND FUNCTIONAL DIVERSITY OF
GRAZING LAWNS IN SATHYAMANGALAM TIGER
RESERVE**

Submitted by

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For the award of the Degree of
Master's Degree in Wildlife Science

Under the supervision of

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July, 2021



**भारतीय वन्यजीव संस्थान
Wildlife Institute of India**

EFFECT OF GRAZING ON
THE COMMUNITY
STRUCTURE AND
FUNCTIONAL DIVERSITY
OF GRAZING LAWNS IN
SATHYAMANGALAM
TIGER RESERVE

Aarooha Malagi

DECLARATION

I, **Aarooha Malagi**, hereby declare that the research work titled “**Effect of grazing on the community structure and functional diversity of grazing lawns in Sathyamangalam Tiger Reserve**”, carried out in partial fulfilment of M.Sc. (Wildlife Science) degree of Saurashtra University, Rajkot is an original piece of research work. This research work was carried out under the supervision of **Dr. B.S Adhikari**, at the Wildlife Institute of India from January 2021 to June 2021. I hereby declare that this work has not been submitted for any other degree of any university.

Date: June 16, 2021

Place: Dehra Dun

Mr. Aarooha Malagi
(XVII M.Sc. Course)

CERTIFICATE

This is to certify that **Mr. Aarooha Malagi** has carried out an original piece of research in partial fulfilment of Master's Degree in Wildlife Science of the Saurashtra University, Rajkot, Gujarat. The topic of his dissertation is **"Effect of grazing on the community structure and functional diversity of grazing lawns in Sathyamangalam Tiger Reserve"**. The study was carried out under our supervision from January 2021 to June 2021. We hereby certify that this work has not been submitted for any degree to any university.

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Co- Supervisor

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Place: Dehradun

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Summary

Understanding the effects of grazing (by both livestock and wild ungulates) on grasslands is paramount to come up with more robust managerial actions to conserve, and increase the ecosystem function of these valuable ecosystems. In the current study, we investigate the effects of grazing on a highly productive, mesic grassland ecosystem, viz. grazing lawn in Sathyamangalam Tiger Reserve, Tamil Nadu, India. We examined how species richness and composition of a grassland patch change across a grazing gradient by carrying out plot-based vegetation sampling in the grazing lawns of Sathyamangalam Tiger Reserve. We also looked at how trait composition and functional diversity changed across the grazing gradient, to better understand the plant functional response and resilience of the grazing lawn complex. We used a Linear Mixed Effect Model (LMM) to investigate the impact of grazing intensity on species richness, and a Non-metric Multidimensional Scaling (NMDS) to look at the differences in species composition between different grazing treatments. Functional composition and diversity were measured using Lavorel and Vileger's index in the 'FD' package of R (4.0.2). We found that grazing lawns were minimally affected by grazing intensity in terms of species richness and trait composition, but showed a significant change in species composition and functional diversity across the grazing gradient.

Keywords: functional trait, grassland conservation, grazing, grazing lawn, tolerance, trait composition

Introduction

Grassland and savannah cover around 25% of the world's terrestrial area (Ramankutty & Foley, 1999); and close to 17% of India's landmass. The Indian sub-continent holds some of the earliest fossil evidence of Poaceae, indicating a long history of the presence of grassland ecosystems (Prasad et al., 2005) in the landscape. It has been posited that most of these habitats have formed as a result of feedback loops between atmospheric CO₂, climate, fire, and grazing (Beerling & Osborne, 2006). The expansion of grassland and savannah ecosystems over the past 8 million years (Miocene) led to an increase in large-bodied grazers that primarily fed on grasses. Over time, these grazers have formed a unique co-evolutionary relationship with these ecosystems, which has subsequently created strong feedback loops between grazers and C4 grasses (Strömberg, 2011). As a result, grazing has emerged as one of the most influential disturbance regimes that shapes plant communities of most grassland and savannah ecosystems (McNaughton, 1983); it acts as a driving force for establishing spatial heterogeneity in an ecosystem by causing shifts in vegetation structure and by aiding in nutrient cycling (P. Adler et al., 2001). Grassland and savannah ecosystems are also in great flux due to anthropogenic

disturbances like land-use change (like agriculture, grazing pasture etc), and climate change (increase in atmospheric CO₂). Since, grazing plays a critical role in shaping the structure and function of grasslands and savannahs, it is important to delineate the effects of grazing on the plant responses of grassland ecosystems (Koerner & Collins, 2014).

Grazing lawns are grassland communities that are strongly influenced by grazing, and are an ideal site to study the effects of different grazing regimes. Grazing lawns are short-statured grasslands that can withstand and support heavy grazing pressure (Cingolani, Posse, et al., 2005; McNaughton, 1984). They are found in a plethora of ecosystems and biomes around the world, and hold high scientific and ecological value. Grazing lawns are a subset of tropical savannah and grassland ecosystems, and they tend to occur in precipitation zones ranging from 400-850mm (Hempson et al., 2015). Lawns generally consist of abundant C₄ grasses which form a mat-like surface, with a sparse distribution of C₃ trees and shrubs.

Grazing lawns were first described by McNaughton in 1984, and since then, they have garnered a lot of scientific attention. The establishment of these communities is still wrought in speculation. However, ecologists have found that the maintenance of such lawns is mediated by both top-down (herbivory and fire) and bottom-up (soil nutrients, precipitation etc) controls (Veldhuis et al., 2014). The proportion of influence of top-down control or bottom-up control in maintaining grazing lawns is contingent on local and regional environmental variability. Thus, a thorough investigation of local abiotic and biotic regimes affecting the interaction milieu between grasses, shrubs, and trees is

necessary to come up with robust predictions about the establishment and persistence of grazing lawns. This will further help us determine if the presence and extent of grazing lawns can be manipulated using management practices (Hempson et al., 2015). Therefore, our study aims to investigate the effect of grazing on the community structure and functional trait composition in a *Chrysopogon* dominated grazing lawn in the Sathyamangalam Tiger Reserve, Tamil Nadu.

Grazing has a significant effect on grassland community structure. It is known to influence species richness, diversity, and composition of grassland communities through biomass uptake and nutrient cycling (Altesor et al., 2005). The extent of influence however depends on the grazing intensity, frequency, and the type of grazer involved (Grime, 1973; Madhusudan, 2004; Lunt, 2007). Since, grazing is a localised phenomenon, its effects are heavily contingent on environmental factors and local grazing history of the grassland patch (Milchunas et al., 1988). Studies from around the globe seem to indicate that grazing has a higher impact on mesic grasslands than arid grasslands. This is attributed to higher biomass levels in mesic grasslands, the accumulation of which leads to decreased species diversity and an increased invasion of shrub and tree species. Thus, grazing will help mediate such deleterious effects by decreasing biomass accumulation (Hayes & Holl, 2003). Arid grasslands on the other hand seem to be minimally affected by grazing because they have special exaptations that confer grazing resistant traits to the plant (P. B. Adler et al., 2004; Díaz et al., 2007). In mesic grasslands, an intermediate level of grazing intensity seems to promote the highest level of species richness and diversity, which conforms to the intermediate-disturbance hypothesis (Milchunas et al.,

1988; Pulungan et al., 2019). Whereas, very high intensities of grazing will lead to the dominance of grazing tolerant species, that are more palatable, and lead to exclusion of species that are susceptible to grazing. Similarly, low grazing conditions will lead to the accumulation of bunch and tall grasses that shade out poor light competitors (Milchunas & Lauenroth, 1993). Grazing history also plays a major role in how communities respond to a change in grazing intensity; wherein communities that have a long history of grazing are minimally affected by an increase in grazing intensity, and communities with short grazing histories are more severely affected by an increase in grazing intensity (Díaz et al., 2007). Thus, aridity and grazing history are thought to be the most important factors mediating the effects of grazing. Currently, there isn't a general framework to predict under what circumstances (and in what habitats), grazing has a positive, negative, neutral, or uncertain effect on plant communities (Lunt, 2007). Hence, the current study aims to investigate the effects of grazing in an Indian tropical grazing lawn complex.

To come up with more generalised predictions of plant responses to herbivory, ecologists are growingly employing a functional trait (PFT) approach (McIntyre et al., 1999; Pakeman, 2004; Schellberg & Pontes, 2012) to look at plant responses to different grazing regimes. Plant functional traits are plant characters that respond to dominant ecosystem processes (Gitay & Noble, 1997). PFTs are particularly useful because they can be compared across communities, biogeographic regions, abiotic gradients etc., and are considered to be more objective predictors of ecosystem dynamics (McGill et al., 2006). PFTs act as a mechanistic link between the environment, the plant, and their ecosystem properties because they're very labile to the abiotic and biotic pressures around

them (Díaz et al., 1999). Thus, a plant functional trait approach will yield greater generality and help us predict plant responses to grazing in a much broader scope.

There have been numerous studies around the globe and in the Indian sub-continent that have looked at the effects of grazing on plant functional traits (P. B. Adler et al., 2004; Chaturvedi et al., 2011; Díaz et al., 2001; Dubey et al., 2011; Peco et al., 2005). The traits that respond well to grazing are plant height, life history, SLA, vegetative structure, seed mass, growth form, and leaf mass (McIntyre et al., 1999). Plant height is one of the best predictors for grazing effects, wherein an increase in grazing pressure will lead to a reduction in plant height. Life history exhibits a strong response to grazing, with annuals increasing and perennials decreasing, with an increase in grazing pressure. Grazing also has a marked effect on vegetative structure, with prostrate species being favoured over erect species with an increase in grazing pressure. Grasses and forbs have varying responses to grazing; grasses tend to show more frequent negative responses to an increase in grazing pressure, whereas forbs generally tend to have a neutral effect (Díaz et al., 2007). There have also been instances where grasses and sedges have been taken over by unpalatable forbs under heavy grazing conditions (Zhang et al., 2018). In addition to quantifying trait composition across different grazing treatments, some ecologists are suggesting a new approach called Functional Diversity (FD) to gauge the functional responses of communities to different disturbance regimes. Functional diversity of a community is defined as the distribution of species and their abundances in a trait space. A trait (or functional) space is a multi-dimensional Euclidean based space where the axes are ecologically relevant traits. FD is a novel approach in trait-based studies, using which

ecologists can quantify the resilience and ecosystem function of a community by visualising how the trait space is being utilised (Mouillot et al., 2013). Thus, FD will enable us to understand the functional responses of communities better, which will help conservationists and managers to come up with better conservation strategies at a community level.

Various studies in the Indian subcontinent have looked at the effects of grazing on the vegetation structure and function of savannah/grassland ecosystems (Adhikari & Rawat, 2006; Bagchi et al., 2012; Pandey & Singh, 1991; Sankaran, 2005). Like most terrestrial ecosystems, grazing lawn dynamics are also strongly influenced by livestock and wild ungulate grazing. Grazing lawns have a long co-evolutionary history with large mammalian grazers, as observed in the African plains; where the frequent and intensive grazing of large mammalian herbivores in a grassland patch will lead to the activation of tillers in grass species and aid in the maintenance of lawns (Hempson et al., 2015). Cattle have also been found to create and maintain grazing lawns in grasslands around the world (Vaieretti et al., 2010). In India however, there is a lack of research on grazing lawns and their response to grazing; hence, we do not have adequate information to gauge the intensity and frequency of livestock and wild ungulate grazing required to maintain such grazing lawn complexes. Such knowledge is paramount to come up with better management practises to conserve and maintain this highly productive grassland community.

To bridge some of the aforementioned gaps, our study tries to investigate the role of grazing in the grazing lawn complex of Sathyamangalam Tiger Reserve, by assessing the community structure and functional traits of lawns that experience livestock and wild ungulate grazing. We asked the following questions to assess the influence of grazing in the grazing lawn complex:

- 1) What effect does grazing intensity have on plant species richness and species composition in the grazing lawns of Sathyamangalam Tiger Reserve?
- 2) How does plant functional trait composition change along a gradient of grazing intensity?

To our knowledge, this is the first study in the Indian sub-continent that looks at the effect of grazing intensity in a grazing lawn complex.

Materials and methods

Study area

The study was conducted in the grazing lawns of Sathyamangalam Tiger Reserve (STR from hereon) from January to May, 2021. STR spans an area of 1400 km² and covers the Sathyamangalam and Thalavadi taluks of Erode district in Tamil Nadu state. The Sathyamangalam Wildlife Sanctuary was established in 2008 and was subsequently upgraded to a Tiger Reserve by amalgamating adjoining reserve forests in 2013. STR lies between 11°24' N to 11°48' N and 77°27' E to 76°50' E at the junction of two distinct biogeographic regions - Western ghats and Eastern ghats. The Sathyamangalam Tiger Reserve is flanked by Biligiri-rangaswamy Temple Tiger Reserve on the East, Mudumalai Tiger Reserve on the West, and MM Hills Wildlife Sanctuary on the North. Thus, STR acts as a pivotal point in a contiguous protected area network for the movement of elephants and the dispersion of tigers.

The reserve is split into two divisions, namely Sathyamangalam division and Hasanur division. The divisions are separated by the picturesque Dhimbam ghats which peaks at 1000m. The Sathyamangalam division is located in the plains with an average elevation of 240m and lies in the rain shadow region of the Dhimbam hills. As a result, the average precipitation in this division is around 700mm per year; owing to the low rainfall and the flat terrain, the vegetation in this division is dominated by dry thorn forests

and dry deciduous forests. Meanwhile, the Hasanur division is located in the hills at an average elevation of 1200m and hence receives around 833mm of rainfall annually; the vegetation profile here is more varied and consists of dry deciduous forest, moist deciduous forest, semi-evergreen forest, and shola-grassland complexes. Two perennial rivers run in the Sathyamangalam division, Moyar and Bhavani. In addition to this, there are several perennial streams originating in the Dhimbam hills which flow through the Thalamalai, Hasanur, and Germalam ranges of Hasanur division.

The vegetation of the Reserve is characterised by the following types: a) Southern tropical dry thorn forest, b) Southern tropical dry mixed deciduous forest, c) Southern subtropical hill forests, d) Southern tropical semi evergreen forest, e) Riparian Forest, and f) Shola-Grassland complexes.

The common tree species found in the grazing lawns of Sathyamangalam Tiger Reserve are *Aegle marmelos*, *Butea monosperma*, *Mitragyna parviflora*, *Anogeissus latifolia*, *Acacia cathechu*, *Ziziphus jujuba*, *Phyllanthus emblica*, and *Erythroxylon monogynum*. The common grass species found in the grazing lawns are *Chrysopogon sp.*, *Bothriochloa pertusa*, *Ischaemum ciliare*, *Heteropogon contortus*, *Setaria pumila* etc. The reserve also has a thriving population of tiger (*Panthera tigris*), leopard (*Panthera pardus*), dhole (*Cuon alpinis*), Asian elephant (*Elephas maximus*), striped hyena (*Hyaena hyaena*), gaur (*Bos gaurus*), four-horned antelope (*Tetracerus quadricornis*), wild pig (*Sus scrofa*), sambar (*Rusa unicolor*), chital (*Axis axis*), black buck (*Antelope cervicapra*), Indian giant squirrel (*Ratufa indica*), black-naped hare (*Lepus nigricollis*) and several other animals. The valleys in the Dhimbam hills act as an excellent catchment area for

rains and are home to several perennial streams; most grazing lawns are concentrated in the valleys and near such perennial streams. These productive grasslands act as a great food source for wild ungulates like gaur, chital, sambar, and wild pig, who are commonly seen grazing in these places; these lawns are also used by the local cattle as grazing grounds. The grazing lawns are concentrated in Hasanur and Thalavadi ranges, and are found mostly on black soil. In recent years, exotic invasive species like *Senna spectabilis* and *Chromolaena odorata* are encroaching into the grasslands and are threatening their structural integrity. The valleys in Hasanur and Thalavadi range also have a high concentration of *Bambusa bambos* thickets which support a thriving population of Asian elephants. *Bambusa bambos* underwent mass-flowering in the study area and adjacent forest areas of M.M Hills Wildlife Sanctuary, Mudumalai Tiger Reserve, Biligiri-Rangaswamy Tiger Reserve, and the Nilgiri forest division during the study period (January to May).

The climate in Sathyamangalam Tiger Reserve is considered to be moderate, it receives 60% of its rains from the North-East monsoon during September, October, and November, while the rest of monsoon occurs during the months of May-July from the South-West monsoon. The average annual rainfall at STR is 700 mm and average humidity hovers around 95%. The average annual temperature in Hasanur division is around 22.8° C, with summer highs reaching around 28° C and winter lows reaching around 15° C; the temperatures are much higher in the Sathyamangalam division with summer highs reaching up to 40° C, and winter lows reaching to around 20° C.

There are several settlements inside the Tiger Reserve belonging to the Irula (Oorali) and Soliga tribe; these tribes are the indigenous peoples of this landscape and strongly claim their right to the forest. All the settlements have been allotted grazing grounds next to their villages, hence grazing pressure around these villages is high. The map of the study area is given in Figure 1.

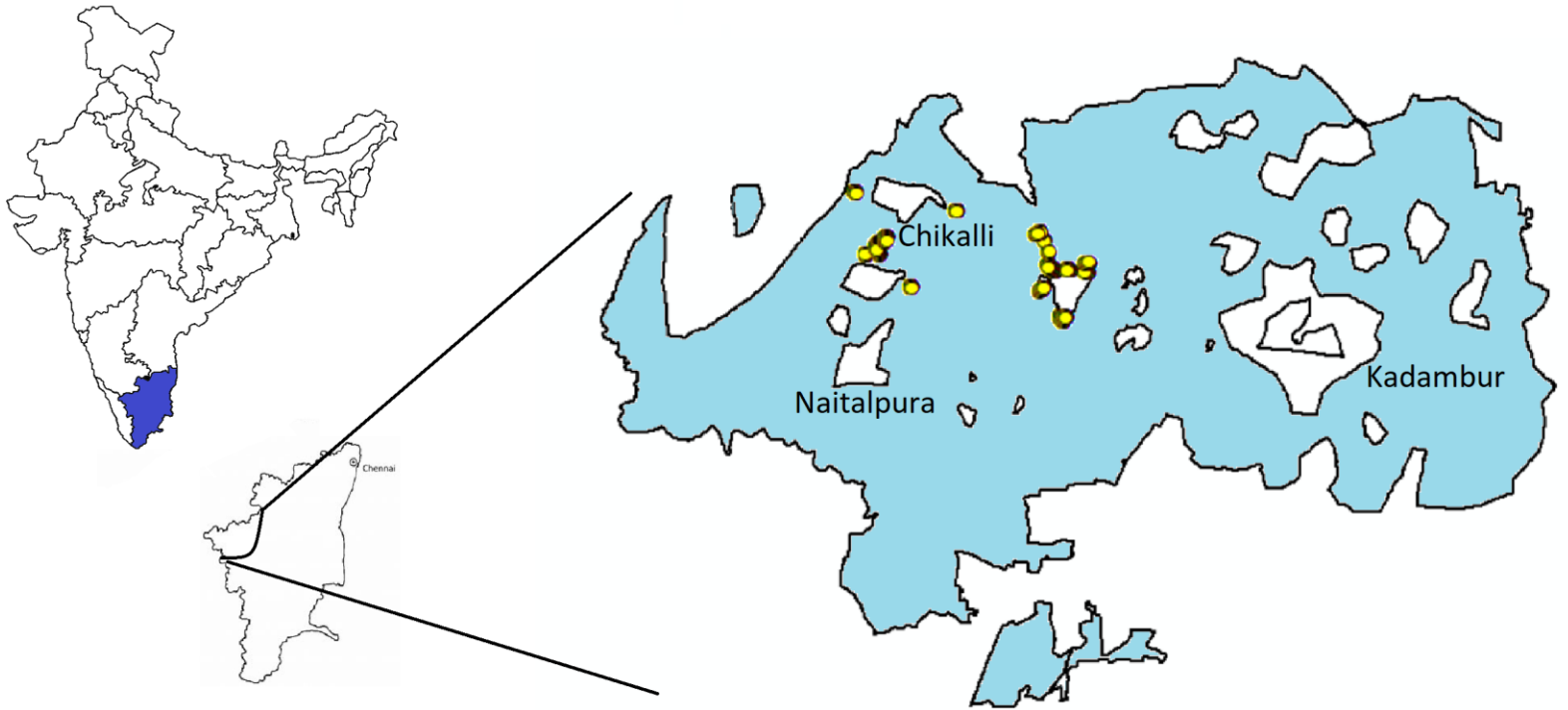


Figure 1: Map outlining Sathyamangalam Tiger Reserve, showing our sampling sites (in yellow).

Sampling design

Vegetation sampling was carried out in the grazing lawns of Sathyamangalam Tiger Reserve to determine the community structure and functional trait response of grasses and forbs along a gradient of grazing intensity.

Selection of sites:

A reconnaissance survey was conducted in January, 2021 to select the appropriate sites for sampling, wherein every grazing lawn in the Hasanur division of Sathyamangalam Tiger Reserve was visited to gauge the viability of sampling. Sites were chosen for sampling if they satisfied the following criteria:

- their size was large enough to establish a plot of 50m × 50m within the perimeter of the site,
- whether or not there was presence of grazing by wild or domestic ungulates in the site.

Thus, a total of 18 sites from two ranges that met the criteria were chosen for sampling.

Once the sites were selected, the area of each site was determined by walking the perimeter of the grassland patch and using ‘Calculate Area’ in the *etrex 30x* GPS

device. The perimeter of all the sites was subsequently plotted on a map of STR using ArcMap 10.8.

A list of all the sampled sites with their attributes is given in Table. 1:

Sl.no	Site	Area (Hectares)	Elevation (m)	Distance to settlement (m)	No. of plots
1	Dodda karai	5.02	966	850	2
2	Gokara karai	2.63	945	154	1
3	Danad karai	1.24	815	213	1
4	Periya karai	10.8	906	504	1
5	Kal karai	1.24	927	464	1
6	Padara karai	12.22	909	374	3
7	Pili karai	0.9	898	2412	1
8	Aspatre 1	1.77	893	2963	1
9	Alad karai	0.59	903	1536	1
10	Mari karai	2.73	885	644	1
11	Aspatre 2	1.42	897	3040	2
12	Ooru karai	3.79	798	745	1
13	Bidaru karai	2.02	870	931	1
14	Gandad karai	20.31	846	1126	3
15	Vaddan karai	3.4	898	1115	1
16	Kumbesh karai	1.62	895	1050	1
17	Ilgalmadu	3.25	824	971	1
18	Amala karai	8.64	863	1507	2

Table 1: Table with our sampling sites and their attributes.

Sampling for community structure

- Vegetation sampling of grasses and forbs was carried out in the months of February, March, and April.
- A plot of (50×50) m² was established inside the chosen sites using ropes to demarcate the boundary; the number of plots to be established was decided based on the total area of the patch.
- Within the (50×50) m², 12 sub-plots of (1×1) m² were established using a stratified random sampling approach based on the heterogeneity and micro-climatic variation inside our plots to record the species diversity of grasses and forbs.
- All the grass and forbs species inside the (1×1) m² sub-plot was recorded along with their abundance on a data-sheet.

Collecting functional trait data

The functional traits, plant height and canopy structure, were collected from the $50\text{m} \times 50\text{m}$ plots in each site. Each trait was collected from 10 individuals of a species in each plot. Plant height was recorded in centimetres using a 5m tape. Canopy structure was recorded as a categorical variable (prostrate, erect, stoloniferous, rhizomatic, or caespitose) in the data-sheet. Two other variables, life history and functional group were obtained from secondary literature.

Quantifying the intensity of grazing

The grazing intensity of each site was quantified using two continuous variables:

- Ungulate biomass/km²

A dung count of all ungulates (domestic and wild) was conducted in each plot (50m × 50m). The dung count was done systematically by placing five transect lines 10m apart (pictured in Figure 2), and recording the dung count of cattle, chital, sambar, gaur, elephant, and wild pig encountered along the transect line. Since, there is some difficulty in differentiating the pellets of young sambar and an adult chital, we decided to exclude ambiguous pellet groups; similarly, the dung of young gaur and adult cattle were excluded if they were found to be ambiguous.

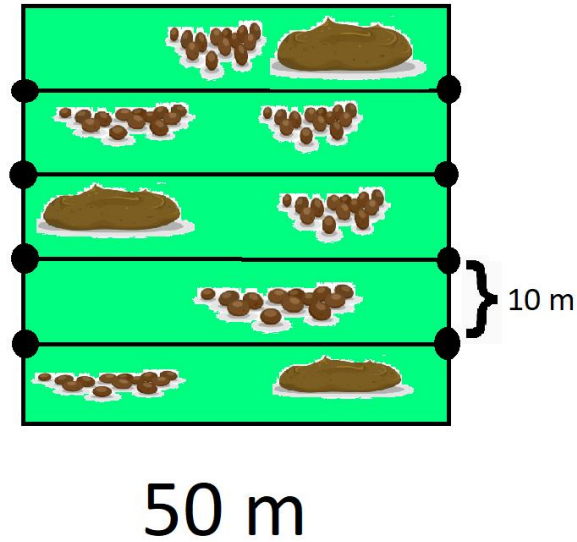


Figure 2: A representation of the line transect design for dung count

The ungulate density D (km^{-2}) was calculated using the formula given by (Pfeffer et al., 2018):

$$D = \frac{n}{a * t * d}$$

Where, n = total number of pellets/dung, a = amount of sampled area (km^2), t = accumulation period of dung (days), and d = defecation rate of each species (per day). We gathered d and t values from Ahrestani et al. (2018), who have ascertained the values in Nagarahole Tiger Reserve. The ungulate density/ km^2 was subsequently converted to biomass/ km^2 by multiplying the density of species by its mass given by Karanth & Sunquist (1992).

- Distance from settlement

The distance from the nearest settlement to the site was obtained by uploading the shapefiles of all sampling sites in ArcMap 10.8, and using the Near Analysis tool to ascertain the geographic distance between the site and the settlement.

Data analysis

All statistical analyses were performed in R version 4.0.2.

A Linear Mixed Model (LMM) was used to investigate the effects of ungulate biomass/km², distance to the settlement (m), and elevation (m) on the species richness at a sub-plot level. The predictor variables (ungulate biomass, distance, and elevation) were standardised before running the LMM to bring them to the same scale. We looked at the combined (additive) effects of all predictor variables put together, followed by looking at an intercept-only model. The predictor variables were used as fixed effects, and the Plot ID was used as a random effect. LMMs were used because the community dataset is hierarchical (nested), and showed plot-wise clustering, since all the sub-plots inside the plots were sampled in the same space and within the same time period. We used the `lmer()` function from 'lme4' package in R to run the LMM. All assumptions for LMM were verified.

An ordination was done to look at the compositional dissimilarity between plots. We performed a Non-metric Multi-Dimensional Scaling (NMDS) to cluster plots according to their relative compositional similarities. We used Bray-Curtis' distance measure to perform the ordination, with 500 random starts, and 3 dimensions (axes). We then plotted a shepherd diagram of the NMDS results to check if the stress levels were acceptable. The scores of the NMDS were used to plot the sites in the ordination space, and the sites were assigned shapes based on their grazing pressure. The grazing pressure

was ranked as 1 (low grazing), 2 (medium grazing) and 3 (high grazing), and was assigned to the plots *a-priori* by using qualitative metrics that were recorded visually on-field. We used the metaMDS() function from the ‘vegan’ package in R to perform the NMDS.

The functional trait composition of Life history, Canopy structure, and Family for all sites was calculated to check if trait frequency changed across the grazing gradient.

The functional richness and evenness of all sites were calculated to understand the functional diversity of the sites across the grazing gradient.

Functional richness: a measure of the trait (niche) space occupied by the species present.

Functional evenness: measures whether means of species traits are regularly distributed within the occupied trait space.

The Gower distance of our trait dataset was calculated and used to determine the functional diversity of our sites using dbFD() function from the R package “FD”. The function is based on indices developed by Villéger et al., (2008).

Results

The species richness of the 25 plots and 300 sub-plots put together was 63 species, out of which 20 species were grass, 35 species were forbs, 5 species were trees, and 3 species were shrub. Of the 63 species, 42 of them have been identified up to species level, 12 species have been identified up to genus level, and 9 species were unidentified, so they were excluded from trait-related analyses. Poaceae was the most abundant family, followed by Fabaceae, Cyperaceae, Acanthaceae, and Phyllanthaceae. The asymptote of the species rarefaction curve for most plots was reached, (Figure 3) indicating that our sampling effort was adequate. The five most abundant species in the sampling area were *Chrysopogon sp.* (44.7%), *Fimbristylis dichotoma* (21%), *Ischaemum ciliare* (7.4%), *Desmodium triflorum* (6.8%), and *Phyllanthus virgatus* (2.1%); together these species made up over 80% of all individuals in the sampling area. A rank abundance curve of species in the study is shown in Figure 4.

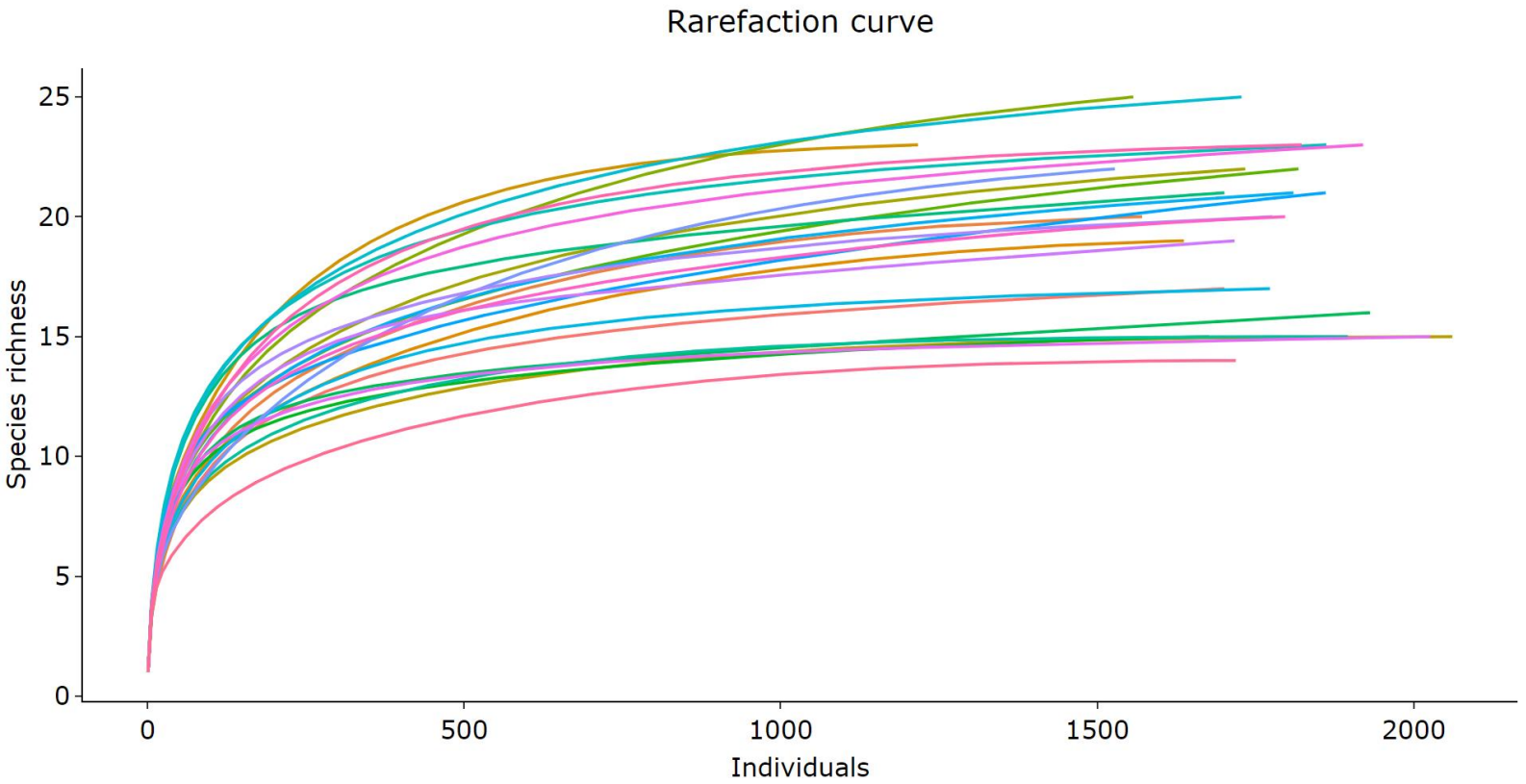


Figure 3: Graph showing the rarefaction curves of the 25 plots, where x-axis are individuals, and y-axis is species richness, and each line represents a site.

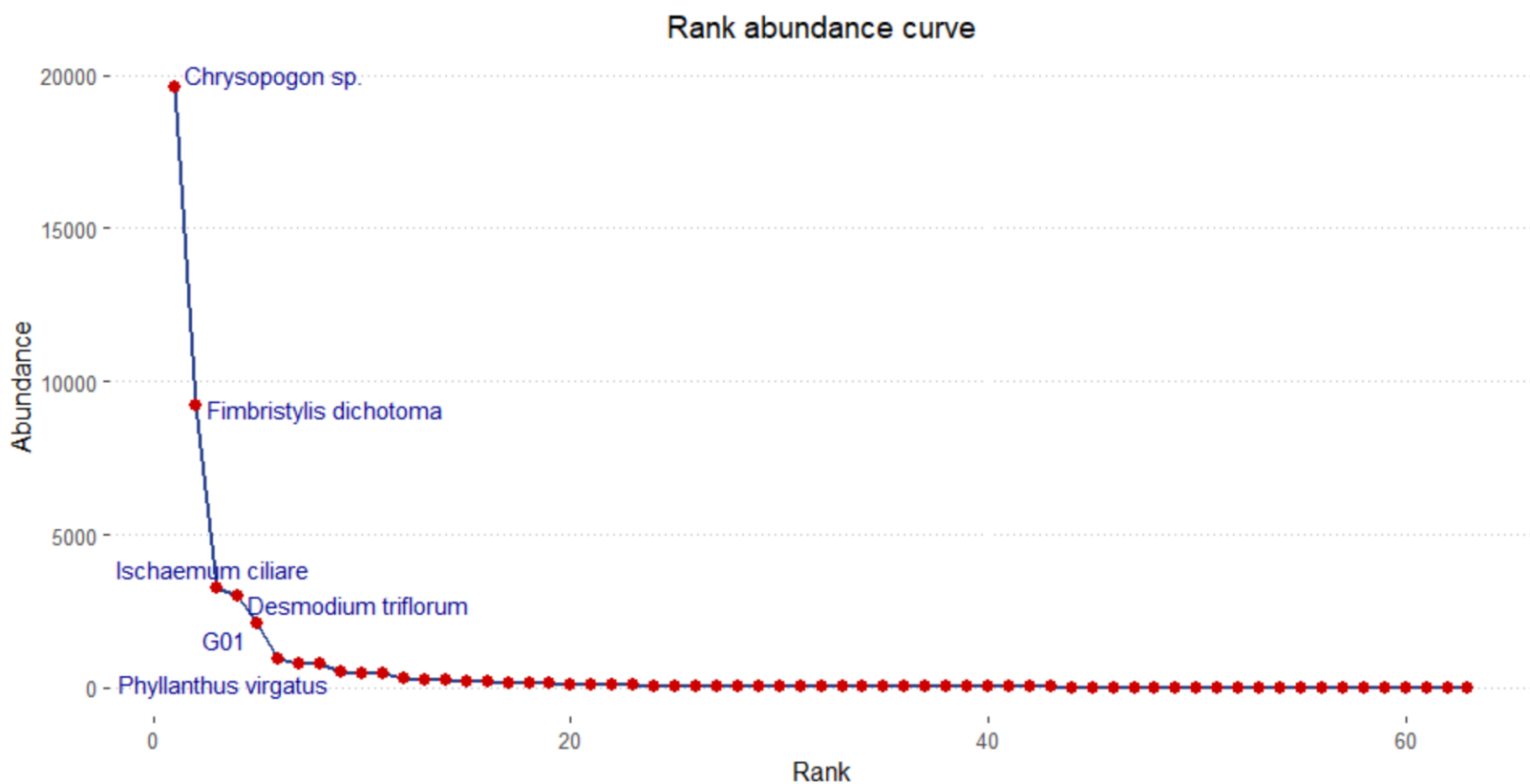


Figure 4: Graph depicting the rank-abundance curves of the species in the sampling area, with x-axis indicating rank of the species, and y-axis depicting their respective abundances. The most abundant species in our study area are: 1) Chrysopogon sp., 2) Fimbristylis dichotoma, 3) Ischaemum ciliare, 4) Desmodium triflorum, 5) G01, and 6) Phyllanthus virgatus.

Linear mixed model

Two models were run to look at the linear relationship of the response variable (sub-plot species richness) with our predictor variables (ungulate biomass, distance, and elevation).

- 1) The universal model which contains all predictor variables:

**Sub-plot spp. Richness ~ Distance + Ungulate biomass + Elevation
standardised + (1|Site)**

<i>Predictors</i>	Effects of grazing on Sub-plot richness		
	<i>Estimates</i>	<i>CI</i>	<i>p</i>
(Intercept)	7.96	7.60 – 8.31	<0.001
Distance	0.10	-0.27 – 0.46	0.598
Ungulate biomass	0.46	0.06 – 0.85	0.022
Elevation	-0.39	-0.78 – 0.00	0.051
Random Effects			
σ^2	2.67		
τ_{00} Site	0.59		
ICC	0.18		
N_{Site}	25		
Observations	300		
Marginal R^2 / Conditional R^2	0.068 / 0.236		

Table 2: Results of our universal model

2) The intercept only model:

$$\text{Sub-plot spp. Richness} \sim 1 + (1|\text{Site})$$

<i>Predictors</i>	Effects of grazing on Sub-plot richness		
	<i>Estimates</i>	<i>CI</i>	<i>p</i>
(Intercept)	7.96	7.57 – 8.34	<0.001
Random Effects			
σ^2	2.67		
$\tau_{00 \text{ Site}}$	0.73		
ICC	0.22		
N_{Site}	25		
Observations	300		
Marginal R^2 / Conditional R^2	0.000 / 0.216		

Table 3: Results of our intercept-only model

We see from Table 2, that ungulate biomass has a significant positive effect (**Confident Interval (CI): 0.06-0.85; p-value = 0.022**) on sub-plot species richness with a slope estimate of 0.46. Since, the CI's are wide, we cannot conclude the strength of the relationship between ungulate biomass and sub-plot richness, but there appears to be a considerable effect of ungulate biomass on sub-plot richness. Elevation seems to have a non-significant effect (**CI: -0.78-0.00; p-value = 0.051**) on sub-plot species richness with a slope estimate of -0.39. Distance from settlement has a non-significant effect (**CI: -0.27-**

0.46; p-value = 0.598) on sub-plot species richness with a slope estimate of 0.10. The universal model has a marginal R^2 (the co-efficient of variation of the fixed-effects only) value of 0.068, and a conditional R^2 (the co-efficient of variation of our fixed and random effects put together) value of 0.236, therefore the universal model explains a 6.8% variation in sub-plot richness by our fixed-effect and 23.6% of the variation in sub-plot richness by random effects and fixed effects put together. Therefore, the fixed effects (predictor variables) have a weak relationship with sub-plot richness, and our random effect (site) explains most of the variation in sub-plot species richness.

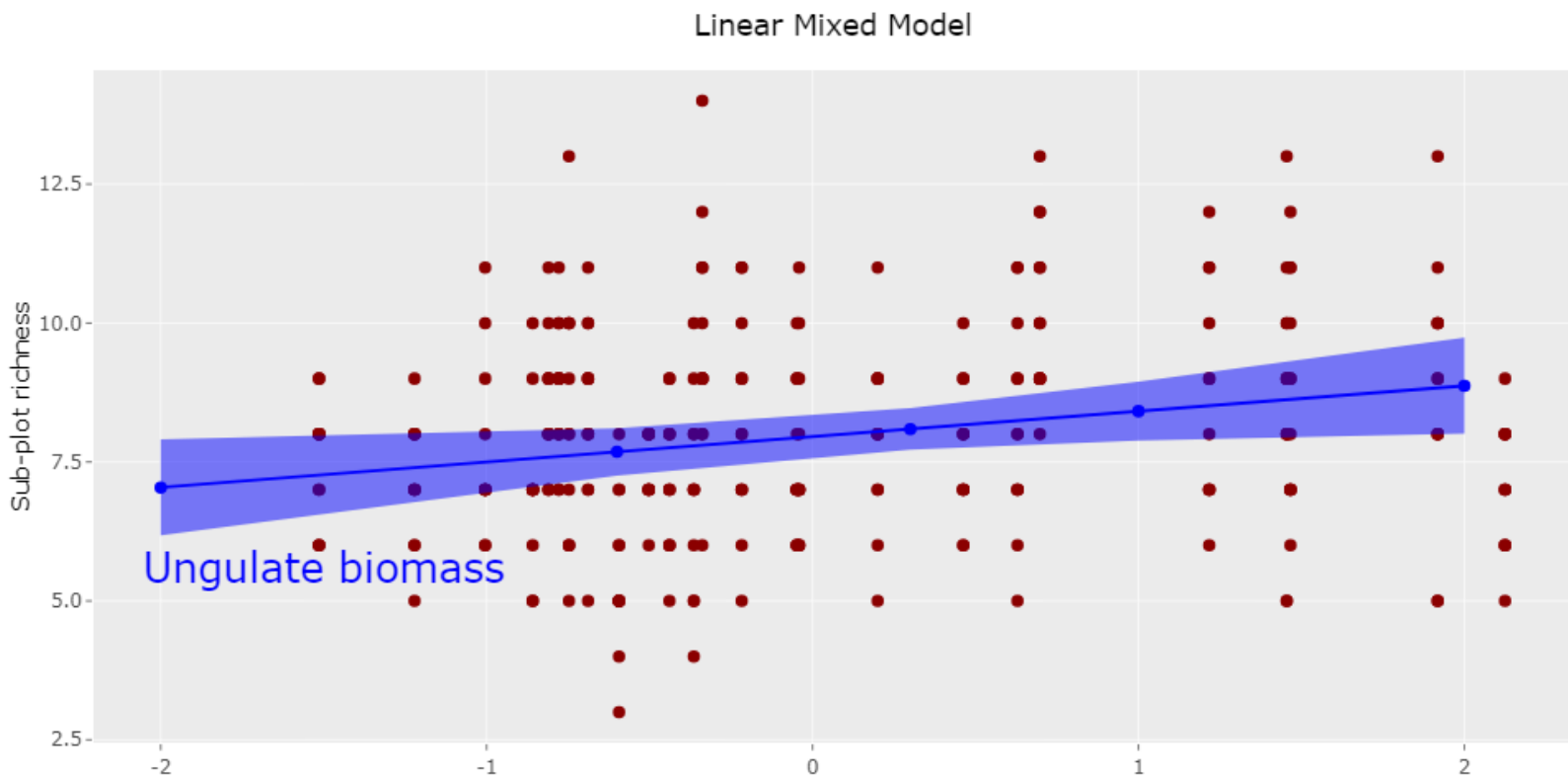


Figure 5: A plot showing the LMM with the slope of ungulate biomass; the points represent the distribution of sub-plot richness

Non-metric multi-dimensional scaling (NMDS)

Two convergent solutions were reached after 20 tries. The stress value of the NMDS is 0.118 (0.12). This indicates that the ordination is a fair fit to our data. The NMDS scores for our community dataset have been plotted below (Figure 6).

Community composition

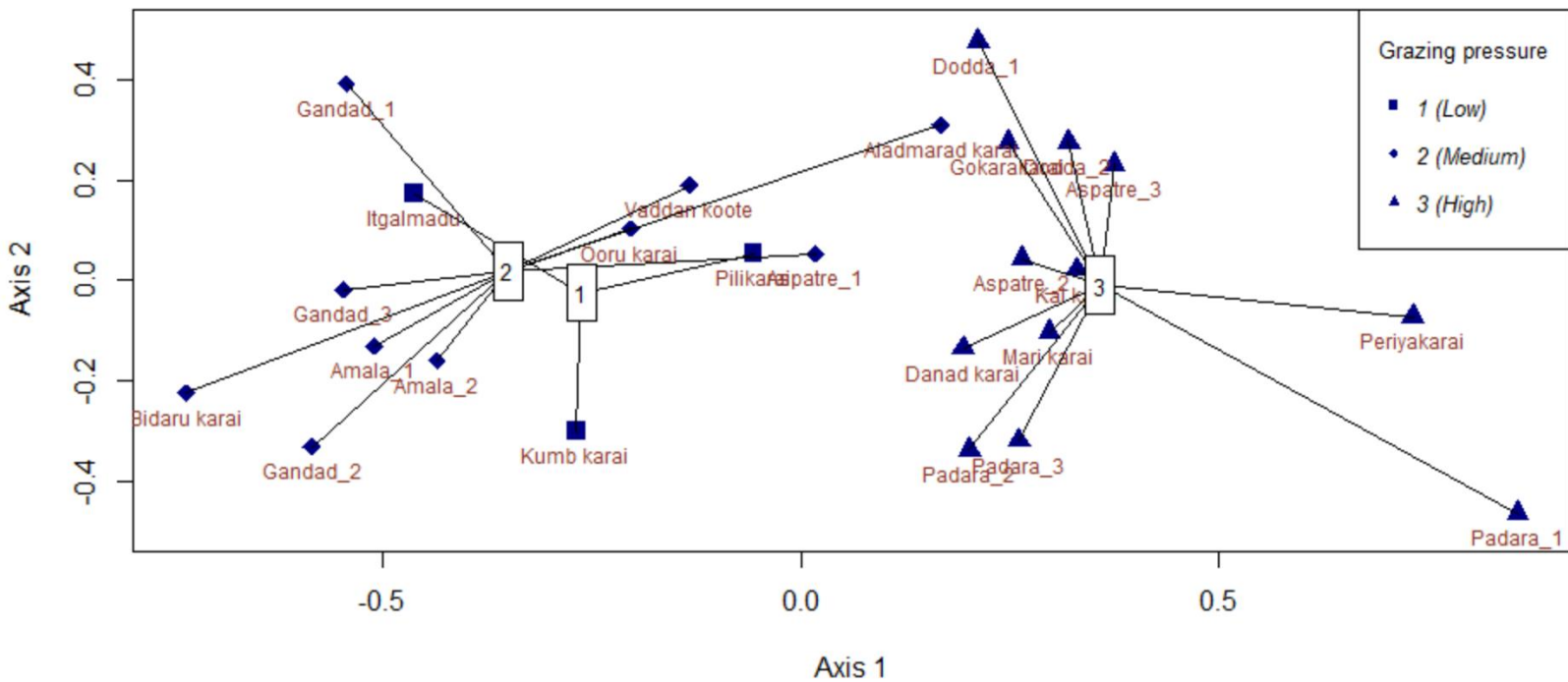


Figure 6: Plot showing the points in the ordination space. The point shapes correspond to the grazing pressure of the plot given by the cluster label (1, 2 & 3).

From the ordination plot in Figure 6, we can observe that there is a noticeable compositional difference between the cluster 3 and 2. The exception is plot Aladmarad

which is part of cluster 2, but it is closer to the plots of cluster 3. The compositional difference between the sites on either extreme of the plot is high. For instance, the distance between Periyakarai (3) and Bidaru (2) is large. However, there is considerable compositional overlap between clusters 1 and 2. Therefore, we can conclude that grazing pressure does have an effect on species composition, however, differences in composition is noticeable only when grazing pressure is very high. Geographic distance between plots also contributes to compositional similarity between plots, since plots that are geographically closer to each other, have similar species composition.

Trait composition of plots

Trait composition will give us the proportion of each of the categorical functional trait in our plots. The functional composition of canopy structure, life history, and family are represented in the figures below.

Figure 7 represents the trait composition of canopy structure in our plots. The x-axis are plots arranged in the increasing order of their ungulate biomass, and the y-axis is the proportion of traits ('erect' and 'prostate') of the plot. From the graph, we can infer that 'erect' is the more dominant trait in most plots. Only 3 plots, Itgalmadu, Bidaru, and Gokara, have more prostate species. We further tested the linear relationship between the canopy structure and ungulate biomass/km², and found that ungulate biomass/km² did not have a relationship with 'erect' (**p-value = 0.28**) or 'prostate' (**p-value = 0.10**) traits. This indicates that grazing intensity has no significant effect on canopy structure in the current study area.

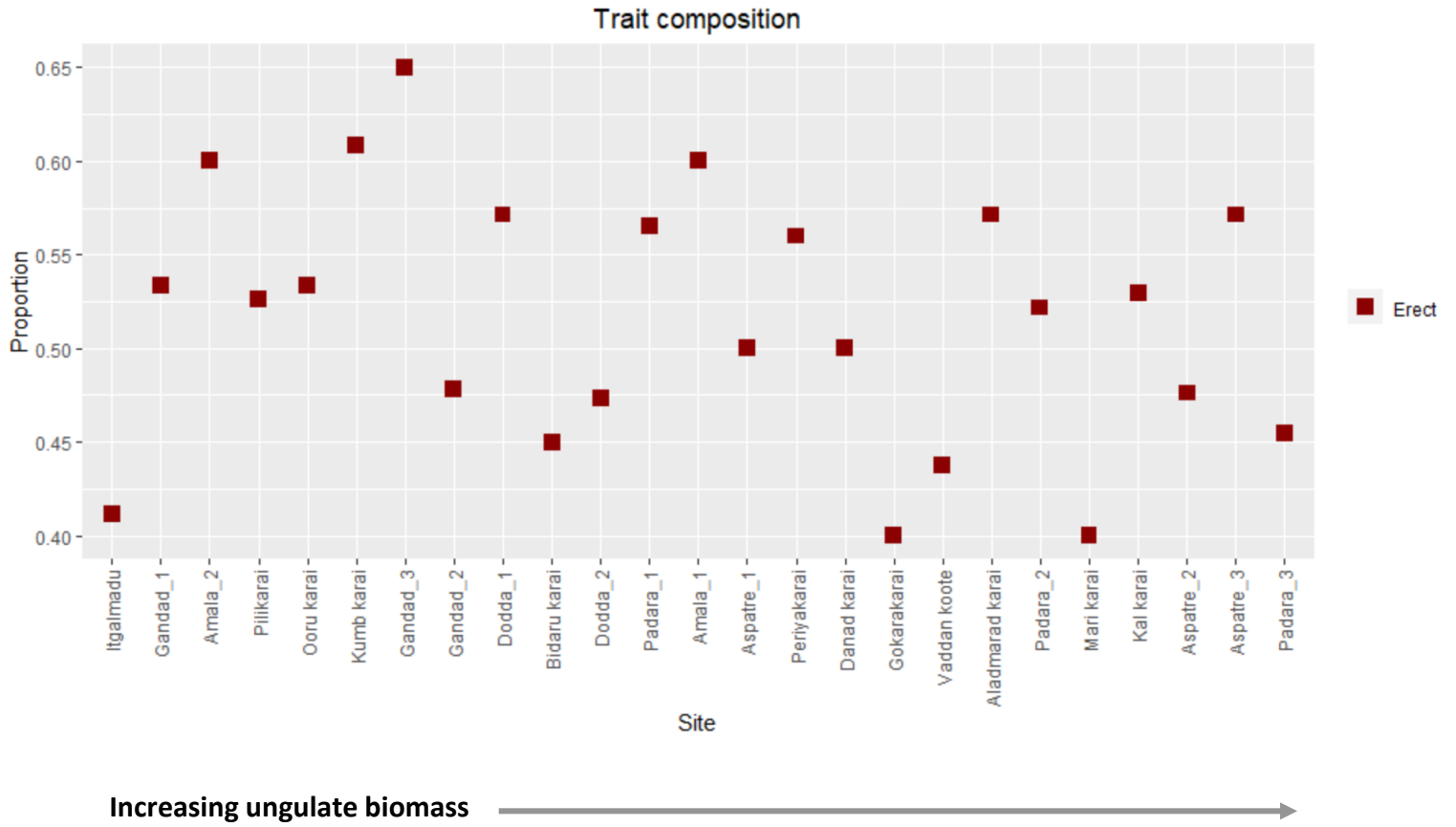


Figure 7: Plots arranged in the increasing order of ungulate biomass (x-axis), plotted against the proportion of ‘erect’ (y-axis).

Figure 8 represents the trait composition of life history across all of our plots. The x-axis represents the plots arranged in increasing order of their ungulate biomass, and the y-axis represents the proportion of traits ('annual' and 'perennial') of the plot. From the graph, we can conclude that 'perennial' is the most dominant trait across all sites, with the exception of Padara1 plot. Further, we looked at the linear relationship between ungulate biomass/km² and life history, and found that ungulate biomass/km² did not have a relationship with 'annual' (**p-value = 0.07**) or 'perennial' (**p-value = 0.44**) traits. This indicates that grazing intensity has no significant effect on life history in the current study area.

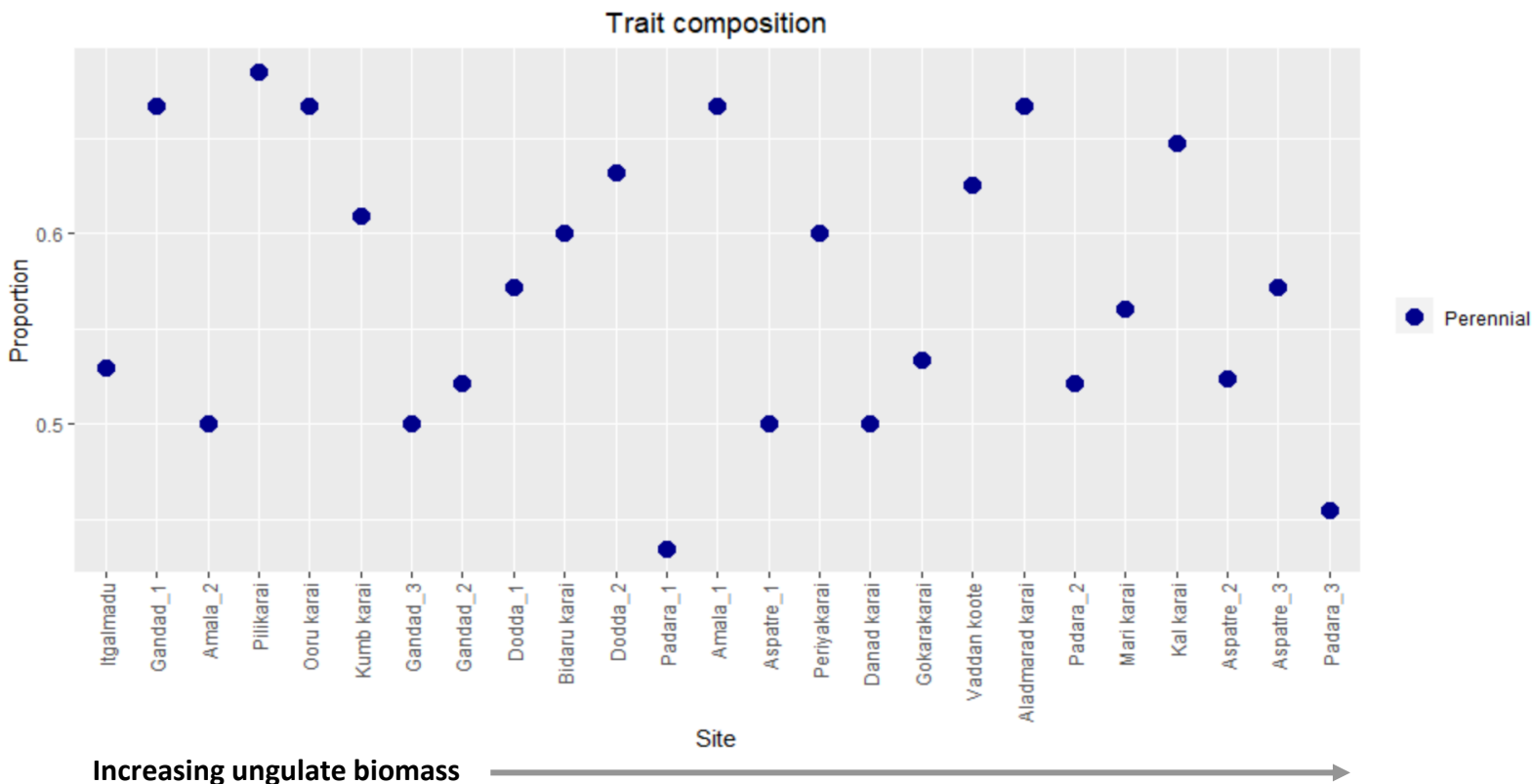


Figure 8: Plots arranged in the increasing order of ungulate biomass (x-axis), plotted against the proportion of 'perennial' (y-axis)

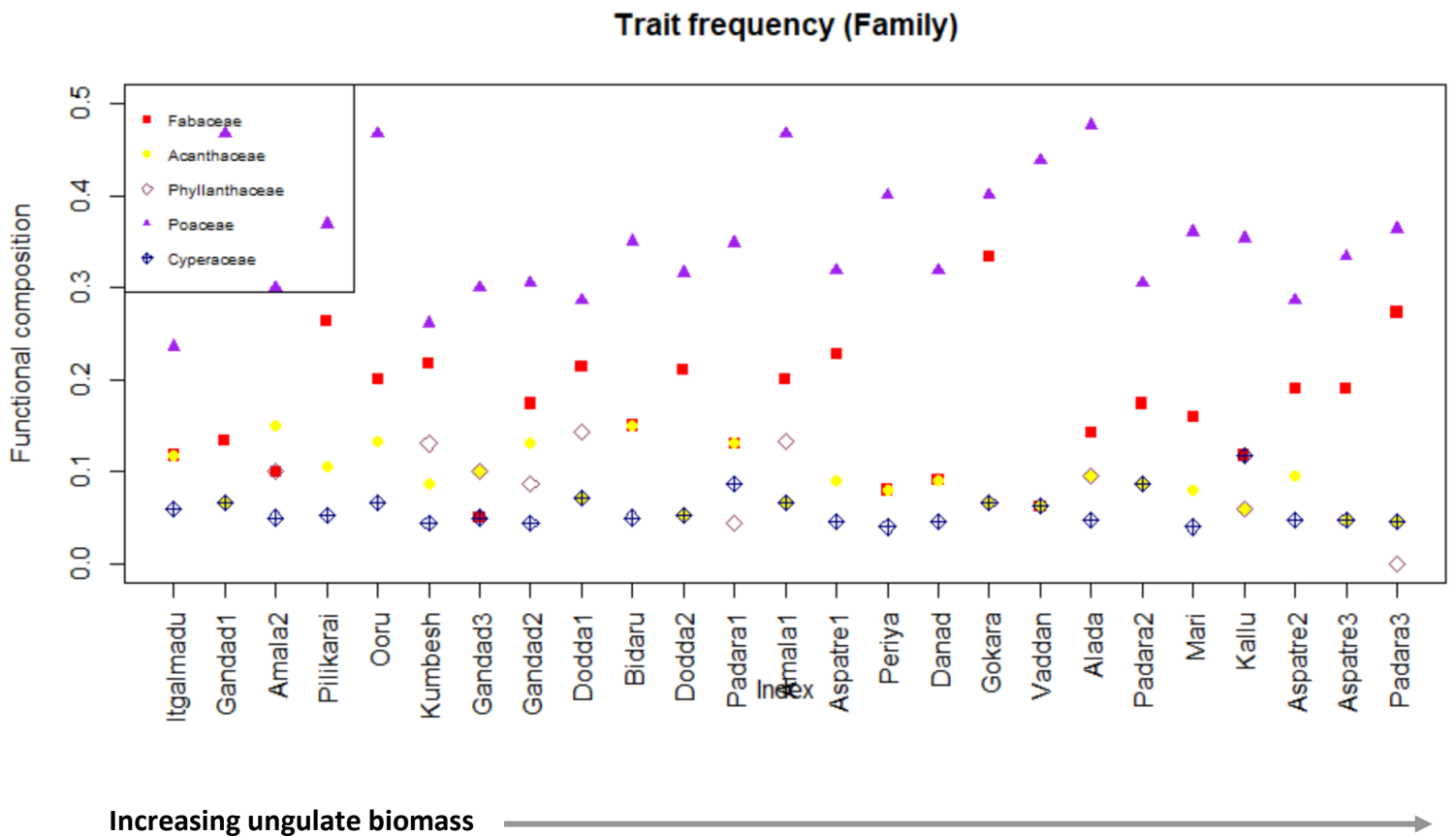


Figure 9: Plots arranged in the increasing order of ungulate biomass (x-axis), plotted against the proportion of each family (y-axis)

Figure 9 represents the trait composition of Family. The x-axis represents the sites arranged in the order of increasing ungulate biomass, and the y-axis represents the functional composition of the plots. From the graph, we can conclude that the most dominant family across all sites is Poaceae, followed by Fabaceae in most sites. Cyperaceae is the least dominant among the 5 families, with the exception of 3 plots, Padara 3, Padara 1, and Kallu. Phyllanthaceae and Acanthaceae seem to be favoured by sites that experience a lower grazing pressure. Overall, grazing intensity does not seem to have a marked effect on family in the study area.

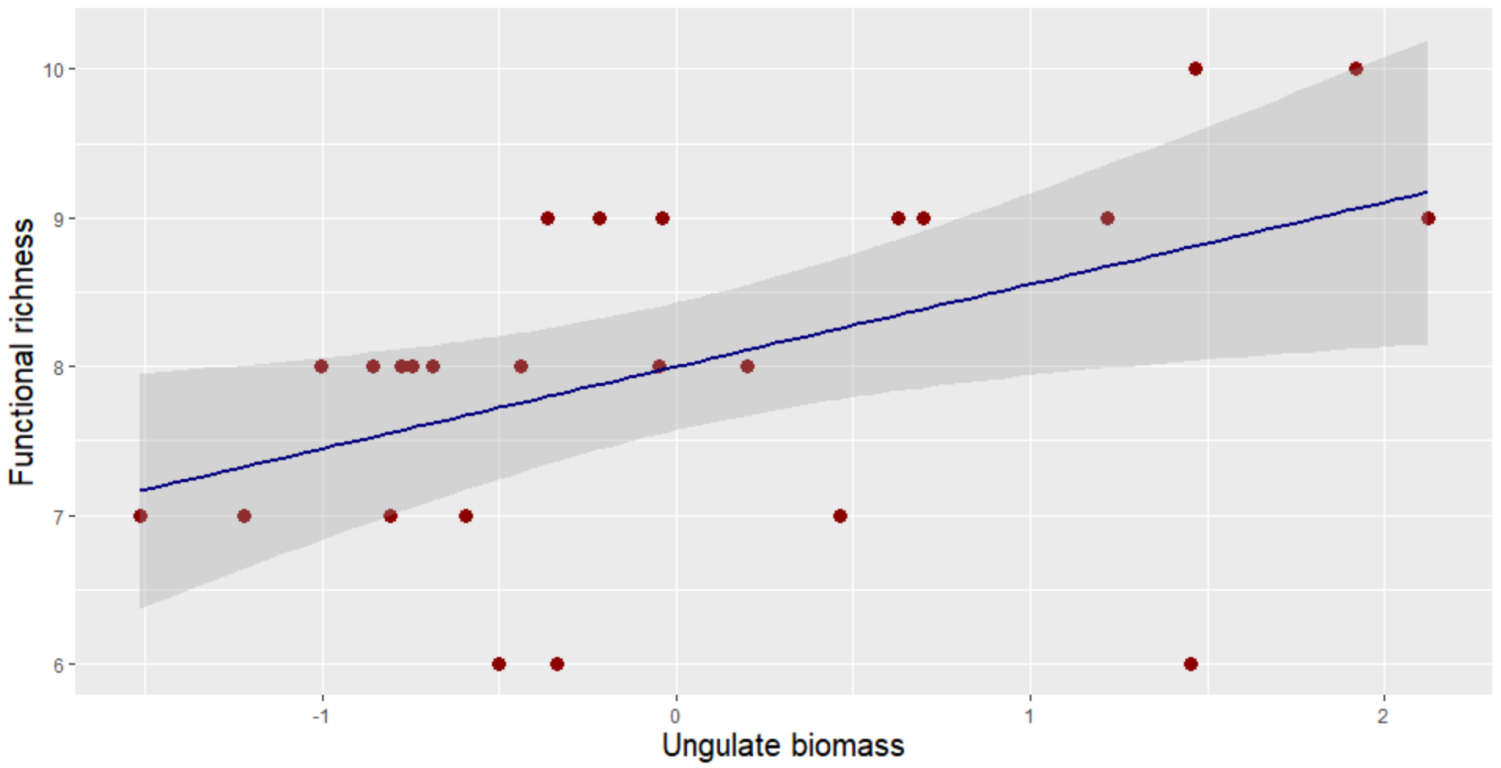
Functional diversity of plots

Functional richness

Functional richness (FRic) is a measure of the number of unique trait combinations in a site, FRic is independent of species abundances. The functional richness of the plots has been listed in Table 6. We ran a simple linear model (given in Table 4) and found that ungulate biomass had a significant effect on functional richness (p-value = 0.016), with a slope value of 0.55. The linear model had an adjusted R-squared value of 0.196, which means that ungulate biomass accounted for close to 20% of the variance in the functional richness of our plots. Thus, indicating that communities which experience higher grazing intensity occupy more trait volume, i.e., plots with higher grazing intensities have a greater number of unique trait values.

Functional richness			
<i>Predictors</i>	<i>Estimates</i>	<i>CI</i>	<i>p</i>
Intercept	8.00	7.57 – 8.43	< 0.001
Ungulate biomass	0.55	0.12 – 0.99	0.016
Observations	25		
R ² / R ² adjusted	0.229 / 0.196		

Table 4: The tables show the linear model of ungulate of ungulate biomass (x) predicting functional richness (y).



Increasing ungulate biomass 

Figure 10: Linear model showing the relationship between FRic and ungulate biomass

Functional evenness

The functional evenness (FEve) indicates how regularly species abundances of a community are distributed in the trait space, and is measured from 0 to 1; values closer to 1 indicate a highly uniform distribution and values closer to 0 indicate a highly non-uniform distribution. Unlike FRic, FEve is weighted by species abundances. The FEve of values are given in Table 7 (below). We ran a simple linear model (given in Table 5) testing the effect of ungulate biomass on functional evenness, and we found that ungulate biomass has a significant (p-value = 0.042) but uncertain effect (confidence intervals overlapped 0) on functional evenness. This indicates that grazing intensity does not have a noticeable effect on functional evenness of the plots.

Functional evenness			
<i>Predictors</i>	<i>Estimates</i>	<i>CI</i>	<i>p</i>
Intercept	0.15	0.12 – 0.18	<0.001
Ungulate biomass	-0.03	-0.06 – -0.00	0.042
Observations	25		
R ² / R ² adjusted	0.167 / 0.131		

Table 5: Table showing linear model for ungulate biomass (x) predicting functional evenness (y).

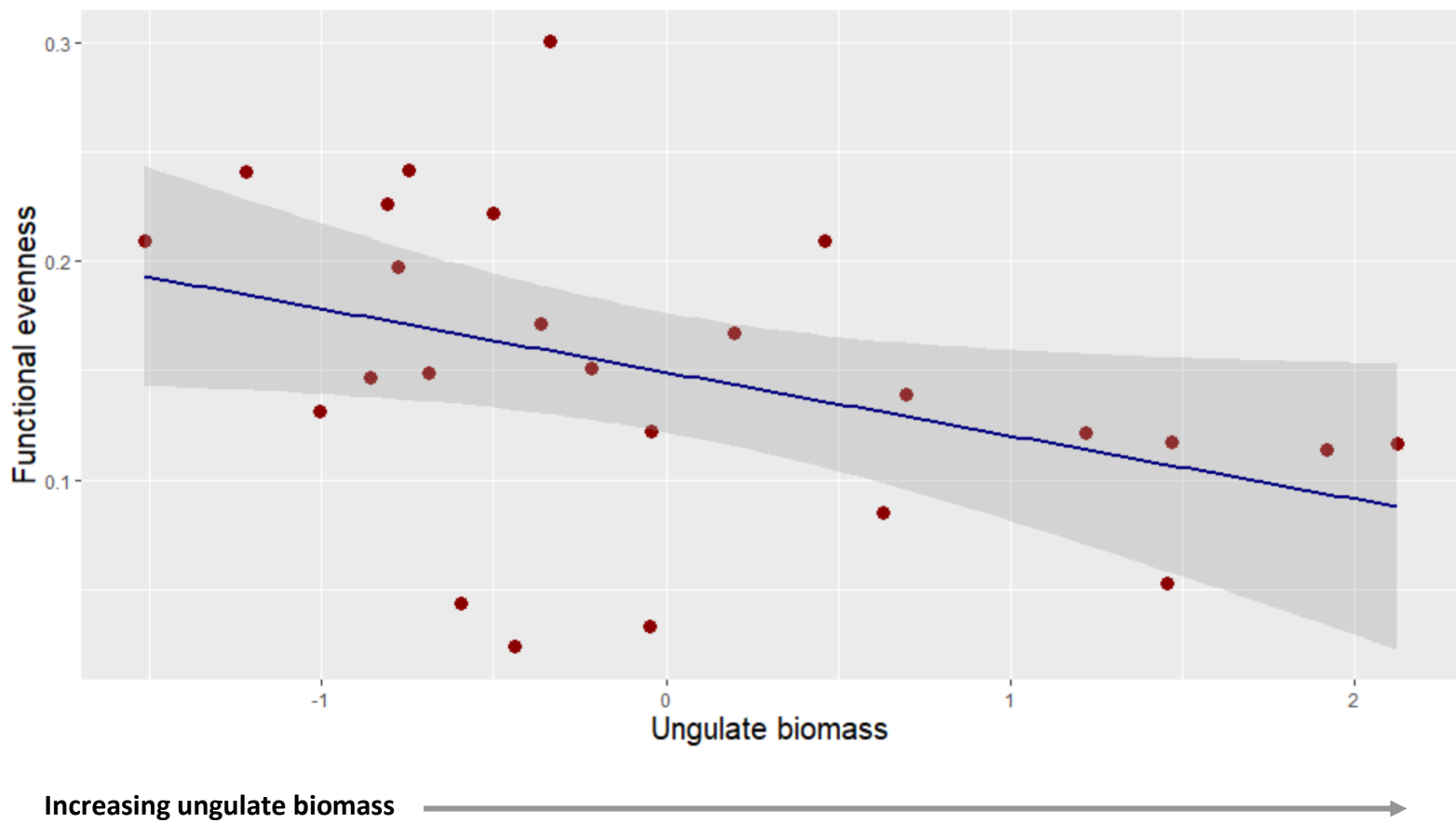


Figure 11: Linear model showing the relationship between FEve and ungulate biomass.

Site	Functional richness
<u>Itgalmadu</u>	8
<u>Gandad 1</u>	7
<u>Amala 2</u>	9
<u>Pilikarai</u>	9
<u>Ooru karai</u>	8
<u>Kumb karai</u>	9
<u>Gandad 3</u>	9
<u>Gandad 2</u>	9
<u>Dodda 1</u>	8
<u>Bidaru karai</u>	7
<u>Dodda 2</u>	9
<u>Padara 1</u>	9
<u>Amala 1</u>	7
<u>Aspatre 1</u>	10
<u>Periyakarai</u>	9
<u>Danad karai</u>	10
<u>Gokara karai</u>	9
<u>Vaddan koote</u>	8
<u>Alad karai</u>	10
<u>Padara 2</u>	11
<u>Mari karai</u>	10
<u>Kal karai</u>	7
<u>Aspatre 2</u>	11
<u>Aspatre 3</u>	11
<u>Padara 3</u>	10

Table 6: Functional richness of plot

Site	Functional evenness
<u>Itgalmadu</u>	0.28
<u>Gandad 1</u>	0.27
<u>Amala 2</u>	0.22
<u>Pilikarai</u>	0.30
<u>Ooru karai</u>	0.27
<u>Kumb karai</u>	0.22
<u>Gandad 3</u>	0.20
<u>Gandad 2</u>	0.20
<u>Dodda 1</u>	0.20
<u>Bidaru karai</u>	0.22
<u>Dodda 2</u>	0.09
<u>Padara 1</u>	0.27
<u>Amala 1</u>	0.27
<u>Aspatre 1</u>	0.18
<u>Periyakarai</u>	0.13
<u>Danad karai</u>	0.09
<u>Gokara karai</u>	0.36
<u>Vaddan koote</u>	0.31
<u>Alad karai</u>	0.09
<u>Padara 2</u>	0.17
<u>Mari karai</u>	0.15
<u>Kal karai</u>	0.28
<u>Aspatre 2</u>	0.16
<u>Aspatre 3</u>	0.13
<u>Padara 3</u>	0.12

Table 7: Functional evenness of plots

Discussion

The results of the study highlight the following findings, 1) Grazing intensity (measured in ungulate biomass/km²) has a significant but marginal effect of 6.8% on the species richness of the grazed communities; 2) Grazing pressure (qualitative metric) has an effect on species composition of the communities, but the difference in composition is stark only when a the grazing pressure is very high; 3) Grazing intensity (ungulate biomass/km²) does not have any noticeable influence on the functional composition of the grazed communities; 4) Grazing intensity influences functional diversity of the grazed communities; wherein functional richness increased with increase in grazing intensity, and functional evenness did not show any significant trends with grazing intensity.

The effect of grazing intensity on species richness is heavily contingent on local environmental factors (mainly moisture) and the grazing history of the grassland (Milchunas et al., 1988). Mesic grasslands that have a long history of grazing show an increase in species richness with increase in grazing intensity, and show a mid-intensity peak. The grasslands in our study area are grazing lawns that have persisted as a result of a long history of grazing; this is corroborated by the presence of a large number of perennial short-graminoid and forb species in the grasslands (Cingolani et al., 2003). The study area also receives close to 900mm of rain annually, and hence the grazing lawns are classified as mesic grasslands. Therefore, our results indicating that grazing intensity has a minimal effect on species richness in mesic grassland communities with a long history

of grazing, is in contrast with results from other studies that show an increase in species richness with increase in grazing intensity (Cingolani, Noy-Meir, et al., 2005). There is however, a slight increase in species richness with increase in grazing intensity, following the trend in the 'MSL (Milchunas-Sala-Lauenroth) model' given by (Milchunas et al., 1988); but, species richness did not reach a maximum in intermediate grazing intensities as predicted by the model. The influence of our random effect (site) on species richness was much higher (21.6%) than our fixed effects. This indicates that plot attributes like micro-climatic conditions and edaphic factors might have an influence on species richness. The productivity of the grassland is also stated to be an important factor that mediates the effect of grazing intensity on species richness (Rusch & Oesterheld, 1997). More productive grasslands are hypothesised to be more affected by increase in grazing intensity; in contrast to this hypothesis, the species richness of the productive grazing lawns in the present study was only slightly affected by grazing intensity. A change in grazing intensity from high to low in such grasslands might result in a turnover of grass species from short-statured to medium statured, however, the overall species richness will remain the same (Herrero-Jáuregui & Oesterheld, 2018). A similar trend was observed in the current study, wherein species richness remained the same, but species composition showed changes between grazing pressure groups.

Species richness is also seen to have a negative linear relation with elevation, reinforcing the fact that other abiotic gradients also play a role in shaping species richness. We also suspect that soil moisture and nutrients play an important role in the way grazing intensity affects species richness (Zheng et al., 2015). The grazing lawns in the study area

are composed of black, clay soil with high water retention rate, and a low water percolation rate. Thus, the high soil moisture might help in buffering the effect of grazing intensity on species richness.

The results of the current study do not conform to the intermediate disturbance hypothesis, since our species richness does not show a unimodal response with a central peak. It rather follows some trends outlined in the MSL model that predict the response of mesic communities with a long history of grazing. The species in grazing lawns employ a tolerance strategy to persist in chronic grazing conditions as a result of their high productivity (Coley et al., 1985; Zheng et al., 2015). These species can withstand heavy grazing pressure by using rhizomes or stolons to reproduce, they also have higher growth rates, are more nutritious, and more palatable than their taller counterparts (Díaz et al., 2001; McNaughton, 1984). Thus, the grazing lawn complex employs a divergent strategy to allay the effects of grazing.

Grazing pressure generally has a marked effect on species composition. Species composition, much like species richness, is influenced by environmental factors (mainly moisture) and grazing history. According to the MSL model, change in species composition is higher as grazing pressure increases in a productive, mesic grassland. It further states that changes in species composition in mesic grasslands are independent of grazing history. In line with the prediction of the MSL model, species composition showed noticeable change between our grazing pressure groups. There is considerable overlap in groups 1 (low) and 2 (medium), but there is a stark difference between the first 2 groups

(low & medium), and the third group (high). This points to the fact that a certain grazing intensity threshold needs to be surpassed for compositional change to be detectable. This is probably because of grazing mediated competitive release of light dependent species with increase in grazing pressure. As the canopy opens up with increase in grazing pressure, light dependent species will start to replace the slow-growing species (Facelli & Springbett, 2009; Lezama et al., 2014). However, there is no change in the composition of the dominant species across our grazing groups. *Chrysopogon sp.*, *Ischaemum ciliare*, *Fimbristylis dichotoma*, and *Desmodium triflorum* are the most dominant species across all of our groups. This indicates that these species are facultative lawn species that can alter their physiognomy according to the grazing pressure, and their presence is unaffected by grazing intensity (Zhang et al., 2018). The presence of such facultative lawn species also point to the fact that grazing lawns are resilient to change in grazing intensity, as stated in the modified generalised model proposed by (Cingolani, Noy-Meir, et al., 2005); and are capable of reverting back to their original composition if the disturbance is removed or brought back. Most of the difference in species composition across our groups was because of the presence of rare species across the grazing gradient. We also observed that native forb species outnumber graminoids in all of our plots, with the exception of Aladmarad plot (Hayes & Holl, 2003). The difference of proportion between forb and graminoid species was much larger in plots with lower grazing intensity. However, this difference in proportion decreased with increase in grazing intensity. This is probably because graminoid species are more tolerant to heavy grazing and will competitively exclude unpalatable forb species as grazing intensity increases.

We noticed that plots that are geographically closer to each other showed similar composition, probably as a consequence of similar climatic conditions. Species composition was also affected by micro-habitat differences in our grazing lawns; for example, some of the grasslands had a higher proportion of tree patches, whose understorey helped in harbouring some grazing intolerant species like *Digitaria bicornis* and *Oplismenus sp.* Similarly, some grasslands had puddles that were waterlogged during rains that promoted the presence of hydrophilic grass and forb species. There was also a clear pattern of increase in exotic invasive species with increasing in grazing intensity, as noted by literature. We noticed a considerable increase in the abundance of *Chromolaena odorata*, *Parthenium hysterophorus*, and *Senna spectabilis*, and slight increase in the abundance of *Solanum viarum* and *Senna tora* as grazing intensity increased. As outlined earlier, in productive mesic grasslands like grazing lawns, grazing-induced compositional changes is higher than in arid/unproductive grasslands because of the divergent strategies they employ to withstand grazing pressure.

It has been hypothesised that a community's response to grazing depends on the frequency and intensity of herbivory that it experiences; subsequently, a prolonged history of grazing selects for grazing resistant traits in arid and less productive systems, and for grazing tolerant traits in mesic and more productive systems. Notwithstanding such general predictions, trait responses to grazing are unique for a given region/eco-system (Oesterheld & Semmartin, 2011). Plants in grazing lawns are grazing tolerant because they can persist and even increase under high grazing intensities (Cingolani, Posse, et al., 2005). In our study, perennial plants occur more frequently across all the plots, this result

is in contrast with the range succession model that predicts annual plants to become more common as grazing intensity increases. We think the long history of grazing in the grazing lawns is one of the reasons for the higher proportion of perennial plants in the study area; perennial plants seem to be more grazing tolerant than annual plants, and hence are more prevalent in grazing lawns, irrespective of grazing pressure. We also suspect that the time period of the study (early summer) might've slightly contributed to the detection of more perennial plants. However, the difference between the proportion of perennial and annuals was too large for sampling bias to make a considerable difference. With respect to canopy structure, prostrate plants occurred most frequently, followed by erect and caespitose plants across most of the plots. This is also a consequence of the grazing history of the lawn. Most lawn species are prostrate irrespective of the grazing intensity. A prostrate growth form will help concentrate reproductive parts closer to the ground and will deliver more food per bite to the grazers. This in turn will make the grazer return to the same patch of grassland, thus creating a positive feedback loop between the grazers and the herbs. This mechanism is one of the main reasons why grazing lawns have such high productivity (Archibald, 2008). Thus, the results of our study do not follow the usual trends predicted by grazing models since it is a grazing lawn complex. The results however reinforce the role of precipitation, grazing history, climatic variables, and eco-evolutionary history of the habitat in mediating trait responses to grazing.

In our study, we looked at the functional richness (FRic) and functional evenness (FEve) of the communities across our grazing gradient. We found that functional richness increased with increase in grazing intensity, which indicates that an increase in grazing

intensity leads to diversification of traits in a grazing lawn complex. Plots with higher grazing intensity are occupying more trait (niche) space than plots with lower grazing intensity. With respect to functional evenness, we found that the effect of grazing intensity on FEve is significant but uncertain, which might indicate that an increase in grazing intensity is leading to an over or under-utilisation of the trait space occupied. This is because the traits in plots with high grazing intensity are not regularly distributed, i.e., some traits are much more abundant than others in the given community (Villéger et al., 2008). This non-uniformity in trait distribution can be attributed to the fact that only some traits are capable of withstanding a heavy grazing pressure, hence, such traits are over-represented with increase in grazing intensity. Though the trait (niche) space occupied by plots with high grazing intensity is larger, they're under/over-utilising their niche, this indicates that such communities are more prone to invasion by exotic or weed species because of the availability of empty niche spaces. However, we should exercise caution while interpreting the results of functional evenness because categorical variables do not scale well for such analysis (Schleuter et al., 2010), all necessary steps have been taken to minimise such a misinterpretation. Notwithstanding such limitations, functional diversity provides us with a novel way of investigating the effects of grazing intensity on ecosystem functioning and invasion propensity and will help managers and ecologists to come up with better strategies for biodiversity conservation.

Conclusion

Grazing lawns are grassland communities with high productivity that are minimally affected by high grazing intensities. They harbour nutritious and grazing tolerant grasses that will help in maintaining a high stocking rate of wild ungulates and livestock. They also contribute to ecosystem functioning because of their role as an excellent rangeland for livestock. The only management action necessary in such ecosystems would be to periodically remove exotic invasive plants so that they don't disrupt ecosystem functioning and dynamics. As a way forward, it would be interesting to look at the soil properties, precipitation, and other environmental factors that might affect the species composition of the lawns. It would also be worthwhile to look at the effects of livestock and wild ungulate independently on the species richness, composition, and functional diversity on grazing lawn complexes.

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Appendix

Species	Life history	Canopy structure	Functional group
Alysicarpous sp.1	Perennial	Erect	Herb
Alysicarpous sp.2	Annual	Prostrate	Herb
Apluda mutica	Perennial	Caespitose	Grass
Arundinella setosa	Perennial	Caespitose	Grass
Bahunia sp.*	-	-	Tree
Balanites roxburghii	-	-	Tree
Biophytum sensitivum	Annual	Prostrate	Herb
Bothriochloa pertusa	Perennial	Stoloniferous	Grass
Butea monosperma	-	-	Tree
Chromolaena odorata	Perennial	Erect	Herb
Chrysopogon sp.*	Perennial	Caespitose	Grass
Crotolaria sp.1	Perennial	Erect	Herb
Crotolaria sp.2	Annual	Erect	Herb
Cymbopogon gidarba	Perennial	Caespitose	Grass
Cyperus pseudokyllingioides	Annual	Erect	Herb
Desmodium triflorum	Perennial	Mat-forming	Herb
Digitaria bicornis	Annual	Caespitose	Grass
Eragrostis tenuifolia	Perennial/Annual	Caespitose	Grass
Fimbristylis dichotoma	Annual	Rhizomatous	Herb
G01	Perennial	Stoloniferous	Grass
G05	Annual	Stoloniferous	Grass
G100	Annual	Caespitose	Grass
H100	Perennial	Erect	Herb
H11	Annual	Erect	Herb
H22	Perennial	Erect	Herb
H30	Annual	Prostrate	Herb
H31	Perennial	Erect	Herb
H65	Annual	Erect	Herb
Hemigraphis sp.*	Perennial	Erect	Herb
Heteropogon contortus	Perennial	Rhizomatous	Grass
Hygrophila auriculata	Perennial	Erect	Herb
Indigofera linnaei	Perennial	Prostrate	Herb
Indigofera trita	Annual	Prostrate	Herb
Ischaemum ciliare	Perennial	Stoloniferous	Grass
Lantana camara	-	-	Shrub

Leucas aspera	Annual	Erect	Herb
Mimosa pudica	Perennial/Annual	Prostrate	Herb
Oldenlandia umbellata	Annual	Prostrate	Herb
Orthosiphon sp.*	Perennial	Erect	Herb
P2		Erect	Herb
Parthenium hysterophorus	Annual	Erect	Herb
Paspalum scrobiculatum	Annual	Caespitose	Grass
Phyllanthus maderaspatensis	Perennial	Erect	Herb
Phyllanthus virgatus	Perennial	Erect	Herb
Polygala arvensis	Annual	Prostrate	Herb
Polygala sp.1	Annual	Erect	Herb
Polygala sp.2	Annual	Erect	Herb
Rhynchosia minima	Perennial	Prostrate	Herb
Rothia indica	Annual	Prostrate	Herb
Rottboellia cochinchinensis	Annual	Caespitose	Grass
Rungia pectinata	Annual	Erect	Herb
Sengalia pennata	-	-	Shrub
Senna spectabilis	-	-	Tree
Senna tora	Annual	Erect	Herb
Setaria flavida	Perennial	Caespitose	Grass
Setaria pumila	Annual	Caespitose	Grass
Solanum viarum	Perennial	Erect	Shrub
Sorghum halepense	Perennial	Rhizomatous	Grass
Sporobolus indicus	Annual	Caespitose	Grass
Striga densiflora	Annual	Erect	Herb
Themeda triandra	Perennial	Caespitose	Grass
Urochloa distachya	Annual	Prostrate	Grass
Zizphus sp.*	-	-	Tree

Table 8: List of all species and their traits in the study area

GRASSLAND PATCHES OF DIFFERENT GRAZING PRESSURE



HIGH GRAZING



MEDIUM GRAZING



MEDIUM GRAZING



LOW GRAZING



