

**Patterns of Ant Species Richness and Composition in Deccan Inselberg-
Matrix systems of Karnataka**

by

Sujay G
Enrolment no: 50BB23A73004

Dissertation Thesis

Submitted to Academy of Scientific and Innovative Research

For the partial fulfilment for the degree

Master of Science
in
Wildlife Science

Under the supervision of

Dr B.S. Adhikari (Scientist - G)



भारतीय वन्यजीव संस्थान
Wildlife Institute of India



June 2025

ACKNOWLEDGEMENTS

Firstly, this wildlife journey would not have started without my mom and brother pushing me to do something other than loafing and playing video games. Thank you for always supporting me and letting me forge my own path in life. Special mention to my lovely amama, who still finds it difficult to explain to people what exactly I do. Tata, even though you're not with us anymore, I know you'd always motivate me to pursue my wildest dreams. Minni, thank you for always giving me advice and helping me improve myself. I love you all.

Tirtho da and Navendu sir, thank you for showing real interest in my scientific growth, and more importantly for being chill, kind people. Special thanks to Navendu sir for introducing me to the beautifully intuitive and interesting, yet complex sub-field of community ecology. Ashish, thanks for introducing the topic of inselbergs in class, and also for helping to shape my ideas through interesting conversations. Ritesh sir, thank you for helping me in trying to create prototypes of pitfall traps. To Adhikari sir, my PI, you accepted me as your student when I had no one else to go to, thank you so much. Thanks to my CDs and ACDs also.

To my field assistant, Gurulingappa anna, I am truly grateful for being always on time and never causing issue regardless of how rigorous and difficult the field work was. To the RFO of Ramanagara taluk, Mohammad Mansoor sir, thank you for your kindness and help in making Ramanagara a less stressful experience.

Negi ji and Umesh ji thank you so much for all the help with any admin work throughout our two years; you are so kind and so helpful always. Thank you to "Aunty" who always greets us with a smile and works so hard to keep our hostel clean. The mess staff, you are an integral component of my life throughout these 2 years, and thanks for letting me take extra gulab jamuns and chicken whenever I asked. Special mention to the hostel staff for always helping us, with a smile.

Sonta, Mew and mewlings, you really brightened up my life on campus with your crazy antics.

I can't imagine life over the past 2 years without Amdo and the always perfect buff momos, soup and chowmein; thank you Choyang bhai and the rest of the Amdo staff.

My peers and friends, without you this journey has not much meaning -

Adi da, you're like a brother to me, but also an inspiration to me in this field of wildlife. I hope our conversations, from wildlife to football to any random nonsense, continue indefinitely.

My batch, while we have had our fair share of drama, have provided me an amazing and unique set of memories throughout our time in the hostel and our escapades on field which I will forever cherish.

Akilan da, thanks for being a sensible, helping figure since our BSc days. Ananya, thanks for being a chill, fun-loving person.

Most special mention to my Bakchods, my brothers, without whom there would be no fun and excitement throughout these 2 years. Chirag, my roommate, always up for chatting about anything and bearing with my nonsense (we'll call it even because of your terrible

morning alarms). Passah, one of the craziest guys I have seen, always ready for anything regardless of what it is. Isaac, and his neverending drive for field and animal handling. Manas, our resident tech expert and always helping me plan and execute pranks. Vikash, one of the kindest, most genuine guys I have come across. Shikhar, our walking herbarium and encyclopedia on anything Himalayas (take us to your home bro). Chinmay, our king of Kiraksal and neverending confidence reservoir. SP, our unofficial big brother and resident coffee addict.

Most importantly, none of this would be possible without me. Never letting any difficulties stop me, continuing to be my spontaneous, carefree self, and following my passion always.

TABLE OF CONTENTS

1. Project Summary	1
2. Introduction	3
2.1 Background	3
2.2 Literature Review	5
2.2.1 International Status	5
2.2.2 National Status	7
2.3 Importance of proposed study	8
3. Aim	10
4. Study area	11
5. Methodology	13
5.1 Site selection	13
5.2 Ant sampling methodology	14
5.3 Quantification of habitat structure	16
5.4 Analytical methods	17
5.4.1 Characterization of habitat structure	17
5.4.2 Ant community diversity	17
5.4.3 Ant community composition	18
5.4.4 Relationship between habitat variables and ant community patterns	18
6. Results	20

6.1 Characterization of habitat structure	20
6.2 Ant community diversity	22
6.3 Ant community composition	26
6.4 Relationship between habitat variables and ant community patterns	27
7. Discussion	31
7.1 Habitat structure	31
7.2 Ant community diversity	31
7.3 Ant community composition	32
7.4 Relationship between habitat variables and ant community patterns	34
8. Conclusion	36
9. Limitations of the study	38
10. References	39

LIST OF FIGURES

Figure 1: Map of study area	11
Figure 2: NMDS plot of habitat structure with environmental vectors	20
Figure 3: Sample based rarefaction curves for respective groups; n = number of traps sampled (Obs = observed species richness, Chao = incidence-based richness estimate)	22
Figure 4: Mean trap richness (SE) across different groups	24
Figure 5: Rank occupancy curves and top 5 most dominant species for respective groups	25
Figure 6: CCA biplot showing relationship between species composition and environmental vectors	29
Figure 7: Venn diagram showing overlap of species between inselberg and matrix (mango plantation, natural habitat)	33

LIST OF TABLES

Table 1: Ocular method of quantifying habitat structure	16
Table 2: Pairwise PERMANOVA and associated PERMDISP results for habitat structure	21
Table 3: ANOVA result for mean trap richness differences across groups	24
Table 4: Pairwise PERMANOVA and associated PERMDISP results for ant community composition	26
Table 5: GLM summary for ant richness	27
Table 6: Coefficient values for predictors of GLM for ant richness	27
Table 7: CCA output - partitioning of scaled chi square and anova result of model	30

1. PROJECT SUMMARY

My study looked into patterns of ant species richness and composition of Deccan inselbergs and surrounding human altered matrix (natural habitat, mango plantation) in Ramanagara taluk, Karnataka, in a bid to recognize their ecological and conservation potential. Ants were chosen as the model taxa, due to their micro-habitat specificity, to better understand environmental gradients and related faunal associations at different scales. Pitfall traps were used as the sampling methodology for ants, and habitat variables were collected at each trap; ants were identified until morphospecies level within respective genera. Data analysis included understanding habitat differences, patterns of species richness and composition, and relating these aspects.

The results showed that inselbergs were distinct in terms of habitat structure as compared to the matrix, with the latter showing less vegetation complexity (lesser in mango plantation). While matrix and inselberg showed comparable levels of ant richness, delving deeper it was seen that natural habitat within matrix showed significantly higher richness as compared to the species poor, uneven mango plantation ant assemblage. Similarly, inselbergs and matrix showed similar average composition of their respective ant communities. However closer inspection showed that natural habitat and plantation, when compared separately with inselbergs, showed compositional dissimilarity to greater magnitude. Habitat variables, while statistically significant in their relationship with patterns of ant composition and richness at finer scales, explained a minimal amount of total variation seen in both.

Inselbergs, as understood through this study, are not “barren wastelands”, but on the contrary are important reservoirs of regional diversity. In light of rapid human alteration of the surrounding matrix and threats like quarrying, invasive species, inselbergs and the lowlying natural habitat need to be given greater conservation importance. This study is hopefully just one of many that are required to further assess the conservation and ecological potential of these amazing ecosystems.

2. INTRODUCTION

2.1 Background

Inselbergs are rocky outcrops mainly comprising granite or gneiss, formed via processes of weathering and differential erosion (Porembski & Barthlott, 2000). They are often referred to as terrestrial habitat islands, with extreme microclimatic conditions like high surface temperatures, low soil availability, low relative humidity, etc. They are highly habitat heterogeneous, having microhabitats including rock crevices, ephemeral pools, boulders, clefts, soil-covered patches, and tree-associated areas, which support specialized and sometimes endemic communities (Ferreira & Silva, 2001; Main, 2000; Porembski & Barthlott, 2000).

While relatively understudied globally, inselbergs have gained recognition as model systems for ecological research, similar to how oceanic islands have been key systems for studying ecological and evolutionary processes — Darwin’s work on the Galapagos islands, Diamond’s community assembly rules, E.O. Wilson and Robert MacArthur’s island biogeography theory which highlight the role of isolation, habitat size, dispersal limitation, etc. in shaping communities (Gotelli, 1999; MacArthur & Wilson, 1963). Inselbergs are important systems to study topics like patterns of species composition/ richness, wildlife-habitat relationships, and adaptations to harsh conditions (Porembski & Barthlott, 2000;

Yates et al., 2019; Yekwayo & Mwabvu, 2019).

The Deccan Plateau's inselbergs are widespread and abundant, often being surrounded by a human-altered matrix of different land-use types, including agriculture, plantations, and pockets of natural habitat (Mutharaj & Rayamane, 2020) (pers. obs.). This makes them ideal for not just studying fundamental ecological processes, but also anthropogenic influence on biodiversity.

Ants, as a result of their small size, have lower dispersal distances compared to other taxa, and are more related to finer scale microhabitats and environmental gradients (Barton et al., 2024; Savitha et al., 2008). This makes them suitable for understanding community assembly and habitat relationships in these heterogeneous inselberg habitats and the surrounding matrix.

This study looks to understand patterns of species richness, composition of ants and their relationship with micro-habitat variables across Deccan inselbergs and surrounding matrix habitats, contributing to a broader understanding of habitat heterogeneity and conservation needs in human-dominated landscapes.

2.2 Literature Review

2.2.1 International Status

On a global scale, inselbergs are well studied in terms of geology, geomorphology, microclimate features, etc. Porembski & Barthlott (2000) talks about the above, in addition to explaining about highly specialized plant communities adapted to arid and nutrient-poor conditions. Distinct microhabitat features, such as exposed granitic surfaces, rock crevices, boulders, clefts, etc. which characterize inselbergs, lend to patterns of floral diversity. These can range from ephemeral flush vegetation and monocotyledonous mats to arid-adapted shrubs and trees occurring in deeper soil patches. Interestingly, many of the shrubs and trees present on inselbergs, are present in the surrounding matrix too (Porembski & Barthlott, 2000).

Research has highlighted how microhabitats influence community dynamics, especially for smaller arthropod taxa. Ferreira & Silva (2001) researched arthropod richness and diversity in Brazilian rocky outcrops and how these related to microhabitat features such as substrate moisture, organic matter, etc. Privet et al. (2018) showed that spider assemblages (epigeal arthropods) on French Guiana inselbergs were different from lowland forests, giving us an understanding of the differences in inselberg communities compared to the surrounding matrix. These differences were shown to be associated with differing habitat types and

vegetation structure on inselbergs. Yekwayo & Mwabvu (2019) explored flightless arthropod communities in South African rocky outcrops, where habitat heterogeneity and structural differences between strata, in addition to disturbance were shown to affect species composition. All these studies point in the direction of needing to capture habitat variation at not just macro-habitat scale, but also at the micro-habitat level. Habitat variables like canopy cover, shrub cover, presence of logs, rocks, etc. have been known to affect species composition and richness of ants at different spatial levels (Barton et al., 2024) (Lassau & Hochuli, 2024). While habitat complexity is generally known to have a positive correlation with species richness, Lassau & Hochuli (2024) reports that ant richness, counterintuitively, was negatively correlated with habitat complexity.

Land-use type and landscape heterogeneity in human dominated areas shape ground dwelling arthropod communities in terms of composition and richness (Schweiger et al., 2005). Relatedly, (Michael et al. (2008), showed that habitat complexity and matrix quality significantly influenced reptile diversity on Australian inselbergs; this study also lends to a crucial understanding that inselbergs can help conserve diversity of the landscape in light of rapid anthropogenic alteration of the surrounding matrix. These insights (though on vertebrate taxa like reptiles) are potentially applicable and important in studying arthropod communities, especially in the Deccan Plateau inselberg-matrix landscape systems which have hitherto not received enough conservation attention.

2.2.2 National Status

In India, rocky outcrop habitats have been poorly studied, mainly restricted to the wet laterite plateaus of Maharashtra, in terms of systematic biodiversity studies. Watve (2013) explains about the biodiversity of these rocky plateaus in the Northern Western Ghats, showing their role as unique habitat islands supporting endemic species and unique microhabitats. The paper also calls for increasing attention to these rocky habitats, in relation to legal protection measures of the Protected Area network. Lekhak & Yadav's (2012) study on lateritic plateaus further highlights the importance of rocky habitats in supporting unique, sometimes endemic flora, and having role in conserving the biodiversity of the surrounding landscape. Threats of quarrying for minerals like bauxite, invasion of non-native plants, etc., are major anthropogenic influences that threaten the biodiversity of these habitats.

The arid granitic inselbergs of the Deccan Plateau have seen minimal scientific attention; previous work on the genetic and demographic aspects of yellow-throated bulbuls (Jha & Vasudevan, 2020), have highlighted the importance of these unique systems. They also highlight the threats of granite quarrying, due to these understudied habitats being considered as barren wastelands.

Ant community ecology studies in India have explored their responses to disturbance and habitat differences. Savitha et al. (2008) observed that habitat characters like canopy cover

and litter positively influenced ant richness around Bangalore, and also providing a basic understanding of the effects of anthropogenic disturbance on ants; these relationships further strengthen the idea of using ants as bioindicator species in human-altered landscapes. Varying land-use types influence patterns in ant diversity and composition in semi-arid region on Northern Karnataka (Begum et al., 2021), further highlighting the need to study inselberg habitats within human-altered surrounding matrix.

The effect of land-use types was shown to shape beta diversity patterns in tropical ant assemblages of Goa (Baidya & Bagchi, 2022), highlighting the importance of understanding biodiversity patterns in landscapes that are continually being altered by human influence.

2.3 Importance of the Proposed Study (knowledge gaps)

While the geology, geomorphology, microclimate, vegetation, etc., of inselbergs have been fairly well studied globally, their faunal aspects remain poorly studied. In studying the faunal aspects in a systematic framework, it provides the scientific community a critical understanding of the biodiversity of these understudied habitats, in addition to advancing knowledge on ecosystem structure and functioning. The limited understanding of fine scale habitat structure on Deccan inselbergs in India will be addressed via this study, in addition to linking the same to taxonomic diversity of ants, something novel to these understudied habitats.

The species composition aspect of the study, comparing the inselbergs vs the surrounding matrix, has large knowledge gaps in global literature, especially for faunal communities and sensitive, micro-habitat specific taxa like ants. This study will aid in understanding finer scale environmental gradients across the inselbergs vs the surrounding matrix and their relation to patterns of species composition, in addition to the effects of human-altered land use types on the same. This will be crucial in highlighting how inselbergs can conserve local, regional diversity in light of rapid alteration of the surrounding matrix by anthropogenic factors.

This study will add to the limited community ecology/ patterns of community structure available in India with respect to understudied taxa like ants, and add to the almost non-existent understanding of the ecology of Deccan inselberg habitats in a systematic framework.

3. AIM

Objective - Patterns of species richness and composition for ants

Q. How does species richness and composition differ between inselbergs and the surrounding matrix?

Prediction: Species richness will be higher on inselbergs, and there will be significant difference in species composition

Reason: Matrix habitat structure are potentially a subset of the habitat types present on inselbergs. More homogeneous land use types like plantations and disturbance by anthropogenic activities in the matrix will likely have a negative effect on ant communities.

Q. How do habitat variables influence ant species composition and richness at trap level?

Prediction: Species composition and richness will be significantly influenced by habitat variables, and differ across trap sites.

Reason: Different trap sites would have varying measures in terms of vegetation, substrate types, etc., affecting the presence of micro-habitat specific ants.

4. STUDY AREA

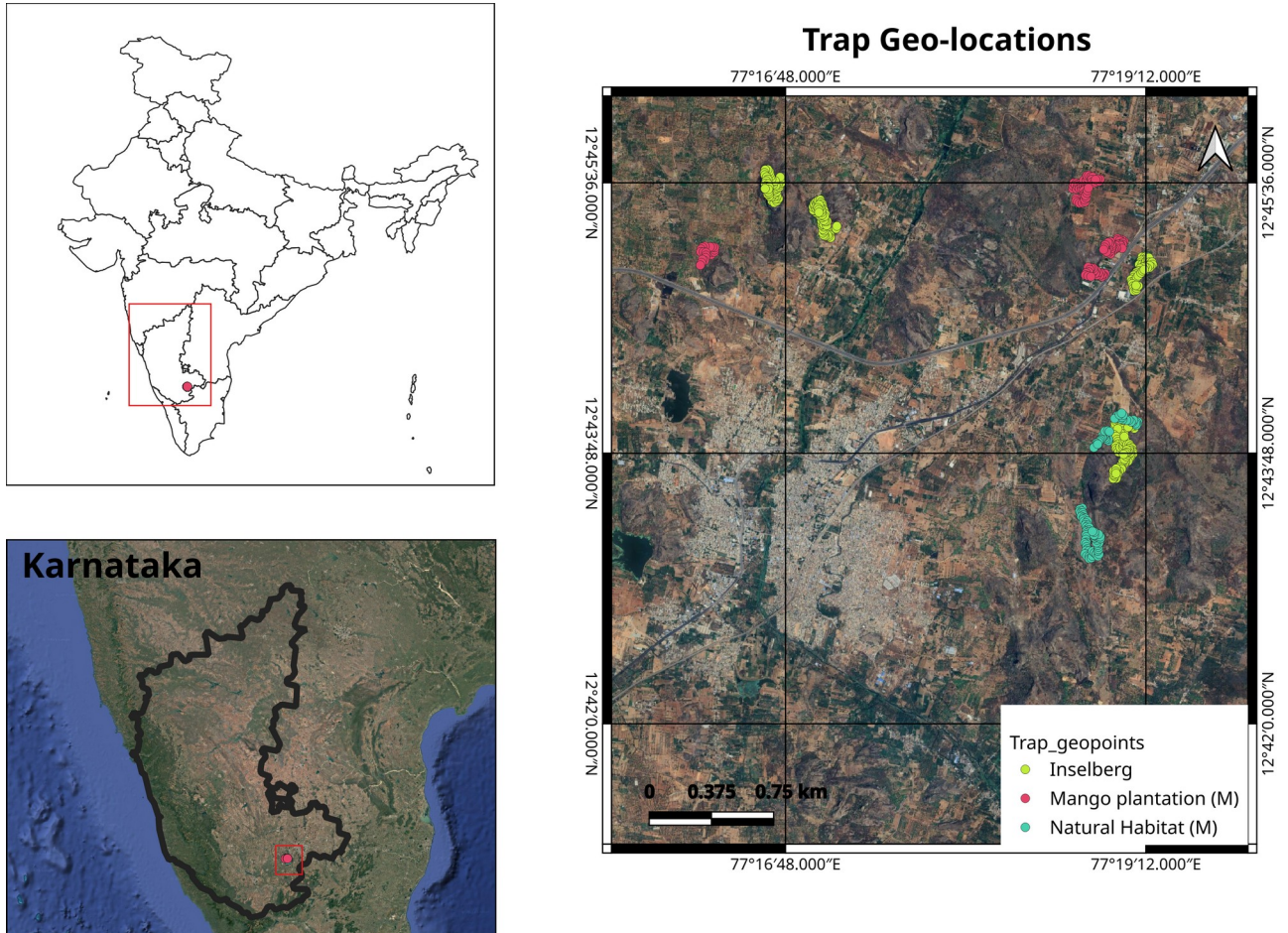


Figure 1: Map of study area

Ramanagara district occurs in the southern boundary of Karnataka, comprising 4 taluks -- Ramanagara, Channapatna, Magadi and Kanakpura (of which Ramanagara taluk is the study site). Located between $12^{\circ} 24'$ and $13^{\circ} 09'$ North latitude and $77^{\circ} 06'$ and $77^{\circ} 34'$ East longitude, the district is flanked by Bengaluru urban and rural to the north, and Tamil

Nadu to the south-east (Mutharaj & Rayamane, 2020). Majority of the district's total area comprises of human-modified land use types like plantations and agriculture, in addition to large areas of built up land, i.e., buildings, towns, etc., as a result of rapid urbanisation (Mutharaj & Rayamane, 2020). A measly 11% of the district's total area is classified under forest land-use category (scrub forests and dry deciduous forests mainly), highlighting the increasing threat to biodiversity in its natural state.

The whole district is situated on the larger biogeographic zone, the Deccan Plateau, consisting of the Deccan Traps Volcanic Province (Kumar et al., 2020). The Dharwar Craton, is observed in the form of the rocky outcrops/ inselbergs present all across the Ramanagara district, forming the basis for my study.

Ramanagara taluk, located towards the center of the district, comprises of adequate number of accessible inselbergs surrounded by different land-use types (pers. obs.), making it an ideal location to carry out my field study. Mango plantations, and to a lesser extent, coconut plantations, agriculture (ragi, mulberry, etc.) and pockets of natural habitat constitute the matrix around the inselbergs.

The inselbergs within the study area are called “bettas” in the local language, and often play host to temples located at their respective summits; hence, they are accessible via the respective paths.

5. METHODOLOGY

5.1 Site Selection

Since the overarching theme of the study is to understand the ecological and conservation importance of Deccan inselbergs in within a matrix of varying human-altered land use types, the study area is broadly characterized as inselbergs and matrix.

Reconnaissance surveys were carried out in the month of December.

Inselbergs

As discussed earlier, these are isolated rocky outcrops (granitic) that rise abruptly from the surrounding landscape, and have distinct microclimate and habitat conditions (Porembski & Barthlott, 2000). They vary in characteristics such as elevation, size, clustering across the study area of Ramanagara taluk. Dominant substrate type is exposed granitic rock surface and associated rock forms (boulders, crevices, rock pools, etc). Pockets of soil and associated vegetation like trees, shrubs, grasses, monocotyledonous mats, etc., related to the soil patch depth and size, comprise the majority of the remaining surface area of inselbergs. A combination of Google Earth Pro and QGIS, in addition to reconnaissance survey was used to classify and select accessible inselbergs within the study area.

Matrix

The land-use types that surround the inselbergs are what constitute the matrix in the landscape. For the purpose of the study, the matrix was represented by 2 major land use types:

Mango plantation (M) – monoculture plantations with low groundstorey vegetation cover that are the dominant land use type of the Ramanagara landscape (pers. obs.). Human activity is prevalent across this land-use type.

Sites were selected in the study area based on accessibility via permissions from plantation owners.

Natural habitat (M) – lowlying (relative to inselbergs) dry deciduous forests and semi-arid scrub forests, that observe minimal human activity. Trees and shrubs found here include *Wrightea tinctoria*, *Adenantha pavonina*, *Acacia nilotica*, *Ziziphus mauritiana*, *Distimake aegyptius*, etc. (pers. obs.).

5.2 Ant sampling methodology

Pitfall traps

As mentioned earlier, based on the reconnaissance surveys conducted in the study area, sites for the inselbergs and matrix (mango plantation, natural habitat) were selected.

(Ant sampling was carried out through the entirety of January and February months.)

Pitfall traps (11cm diameter plastic containers) were used as the sampling method, since they have been shown to be effective in capturing ants for community ecology studies (Barton et al., 2024; Lassau & Hochuli, 2004; Savitha et al., 2008;). Traps were placed such that the rim of the container was flush with the substrate of deployment, and were completely filled with detergent water to reduce surface tension.

Traps were spaced a minimum of 30m apart within each land-use type to ensure independence of ant captures (Landsman & Thiel, 2021).

As passive sampling technique, they were left out for a period of 24-25 hours. A period of one day was selected based on observations made during reconnaissance surveys; high evaporation rates and good ant capture rates.

On collection of traps, ants were separated from any debris, and stored in 50ml plastic containers (labeled with trap ID) filled with 70% ethanol (Savitha et al., 2008) for later identification.

Identification of ants

Using Fayle et al. key for ant genera in Borneo (Fayle et al., 2014), ants were identified up until genus level, and further identified to morphospecies level based on morphological differences, using microscope.

This key contained majority of genera pertinent to the study system of Deccan inselbergs of Ramanagara taluk, with the exception of a few. Information from AntWeb and AntWiki were also used as a supplement to the above key.

Each morphospecies within a genus was given an ID. For example:- Monomorium A, Monomorium B, Monomorium C, etc.

In species with major and minor workers, only minor workers were considered for identification.

NOTE: In the context of this study, morphospecies are considered as species.

5.3 Quantification of Habitat Structure

To understand environmental gradients, and their relationship with patterns of ant community, habitat variables were measured at each trap location. Canopy cover, shrub cover, herbaceous vegetation cover, exposed (granite) rock cover were ocularly measured (Lassau & Hochuli, 2004) (Table 1) within a 2m radius, centered on the pitfall trap. GPS location for each pitfall trap was obtained using LocusMap app on mobile; elevation readings via digital elevation models (DEM) in QGIS software, were extracted post hoc.

Habitat variable	Score ->	0	1	2	3
Canopy Cover		0	< 30	30–70	> 70
(Exposed) rock cover		0	< 30	30–70	> 70
Shrub cover		0	< 30	30–70	> 70
Herbaceous vegetation cover		0	< 30	30–70	> 70

Table 1: Ocular method of quantifying habitat structure

5.4 Analytical Methods

5.4.1 Characterisation of Habitat Structure

To show that apriori classification of study area into inselberg vs matrix (mango plantation + natural habitat) was justified, and to visualize differences between the groups in terms of measured habitat variables, NMDS using Gower dissimilarity index was performed.

Compositional differences between groups was checked for significance using pairwise permutation multivariate analysis of variance (PERMANOVA) (Anderson & Walsh, 2013). To check for homogeneity of dispersion between different pairs of groups, permutational multivariate analysis of dispersion (PERMDISP) was carried out. Results of pairwise PERMANOVA were interpreted in the context of respective pairwise PERMDISP.

5.4.2 Ant Community Diversity

Basic community metrics like observed species richness, mean richness per trap, diversity indices, etc. were quantified for characterization of groups and their differences.

Rarefaction curves and Chao2 incidence-based richness estimator were used to check for adequacy of sampling across groups.

Mean richness per trap were calculated for respective groups, and analyzed for differences using analysis of variance (ANOVA) and checked for pairwise significance using Tukey's

HSD post-hoc test.

Rank occupancy curves (Mayor et al., 2015) were also plotted for each group for a visual representation of evenness, rarity.

5.4.3 Ant Community Composition

To visualize ant compositional differences between the groups, NMDS using Jaccard dissimilarity index was performed. Compositional differences between groups was checked for significance using pairwise permutation multivariate analysis of variance (PERMANOVA) (Anderson & Walsh, 2013). To check for homogeneity of dispersion between different pairs of groups, permutational multivariate analysis of dispersion (PERMDISP) was carried out. Results of pairwise PERMANOVA were interpreted in the context of respective pairwise PERMDISP.

5.4.4 Relationship between Habitat variables and Ant community patterns

Correlation test was run for all the habitat variables, and only those that were < 60% correlated were used for further analysis.

To understand how habitat variables influence ant species richness, Generalized Linear Model (GLM) was run with Poisson distribution, after checking for overdispersion of data. Prior to running the model, predictors were scaled to make sure output showed relative significance,.

To link patterns of ant species composition with patterns of habitat variables (at trap level), canonical correspondence analysis was performed. To account for presence of rare species, all singletons (species present in only a single trap) were excluded from the CCA (Matos et al., 2012). Permutation based significance of the CCA model was done using ANOVA (analysis of variance) in Rstudio.

6. RESULTS

6.1 Characterization of Habitat Structure

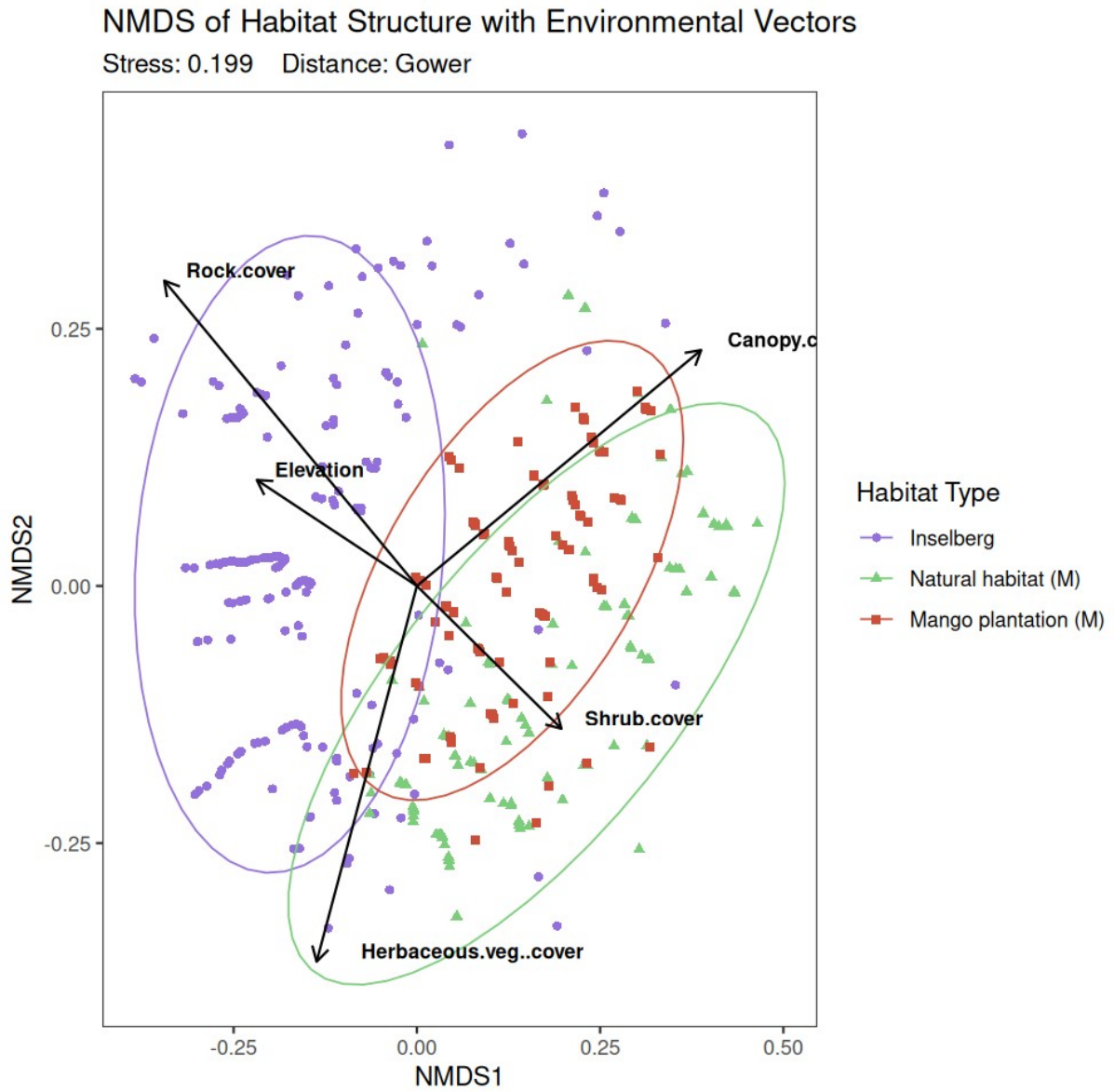


Figure 2: NMDS plot of habitat structure with environmental vectors

Visually, the NMDS plot (Figure 2) showed distinct clusters for inselberg and the 2 matrix land use types → natural habitat and mango plantation. The inselberg sites were positively associated with elevation and rock cover, something that the matrix was not characterised by. Natural habitat and mango plantation sites were more similar in habitat structure, mainly associated with the vegetation variables (canopy cover, shrub cover and herbaceous vegetation cover). Natural habitat sites were more strongly associated with shrub cover (visually) than mango plantation, indicating a higher vegetation structure complexity.

Comparison	R ²	F (PERMANOVA)	p-value (PERMANOVA)	F (PERMDISP)	p-value (PERMDISP)
Inselberg vs Matrix	0.35	250.49	0.001	1.06	0.280
Inselberg vs Natural Habitat	0.35	181.01	0.001	0.47	0.500
Inselberg vs Plantation	0.33	176.10	0.001	4.53	0.040
Plantation vs Natural Habitat	0.16	44.40	0.001	24.42	0.001

Table 2: Pairwise PERMANOVA and associated PERMDISP results for habitat structure

PERMANOVA results (Table 2) were significant ($p = 0.001$) for all pairwise combinations, indicating that average habitat structure was statistically different across groups. Habitat structure of inselbergs was on average, significantly different from matrix ($R^2 = 0.35$), and natural habitat ($R^2=0.35$). While inselbergs were dissimilar to mango plantation sites ($R^2 = 0.33$), significant PERMDISP output ($p = 0.04$) implies that the habitat structure differences are influenced by heterogeneity of dispersion. The same is the case for dissimilarity of the 2 matrix land-use types in terms of habitat structure ($R^2 = 0.16$).

6.2 Ant community diversity

A total of 462 traps captured 63 ant species - 29 genera – 6 subfamilies, across the entire study area in Ramanagara taluk, Karnataka. Myrmicinae was the most widespread subfamily, with 11 genera constituting 25 species. *Paratrechina A* was the species that occurred in most number of traps across the study area.

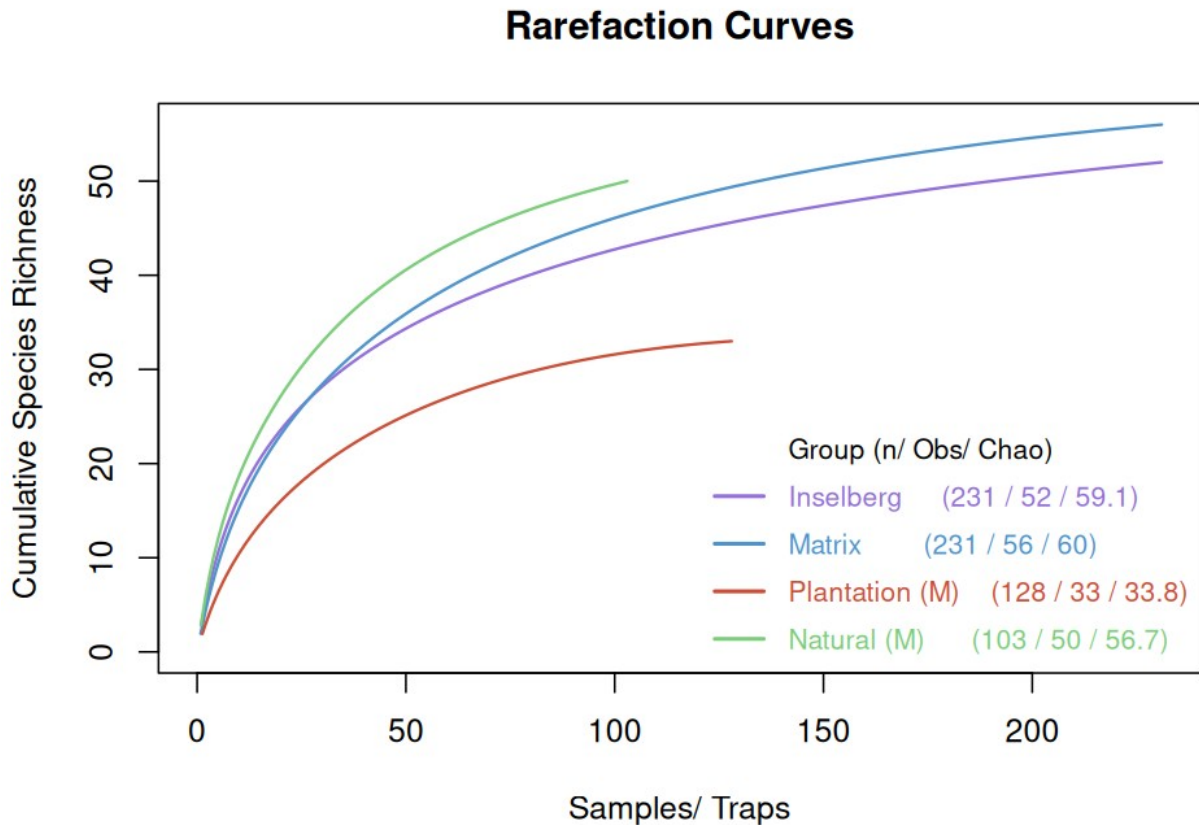


Figure 3: Sample based rarefaction curves for respective groups; n = number of traps sampled (Obs = observed species richness, Chao = incidence-based richness estimate)

The inselbergs and matrix were sampled equally as seen in the rarefaction curves (Figure 3), with 231 traps respectively being deployed. Within the matrix, 103 of the traps were in natural habitat group vs 128 traps in the mango plantations. The observed species richness for matrix (56) was slightly higher than for inselbergs (52). Delving deeper, it was found that natural habitat (50) had much higher observed species richness compared to mango plantations (33) despite having fewer traps. Based on the rarefaction curves, inselbergs and matrix seem to be fairly well sampled, though more sampling is needed to reach species saturation. This finding is supplemented by the values of chao2 richness estimation, which show that there are potentially still undetected species. While mango plantation is well sampled, the upwards trend of the natural habitat rarefaction curve and disparity between observed richness and chao2 estimated richness (50 vs 56) show that more sampling is required.

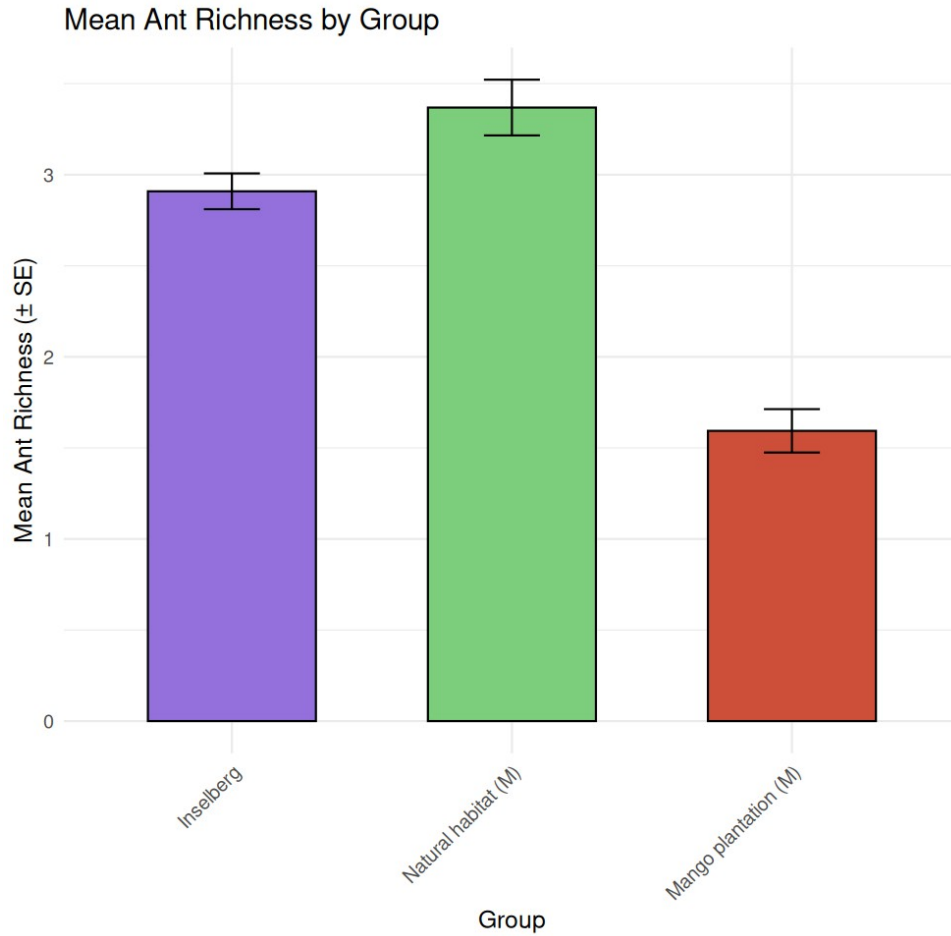


Figure 4: Mean trap richness (SE) across different groups

	Inselberg	Natural Habitat (M)	Mango Plantation (M)	p-value (ANOVA)
Mean Trap Richness (SE)	2.91 (0.09)	3.37 (0.15)	1.59 (0.12)	< 0.001

Table 3: ANOVA result for mean trap richness differences across groups

Mean trap richness was seen to be highest for natural habitat, and lowest for mango plantations (Figure 4). Inselbergs, while not as species rich at trap level as natural habitat, were much higher than mango plantations in terms of the same. The ANOVA results (Table

3) showed statistical significance ($p < 0.001$) for differences between the respective groups, while Tukey's HSD post-hoc test showed that all pairwise differences were statistically significant.

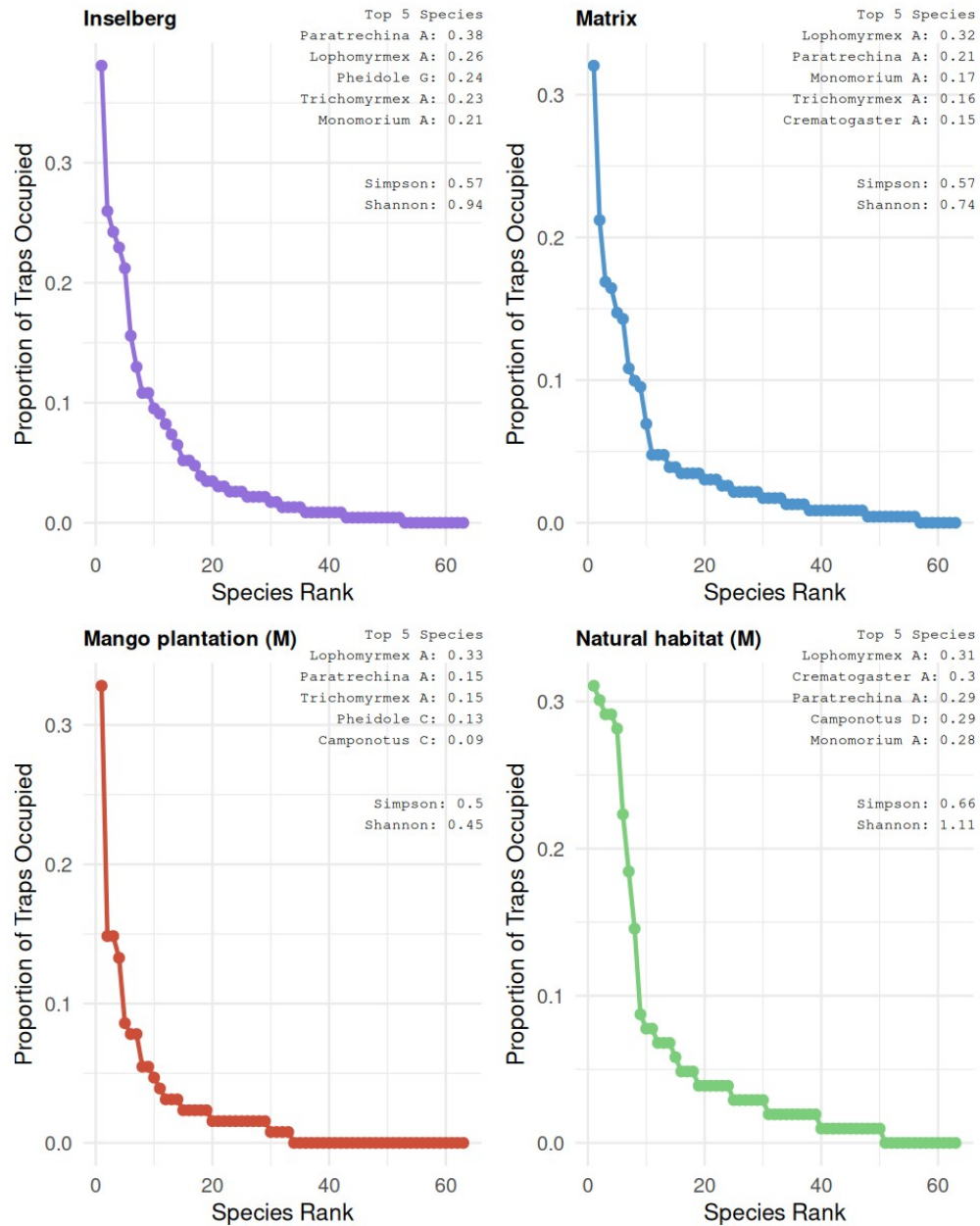


Figure 5: Rank occupancy curves and top 5 most dominant species for respective groups

The rank occupancy curves and Simpson diversity index value (Figure 5) showed similar unevenness for both inselbergs and matrix (Simpson = 0.57). Mango plantation was the most uneven (Simpson = 0.5) with *Lophomyrmex A* occupying the most traps (33%), and low associated Shannon value (0.45) due to least species richness. Natural habitat was the most even, with the top 5 species having almost similar proportion of traps occupied. *Paratrechina A* and *Lophomyrmex A* were the 2 most dominant species in both the inselbergs and matrix.

6.3 Ant Community Composition

Comparison	R ²	F (PERMANOVA)	p-value (PERMANOVA)	F (PERMDISP)	p-value (PERMDISP)
Inselberg vs Matrix (combined)	0.02	5.14	0.001	2.29	0.130
Inselberg vs Natural Habitat (M)	0.18	45.36	0.001	15.01	0.001
Inselberg vs Plantation (M)	0.16	42.66	0.001	56.92	0.001
Plantation vs Natural Habitat	0.10	15.17	0.001	8.32	0.009

Table 4: Pairwise PERMANOVA and associated PERMDISP results for ant community composition

All of the pairwise PERMANOVA results (Table 4) were statistically significant ($p = 0.001$), showing that average community composition of groups is different. Despite statistical significance of difference in average ant species composition for inselbergs vs matrix, the effect size (of group classification) is low ($R^2 = 0.02$), implying that they are actually quite similar in terms of their ant average community composition. The other 3

pairwise PERMANOVA ranged from 0.1 to 0.18, showing greater average dissimilarity in ant species composition. However the PERMDISP results for the above mentioned pairs were significant, indicating an influence of heterogeneity of dispersion on the respective pairwise PERMANOVA results.

6.4 Relationship between Habitat variables and Ant community patterns

Model Formula	Ant_Richness ~ Rock.cover + Canopy.cover + Shrub.cover + Herbaceous.veg.cover + Elevation
Model Family	Poisson
Residual Degrees of Freedom	456
McFadden's R-squared	0.03

Table 5: GLM summary for ant richness

	Estimate (SE)	p-value
(Intercept)	0.95 (0.03)	< 0.001
Rock cover	0.12 (0.04)	< 0.001
Canopy cover	-0.08 (0.04)	0.03
Shrub cover	0.12 (0.03)	< 0.001
Herbaceous veg. cover	0.11 (0.03)	0.001
Elevation	-0.08 (0.03)	0.02

Table 6: Coefficient values for predictors of GLM for ant richness

The GLM with all habitat variables as predictors, using Poisson distribution was performed (Table 5). The McFadden' pseudo R^2 value (0.03) suggested a poor fit of the model for the

collected data.

All the predictor variables were significant in explaining the ant richness observed (Table 6). Rock cover, shrub cover and herbaceous vegetation cover were all positively correlated to ant richness. However, canopy cover and elevation were seen to be negatively associated with ant richness.

CCA Ordination: Ant Composition ~ Habitat Structure

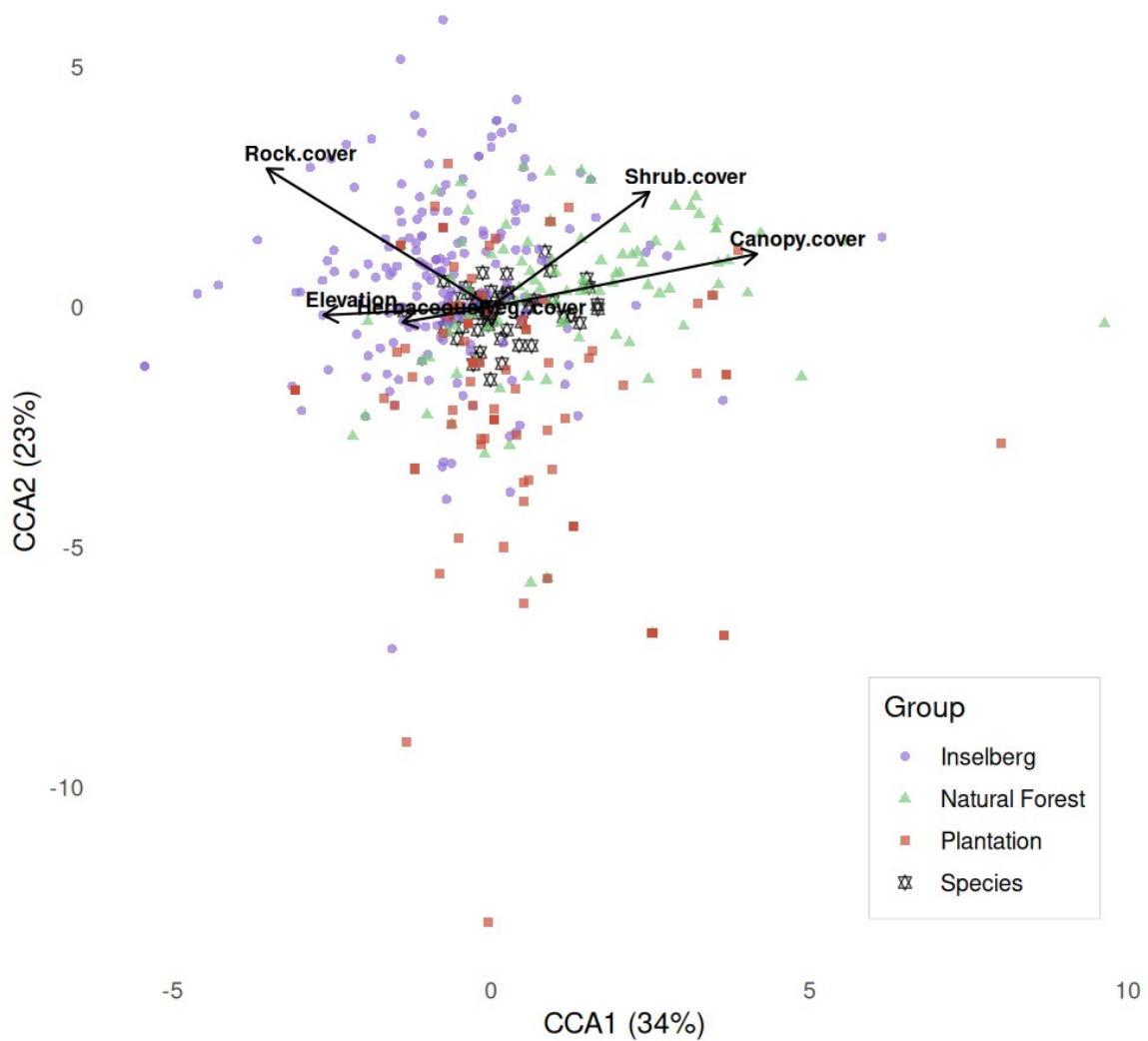


Figure 6: CCA biplot showing relationship between species composition and environmental vectors

The CCA biplot (CCA1 = 34%, CCA2 = 23%) visually suggests clustering of traps/ sites based on broad habitat type, i.e., inselbergs, natural habitat, mango plantation, with greater overlap between the latter two (Figure 6). Rock cover and canopy cover seem to be influencing the ant communities (trap level) as indicated by their longer arrow lengths.

V1	Inertia	Proportion	F(ANOVA)	p-value(ANOVA)
Total	17.8	1		
Constrained	0.51	0.029	2.48	0.001
Unconstrained	17.29	0.97		

Table 7: CCA output – partitioning of scaled chi square and anova result of model

The permutation test (ANOVA) for the CCA (Figure 7) showed statistical significance (F = 2.48, p = 0.001), indicating that the combination of environment variables have an influence on the patterns of ant composition in the study area. However, on closer inspection, the proportion of total variance in ant composition explained by the CCA was 2.9%, which highlights minimal effect size of the the combination of environment vectors.

7. DISCUSSION

7.1 Habitat Structure

My study of ant communities in Ramanagara taluk, Karnataka was built on the foundational idea that inselbergs exist as unique island-like landforms within a human-altered matrix of multiple land-use types. The significant differences in habitat structure of inselbergs compared to the matrix (natural habitat, mango plantation) align with the apriori classification of broad scale habitat types. The strong association of inselberg sites with rock cover and elevation, coupled with inconsistent vegetation occurrence relate well with global characterization of inselbergs as unique habitats (Porembski & Barthlott, 2000). The matrix was not consistent in relation to vegetation structure/ complexity. Mango plantations were less structurally complex compared to natural habitat, highlighting that continued human alteration of matrix will be linked to loss of habitat complexity.

7.2 Ant Community Diversity

This study explored ant community across the landscape and its constituent groups, providing much needed information in relation to understudied inselberg- matrix systems

and systematic studies of faunal communities associated with them. Basic community metrics were very informative; inselbergs showed comparable richness to matrix (Privet et al., 2018), highlighting that these neglected, threatened ecosystems (Porembski et al., 2016) do not align with the notion of being “barren wastelands” in the slightest. Closer inspection of matrix in terms of the 2 major land use types, i.e., natural habitat and mango plantation showed stark differences. Not only were mango plantations more uneven in terms of relative presence of different species (disproportional dominance), they were also much more species poor than natural habitat as a whole. Intuitively, in light of rapid land-use alteration and associated loss of natural habitat, this disparity suggests significant loss of ant diversity within the matrix in the future. This loss is potentially of greater magnitude since the natural habitat sites cumulatively did not reach species saturation, in contrast to the mango plantations. The idea of inselbergs acting as biodiversity refugia in light of the rapid human mediated alteration of surrounding matrix is further reinforced via patterns of ant diversity observed within the landscape.

7.3 Ant Community Composition

On average, the composition of inselbergs was quite similar to the matrix ($R^2 = 0.02$); likely due to some widespread species present all across the landscape. However, on closer inspection of pairwise compositional differences, it can be seen that the inselbergs vary in ant composition to a greater degree when compared to mango plantation ($R^2 = 0.16$) and

natural habitat ($R^2 = 0.18$) as separate entities. These results further signify that alteration of matrix more towards mango plantation dominance and associated loss of natural habitat can lead to increasing importance of inselbergs as biodiversity refugia.

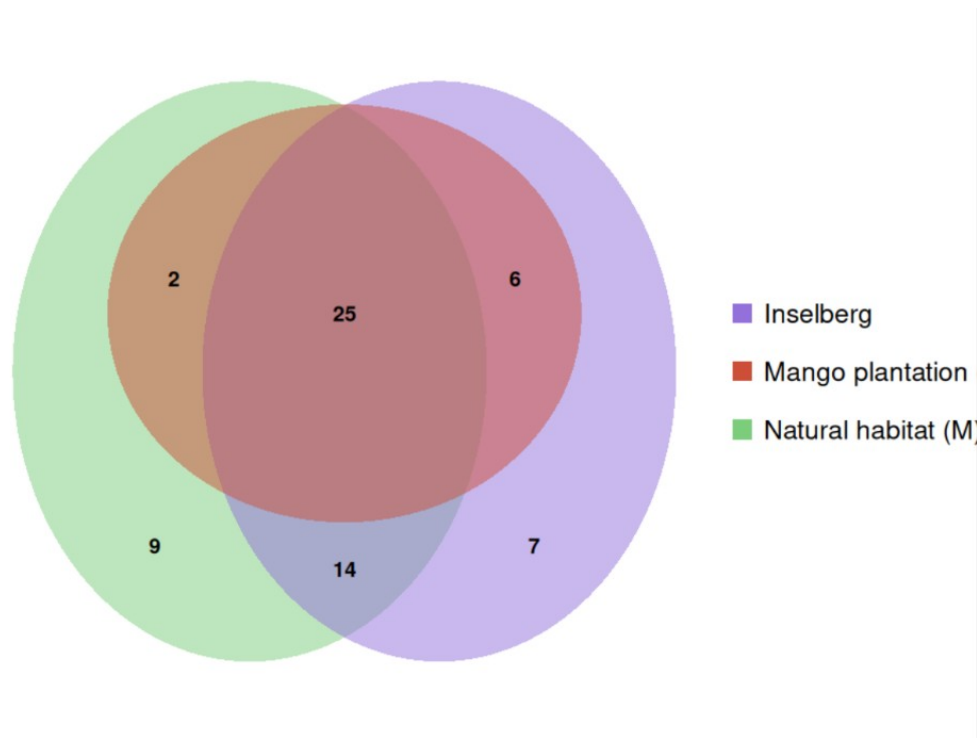


Figure 7: Venn diagram showing overlap of species between inselberg and matrix (mango plantation, natural habitat)

Visually from the Venn diagram (Figure 7), it can be seen that inselbergs have species that are not present within the matrix (Privet et al., 2018), indicating turnover is influencing the difference between the two broadly defined strata. Plantation species are a subset (high nestedness) of the species composition of the inselberg and natural habitat groups. Matrix alteration to more mango plantation dominance will potentially cause the loss of unique

species present in natural habitat and reduce the overall species richness of the landscape. This is further reasoning that indicates the importance of inselberg conservation, and conserving regional diversity.

7.4 Relationship between Habitat variables and Ant community patterns

The GLM for which ant richness was the response variable, showed that habitat variables like shrub cover and herbaceous vegetation cover positively influence ant richness at the trap level; increase in habitat complexity correlating with species richness (McCoy & Bell, 1991). The positive correlation of rock cover and species richness also hint at the same relationship. The presence of boulders, clefts, rock crevices (Porembski & Barthlott, 2000) are likely creating a more complex, heterogeneous habitat, influencing the ant community. Canopy cover was seen to be negatively associated with ant species richness, going against the pattern seen in similar studies (Barton et al., 2024; Savitha et al., 2008). However low canopy cover, in addition to the higher temperatures of granite surface of inselbergs (Porembski & Barthlott, 2000) could be positively facilitating the occurrence and richness of ants, which are thermophiles (Lassau & Hochuli, 2004)

While we discussed earlier about how the habitat structure varied across different trap sites, this habitat gradient was not a strong predictor of ant composition patterns at trap level (despite showing statistical significance). While the combination of habitat variables like canopy cover, rock cover, shrub cover, herbaceous vegetation cover are significant in shaping the ant community, there are likely other factors shaping the composition and

richness patterns. The significant differences seen in mean trap richness between groups might be due to some other factors, apart from habitat structure measured in this study. Microclimate variables like ambient temperature, surface temperature, humidity, soil characteristics, or generalist species' local distribution could be influencing the patterns observed (Ferreira & Silva, 2001; Lassau & Hochuli, 2004).

8. CONCLUSION

My study aimed to understand patterns of ant community as a proxy for highlighting the ecological and conservation potential of understudied, neglected Deccan inselbergs. Despite being a relatively short term study, the findings were of paramount importance. Inselbergs, which may look barren at first glance, were shown to harbor significant diversity as compared to the surrounding matrix in the study area of Ramanagara taluk. Not only was ant richness comparable between the two, inselbergs showed dissimilarity in species composition, especially when compared to the natural habitat and mango plantations as separate entities. There were stark differences between mango plantations and natural habitat within the matrix too; the human altered plantations are a risk to ant diversity within the Ramanagara landscape, showing uneven community structure and lowered species richness. The natural habitat, however, were observed to be excellent reservoirs of ant diversity. From a conservation standpoint, the natural habitat and associated ecological diversity is at greatest risk of land-use alteration to plantation, due to how accessible it is to humans. Seeing how rapid the land use of Ramanagara has been altered, it is not unrealistic to visualize a near-future scenario of minimal natural habitat remaining within the matrix. Inselbergs in that case, with their distinct habitat structure and inaccessibility for agriculture/ plantation, can act as refugias and help conserve regional biodiversity. However, threats to inselbergs like quarrying for granite, invasion by non-native species, etc. need to be mitigated in order for them to realize their full ecological, conservation potential.

In relation to the fine-scale habitat gradients, while they were shown to be drivers of richness and composition patterns, they explained a small portion of the total variation seen. To supplement our understanding of community assembly in inselberg-matrix systems at fine scales, further studies need to incorporate understanding of temperature, humidity, soil characteristics, species specific ecological aspects and dispersal capabilities, etc. Also, ants are just one taxa amongst many present within the inselberg ecosystems. Other micro-habitat specific taxa like spiders and lizards can provide a more comprehensive understanding of the ecological distinctness and potential of inselbergs, in comparison to their surroundings.

9. LIMITATIONS OF THE STUDY

Pitfall traps by themselves cannot capture the entire diversity of ants present. They need to be supplemented with other sampling techniques like visual surveys (day and night), bush beating, sweep netting, etc. This can capture arboreal ants better for example, the lack of which can skew compositional and richness patterns.

The rarefaction curves show that species richness has not reached saturation for some of the groups. This needs to be addressed with greater sampling effort.

10. REFERENCES

Anderson, M. J., & Walsh, D. C. I. (2013). PERMANOVA, ANOSIM, and the Mantel test in the face of heterogeneous dispersions: What null hypothesis are you testing? *Ecological Monographs*, 83(4), 557–574. <https://doi.org/10.1890/12-2010.1>

Baidya, P., & Bagchi, S. (2022). Influence of human land use and invasive species on beta diversity of tropical ant assemblages. *Insect Conservation and Diversity*, 15(1), 73–85. <https://doi.org/10.1111/icad.12536>

Barton, P. S., Evans, M. J., & Lewis, J. (2024). Microhabitats shape ant community structure in a spatially heterogeneous grassy woodland. *Ecosphere*, 15(4), e4798. <https://doi.org/10.1002/ecs2.4798>

Begum, R., Majagi, S. H., & K.Vijaykumar. (2021). Ants species richness and diversity in relation to different ecological habitat in selected localities of the semi-arid region of Karnataka, India. *Environmental Monitoring and Assessment*, 193(3), 145. <https://doi.org/10.1007/s10661-021-08941-2>

Fayle, T., Yusah, K., Hashimoto, Y., 2014. Key to the ant genera of Borneo in English and Malay. [http://www.tomfayle.com/Ant% 20key. htm](http://www.tomfayle.com/Ant%20key.htm).

Ferreira, R. L., & Silva, M. S. (2001). *Biodiversity under rocks: The role of microhabitats in structuring invertebrate communities in Brazilian outcrops*.

Gotelli, N. J. (1999). How Do Communities Come Together? *Science*, 286(5445), 1684–1685. <https://doi.org/10.1126/science.286.5445.1684a>

Jha, A., & Vasudevan, K. (2020). Demographic history of the fragmented yellowthroated bulbul (*Pycnonotus xantholaemus*) population in the Deccan Peninsula, India. *Endangered Species Research*, 43, 199–207. <https://doi.org/10.3354/esr01062>

Kumar, S., Gupta, S., Kanna, N., & Sivaram, K. (2020). Crustal structure across the Deccan Volcanic Province and Eastern Dharwar craton in south Indian shield using receiver function modelling. *Physics of the Earth and Planetary Interiors*, 306, 106543. <https://doi.org/10.1016/j.pepi.2020.106543>

Landsman, A. P., & Thiel, C. R. (2021). Habitat characteristics and climatic factors influence microhabitat selection and arthropod community structure in a globally rare central Appalachian shale barren. *Ecology and Evolution*, 11(24), 18169–18180. <https://doi.org/10.1002/ece3.8413>

Lassau, S. A., & Hochuli, D. F. (2004). Effects of habitat complexity on ant assemblages. *Ecography*, 27(2), 157–164. <https://doi.org/10.1111/j.0906-7590.2004.03675.x>

MacArthur, R. H., & Wilson, E. O. (1963). AN EQUILIBRIUM THEORY OF INSULAR ZOOGEOGRAPHY. *Evolution*, 17(4), 373–387. <https://doi.org/10.1111/j.1558-5646.1963.tb03295.x>

Main, B. Y. (2000). Journal of the Royal Society of Western Australia. *Journal of the Royal Society of Western Australia*.

Matos, M. C. B., Sousa-Souto, L., Almeida, R. S., & Teodoro, A. V. (2012). *Contrasting Patterns of Species Richness and Composition of Solitary Wasps and Bees (Insecta: Hymenoptera) According to Landuse*.

Mayor, S. J., Boutin, S., He, F., & Cahill, J. F. (2015). Limited impacts of extensive human land use on dominance, specialization, and biotic homogenization in boreal plant communities. *BMC Ecology*, 15(1), 5. <https://doi.org/10.1186/s12898-015-0037-9>

McCoy, E. D., & Bell, S. S. (1991). Habitat structure: The evolution and diversification of a complex topic. In S. S. Bell, E. D. McCoy, & H. R. Mushinsky (Eds.), *Habitat Structure* (pp. 3–27). Springer Netherlands. https://doi.org/10.1007/978-94-011-3076-9_1

Michael, D. R., Cunningham, R. B., & Lindenmayer, D. B. (2008). A forgotten habitat? Granite inselbergs conserve reptile diversity in fragmented agricultural landscapes. *Journal of Applied Ecology*, 45(6), 1742–1752. <https://doi.org/10.1111/j.1365-2664.2008.01567.x>

Mutharaj, D., & Rayamane, A. S. (2020). LAND UTILIZATION CHANGES IN RAMANAGARA DISTRICT: A GEOGRAPHICAL APPROACH. *Geographical Analysis*, 9(2), 7–10. <https://doi.org/10.53989/bu.ga.v9i2.2>

Porembski, S., & Barthlott, W. (Eds.). (2000). *Inselbergs* (Vol. 146). Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-642-59773-2>

Porembski, S., Silveira, F. A. O., Fiedler, P. L., Watve, A., Rabarimanarivo, M., Kouame, F., & Hopper, S. D. (2016). Worldwide destruction of inselbergs and related rock outcrops threatens a unique ecosystem. *Biodiversity and Conservation*, 25(13), 2827–2830. <https://doi.org/10.1007/s10531-016-1171-1>

Privet, K., Courtial, C., Decaens, T., Djoudi, E. A., Vedel, V., Ysnel, F., & Pétillon, J. (2018). *Spider assemblage structure in a neotropical rainforest-inselberg complex: Ecological and methodological insights from a small-scale intensive survey.*

Savitha, S., Barve, N., & Davidar, P. (2008). Response of ants to disturbance gradients in and around Bangalore, India. *Tropical Ecology*, 49(2), 235-243.

Schweiger, O., Maelfait, J. P., Van Wingerden, W., Hendrickx, F., Billeter, R., Speelmans, M., Augenstein, I., Aukema, B., Aviron, S., Bailey, D., Bukacek, R., Burel, F., Diekötter, T., Dirksen, J., Frenzel, M., Herzog, F., Liira, J., Roubalova, M., & Bugter, R. (2005). Quantifying the impact of environmental factors on arthropod communities in agricultural landscapes across organizational levels and spatial scales. *Journal of Applied Ecology*, 42(6), 1129–1139. <https://doi.org/10.1111/j.1365-2664.2005.01085.x>

Watve, A. (2013). Status review of Rocky plateaus in the northern Western Ghats and Konkan region of Maharashtra, India with recommendations for conservation and management. *Journal of Threatened Taxa*, 5(5), 3935–3962. <https://doi.org/10.11609/JoTT.o3372.3935-62>

Yates, C. J., Robinson, T., Wardell-Johnson, G. W., Keppel, G., Hopper, S. D., Schut, A. G. T., & Byrne, M. (2019). High species diversity and turnover in granite inselberg floras highlight the need for a conservation strategy protecting many outcrops. *Ecology and Evolution*, 9(13), 7660–7675. <https://doi.org/10.1002/ece3.5318>

Yekwayo, I., & Mwabvu, T. (2019). Diversity and composition of flightless arthropods on rock outcrops and adjacent vegetation in the savannah, Mpumalanga Province, South Africa. *African Journal of Ecology*, 57(3), 443–447. <https://doi.org/10.1111/aje.12617>