RICHNESS AND COMPOSITIONAL RESPONSES OF ANTS TO LAND USE CHANGE

Thesis submitted for the award of

MASTER'S DEGREE
in
WILDLIFE SCIENCE

by

MOHAMMAD ABDUS SHAKUR

to

Saurashtra University
Rajkot - 360005

Under the Guidance of

Dr. Gautam Talukdar
Dr. Navendu Page
Dr. M. Jadegowda

भारतीय वन्यजीव संस्थान
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DECLARATION

I, **Mohammad Abdus Shakur**, hereby declare that the research work entitled **"Richness and compositional responses of ants to land use change",** 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. Gautam Talukdar, Dr. Navendu Page and Dr. Jadegowda at the Wildlife Institute of India from January 2021 to July 2021. I hereby declare that this work has not been submitted for any other degree of any university.

Mr. Mohammad Abdus Shakur
(XVII M.Sc. Wildlife Science

Date: 13th August, 2021
Place: Dehradun

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CERTIFICATE

This is to certify that **Mr. Mohammad Abdus Shakur,** 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 her dissertation is **"Richness and compositional responses of ants to land use change".** The study was carried out under our supervision from January 2021 to July 2021. We hereby certify that this work has not been submitted for any degree to any university.

[Dr. Gautam Talukdar]	**[Dr. Navendu Page]**	**[Dr. M. Jadeyegowda]**
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CERTIFICATE OF PLAGIARISM CHECK

It is certified that the M.Sc thesis titled "**Richness and compositional responses of ants to land use change**" submitted by Mr. Mohammad Abdus Shakur has been examined by us for plagiarism check as per UGC (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations. The following inferences are drawn from this check:

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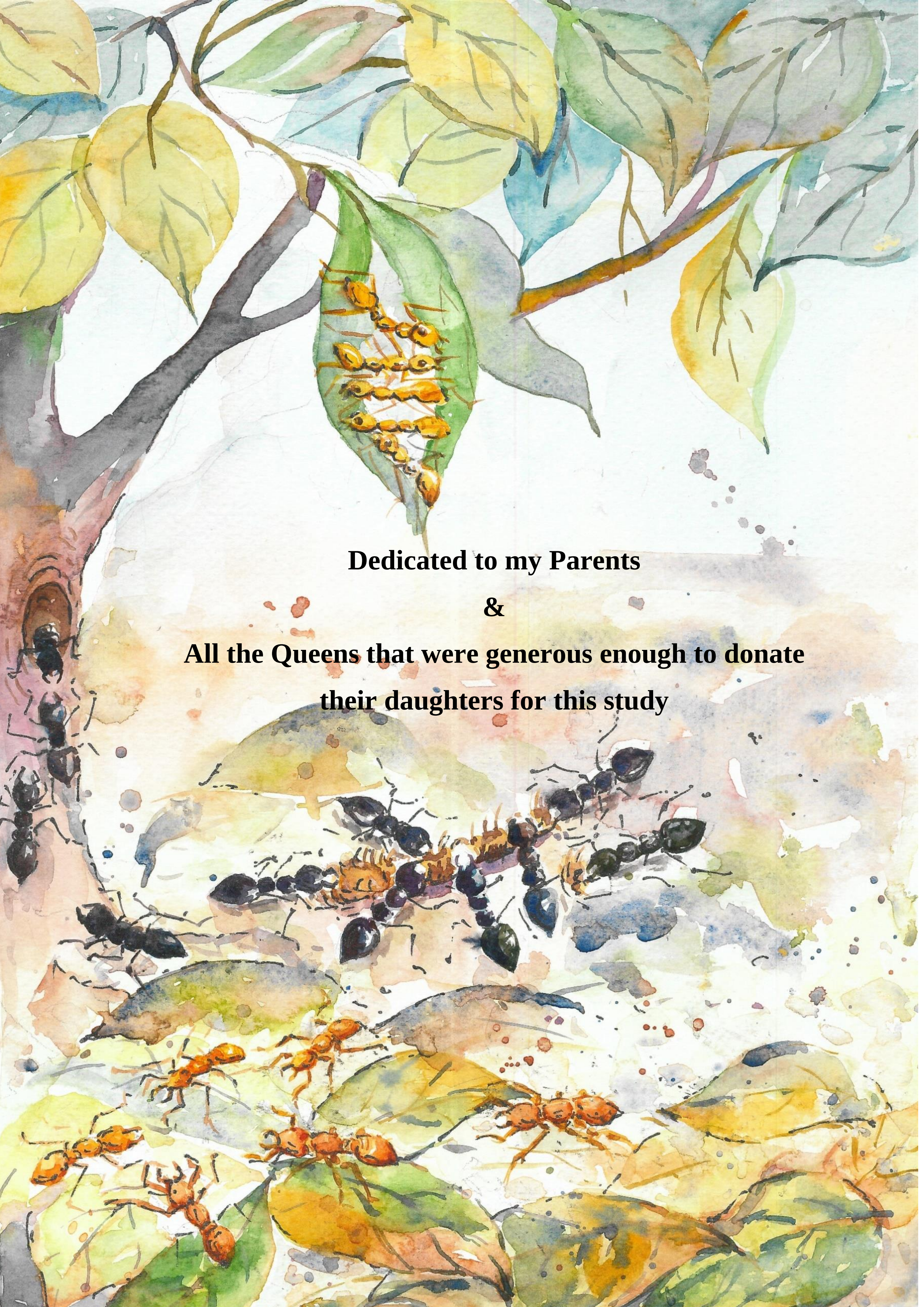

Dedicated to my Parents

&

All the Queens that were generous enough to donate their daughters for this study

Painting by: Poonam pal

Species in the painting from top to bottom -

1. *Oecophylla smaragdina*, (Asian Weaver Ant) weaving its nest
2. *Crematogaster* sp. feeding on a caterpillar
3. *Strumigenys* sp. foraging amidst the leaf litter

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SUMMARY

Human-made changes to the ecosystem are leading to the loss of biodiversity across the world. Western Ghats (WG) known for its rich biodiversity has historically undergone fragmentation and loss of its primary forest cover which has significant negative effects on biodiversity. Studies have shown that fragmentation almost invariably leads to a decrease in species richness, a pattern consistently observed across different taxonomic groups. Ants, one of the numerically dominant groups in forest ecosystems, play a vital role in many ecosystem processes and yet is one of the least studies groups within the WG landscape. The effect of land use change on ants in forests, fragments, native shaded coffee plantations and silver oak shaded coffee plantations was studied in the Kodagu district of Karnataka, India. We hypothesized that habitat heterogeneity would decrease from forests to fragments to native shaded coffee plantations and silver oak shaded coffee plantations and this would consequently lead to a decline in the richness and change in species composition of ants along this gradient. To test this prediction, ants were sampled along transects in the four-land use types using both pitfall traps and modified wrinkler extractors. As expected, there is a reduction in structural complexity across forest, fragments, native shade coffee and silver shade coffee plantations. We found that at the level of a transect, species richness reduced from forests to coffee plantations. Interestingly, the trend reversed when viewed at the scale of the land use, where all the forest sites together were the least species rich while the coffee plantations collectively showed the highest species richness. With respect to species composition, we found that coffee plantations had species adapted to drier environments whereas species inhabiting leaf litter were primarily found in forests and fragments. Coffee plantations with human residence inside had higher species compared to those not inhabiting. This study highlights the importance of scale for assessing the biodiversity potential of human modified habitats and for assessing their conservation potential.

Keywords- Formicidae, Western Ghats, Coffee plantations, Beta diversity, Land use change

INTRODUCTION

Human-induced changes in the ecosystems in the form of habitat fragmentation, habitat conversion, and degradation are causing loss of biodiversity both locally and globally (Newbold et al., 2015). Tropical forests, although harbouring a large chunk of biodiversity, are at the receiving end due to the human induced changes and need prioritized conservation (Laurance and Bierregaard, 1997; Malhi et al., 2014). Studies on the effects of fragmentation and habitat alterations have used a diverse set of groups ranging from mammals, birds, herpetofauna, and invertebrates (Almeida et al., 2016; Kapoor, 2008; Kurz et al., 2014; Ramesh and Downs, 2015). Some of the studies have found that habitat fragmentation and habitat alterations pose a serious threat not only to species but also to the key ecological processes like predation, decomposition, pollination, and parasitism (Baur and Erhardt, 1995; Kareiva, 1987; Klein, 1989; Koh, 2007; Kruess and Tscharntke, 2000; Powell and Powell, 1987; Riemann et al., 2017). Ants have been used as models to study the effects of fragmentation and land use changes (Andersen et al., 2002; Armbrecht and Perfecto, 2003; Brühl et al., 2003; JingWen et al., 2017; Leal et al., 2012; Tawatao et al., 2014). They are regarded as one of the best groups to study the response to land use change due to their functional and ecological dominance in the environments they live in and due to the range of functional roles they carry out as indirect herbivores, scavengers, and predators (Fittkau and Klinge, 1973; Wilson, 1990; Wilson and Hölldobler, 2005).

The conversion of land from its natural state has profound effect on various abiotic and biotic components, which are crucial in many ecosystem processes (Brambilla et al., 2010; Hadi et al., 2000). Interacting with other global changes, modifications in land use have a strong impact on the structure of biological communities factors (Arinaminpathy et al., 2009; Berg et al., 2015; Sala et al., 2000). The majority of the studies on land use changes have focused on understanding the effect of forest conversions into plantations within agroforestry systems.

These studies consistently report a negative impact on the species richness and alternation of community structure (Bickel and Suparoek, 2005; Brühl and Eltz, 2010; Fayle et al., 2010; Liu et al., 2016; Mauda et al., 2018; Nazarreta et al., 2020; Pacheco et al., 2009; Ratsirarson et al., 2002). Although agroforestry reduces the biodiversity of an area, traditional agroforestry systems like shade-grown coffee, which retains much of the native tree cover act as a refuge for biodiversity when compared to the altered matrix (Donald, 2004; Perfecto et al., 1996). However, intensification of management practices involving the replacement of native shade trees, with fast-growing exotic trees can significantly exacerbate the effect of fragmentation on ant communities (Armbrecht et al., 2005; Armbrecht and Perfecto, 2003; Asfiya et al., 2015; Perfecto et al., 1997; Philpott, 2005; Roth et al., 1994).

Studies have shown that fragmentation results in the alternation of ant community structure, disproportionate loss of specialist species, the proliferation of generalist and tramp species (species that have been spread around the world inadvertently by human commerce), and an overall reduction in the ant species richness by up to 50% (Brühl et al., 2003; Bruna et al., 2005; Gibb and Hochuli, 2002; Leal et al., 2012; Schoerder et al., 2004). Studies have also documented a reduction in the abundance of species that manage to persist post fragmentation (Leal et al., 2012; Tawatao et al., 2014). The decrease in the size of fragments has also been found to reduce the diversity of ants (Schoerder et al., 2004). Primary drivers of change in species richness of ant communities post fragmentation have been attributed to the alteration in the habitat characteristics like reduction in tree cover, tree density which possibly leads to altered microhabitats (for example- less leaf litter can be found, if the tree density is less thus affecting the leaf litter dwellers), increase in disturbances and prominent edge effects (Barrera et al., 2015; Carvalho and Vasconcelos, 1999; Debuse et al., 2007; Tawatao et al., 2014; Vasconcelos et al., 2006; Watt et al., 2002). In a recent study by González et al. it was found that there is an increased diversity of ants near the forest edges than the interior in fragmented forests which they attributed to the influence of species from the matrix (González et al., 2018).

In the Indian context, very few studies have investigated the effect of fragmentation on ants, although the findings from these are largely consistent with studies from other parts of the world; they have considered largely the taxonomic diversity (Badrinarayanan, 2001; Gadagkar et al., 1993; Mone et al., 2014; Mujeeb Rahman et al., 2012; Rajan and Marathe, n.d.; Vineesh et al., 2007). The Western Ghats in India is recognized as one of the global biodiversity hotspots due to high levels of diversity, endemism, and loss of primary forest cover (Myers et al., 2000). The landscapes in the Western ghats of India represent some of the oldest human-modified tropical forests and thus provide an opportunity to understand the responses of biodiversity to long-term habitat change (Anand et al., 2010). The understanding of ant communities in a highly fragmented landscape is lacking and a better understanding will give an important perspective of the group that is numerically dominant in these landscapes.

AIM

Objectives: To determine the effect of land use change on ant communities

Hypothesis:
As studies have shown that there is a decrease in species richness with a reduction in tree diversity and abundance. We hypothesized that a reduction in structural complexity of the vegetation from contiguous forests to forest fragments to native shade coffee to exotic shade coffee will lead to a reduction in species richness, change in species composition.

Research Questions:

1. How does ant species richness vary across different land use types?
2. How does the community composition vary across different land use types?

STUDY AREA

The Kodagu district of Karnataka, known widely as Coorg, is a land of mist and greenery, carved by the diverging roads and never-ending list of hill stations. It is one of the sparsely populated districts of the Karnataka state and places are well connected by road ("Kodagu District, Government of Karnataka," 2021). The district lying amidst the Western ghats mountain chain is rich in biodiversity and exhibits a high percentage of endemic flora and fauna. The district has an elevation ranging from 80 m at the Makutta section to ~1750 m on the top of the Tadiandamol peak (the highest peak in the district). Most of the district lies in the elevation range of 800- 1100 m creating a landscape that is dotted with hills all along. Major towns namely, Madikeri, Virajpet, are located on top of these hills and are less populated as there are many small villages spread out around. The hills, if not populated, are dotted with trees intended for agroforestry, dominated by coffee and other plantation crops. The valley floors are used as paddy fields and appear as wastelands during the non-growing season as they remain waterlogged and other grasses and shrubs grow. These agroforestry coffee plantations make Kodagu the topmost coffee-producing district in the country (Coffee Board of India, 2021). The district receives an average of 2000 – 5000 mm rainfall in the central and western parts and central-eastern parts receiving about 1500- 2000 mm annually and an average temperature of 24°C and increasing up to 30°C in the hotter months. It received an average rainfall of 2664 mm between the years 2014-18 (Indian Meteorological Department, 2021). The study area experiences a dry season of about 4-5 months from December and April characterized by low moisture levels (Bhagwat, 2002).

The study was carried out during the late winter (mid-January to the first week of March) and was confined to the Virajpet taluk of the district. Wet-evergreen forest is the most dominant vegetation type within this district. Although the majority of the time it was dry, it rained heavily during the mid-January and late-February period for at least two days. During late February, the coffee plantations were immersed in fog during the early hours of the day which cleared out by 9 AM.

The major land-use types of this area include undisturbed forests, forest fragments, coffee plantations, and paddy fields.

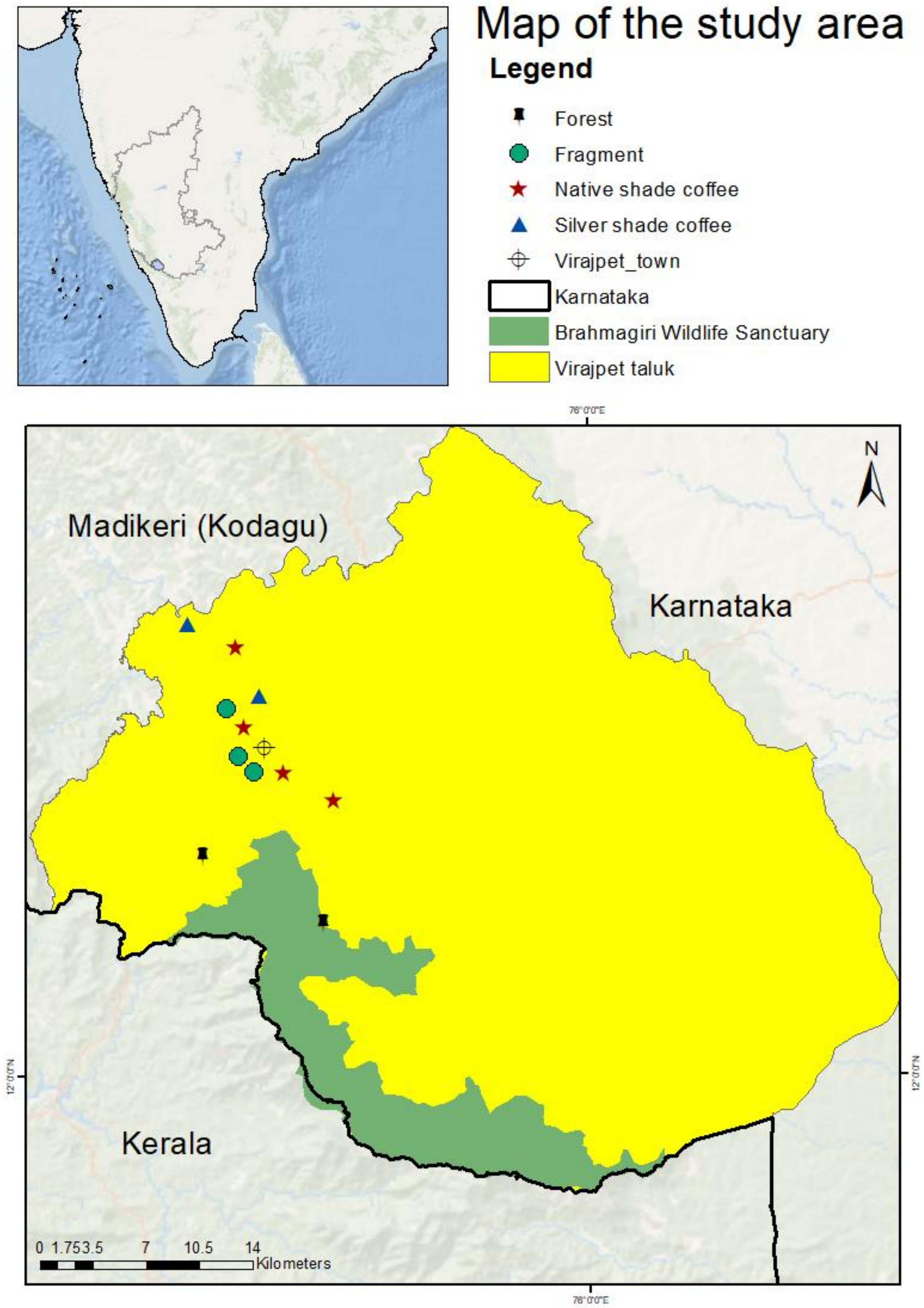

Figure 1: Map of the study area.

Continuous and undisturbed forests

The Kodagu district is covered by evergreen forests along the Western Ghats mountain chain on the western and north-western parts while the deciduous forest is mostly found along the eastern parts of the district. Much of the continuous and undisturbed forests exist either in the form of protected areas (Wildlife sanctuaries or National parks) or in the form of reserve forests. The forests in the Western Ghats section are protected as Brahmagiri Wildlife Sanctuary (WLS), Talacauvery WLS, Pushpagiri WLS, and reserve forests. All the sampling sites including the forest fragments, coffee plantations, and the contiguous forests fall within the wet-evergreen forest type.

Figure 2: The different land use types considered in this study, each different from the other. (Taken in: Feb-2021)

Forest fragments/ Sacred grove

A large number of forest fragments lie scattered in the form of sacred groves. Being primarily forest lands, these are owned by the forest department and are thus legally protected but are managed by the local communities as common property. Locally called “Devarakad/ Devarakadu”, each fragment has a deity of its own that is worshipped and maintained by the locals and a small water body for the associated activities. Each village has at least one devarakadu associated with it and the overall density of sacred groves in Kodagu is one in every 300 ha (Bhagwat et al., 2005a; Kushalappa and Bhagwat, 2001). These sacred groves often range from less than a hectare to a few ten hectares in area (Bhagwat et al., 2005b). There are around 121 different deities each with its unique forms of worship practiced by 18 different local communities. Bhadrakali, Bhagavathi, Naga, Aiyappa, Eshwara, and Ajappa are some of the common deities worshipped in Devarakadu and each deity has an associated folk story, which connects them closely to the villagers. These deities are considered as protectors and guardians of villages they are huddled in. All the local villagers gather annually/ biannually in the Devarakadu to celebrate the ‘Devarakadu Habba’ or the sacred grove festival (Kushalappa, 2014). Apart from these festival gatherings only the priest visits daily for the puja, or few devotees visit during the off season.

Figure 3: A) A Devarakadu in a matrix of Paddy. B) A fragment that is encroached for resources (here red soil for construction). (Taken on: 16-Mar-2021)

Each of these Devarakadus differs in their deity and also in the way they are maintained. Some of them have just a deity and a small area roughly of 10 m^2 around it for the devotees and a central large tree in it and a well-used trail often overgrown with weeds lead to the deity.

Few of them are further upgraded to a small temple for the deity and a gravel path leading towards it. While those having gotten sponsors have a metalled road leading to the temple area with a small temple for the deity and few more buildings for devotees to sit during the festival. These fragments are threatened by humans either directly due to encroachment of the area from outside or inside for ever-growing coffee plantations, or for excavating soil that can earn huge profits and indirectly by the growth of weeds alongside the edges (both path and the periphery). These fragments deal with huge pressures from human activities daily. There is an increasing trend of people moving out of the villages and this has partly resulted in erosion of the faith and conservation values associated with this informal system of protection. As these forest patches get their protection mainly due to the underlying socio-religious beliefs, when the beliefs are no longer there, the existence is threatened.

Figure 4: The path leading to deity. A) A narrow and gravelled road preserving natural environment. B) A wide metalled road at the cost of the native trees. (Taken on: 16-Mar-2021)

Coffee Plantations

Coffee plantations are one of the prominent land use categories occupying up to 60% of the area in the district (Bhagwat et al., 2005b). *Coffea robusta* is the predominant type of coffee grown in Kodagu which is also the top contributor of this variety in the country (Coffee Board of India, 2021). Much of the coffee is shade-grown, as coffee is a shade-demanding species, for which most of the native tree cover is retained to provide shade for the coffee. Management practices like removal of the grasses and leaf litter during the growing season (April to November) make the coffee the only layer of understorey vegetation. The shade-giving trees are also pruned or felled to provide the optimum shade for the coffee below, which varies across the plantations.

Sometimes a few selected native trees are grown for their benefits like the *Artocarpus heterophyllus* (Jackfruit) whose canopy provides shade to coffee and fruits. While the usage of pesticides in the plantations hasn't been encountered, some of the plantations use insecticides like '**Gammaxene**' and '**Cypermethrin**' (0.25% DP) and the latter being used predominantly during the harvesting period. These are generally dusted in small amounts on the coffee fruits where ants are patrolling heavily, which kills the ants and the coffee fruits can be harvested.

Species of ants that are predominantly targeted are *Oecophylla smaragdina* (Asian weaver ant) and *Crematogaster* sp. which are arboreal and defend their nests and nesting trees aggressively and are frequently encountered nesting on the coffee plants. Sometimes other species which are not that aggressive also get killed when they move along the coffee plant. Very few plantation owners go to the extreme of dusting the whole coffee trees and the whole ground below coffee (after the harvest) giving it a makeover that essentially removes the majority of other invertebrates less alone ants. Very few coffee plantations exist in the landscape that are not managed and one can see another layer of vegetation growing below the coffee and the canopy trees not being pruned.

The coffee plantations are further classified into two types based on the nature of shade-giving trees (Nath et al., 2011).

1. **Native-Shaded Coffee Plantations (Native shaded coffee)**

   In these plantations, the shade is provided predominantly by the trees that are native and common in the region. Their canopies spreading far and wide are the predominant type of plantations. Some plantations have a small amount of young silver oak trees.

1. **Silver oak/ Exotic-Shaded Coffee Plantations (Silver shaded coffee)**

   With the added advantage of harvesting, the non-indigenous silver oak has been predominantly planted in some plantations replacing the native trees either completely or partially and predominates the canopy. It makes a uniform canopy layer due to their similar time of planting.

The study sites were selected such that they represent a uniform area (8-11 hectares), similar elevation (class range of 780- 910 m), evergreen vegetation type, and have similar matrix around them. All of the coffee plantations and fragments have paddy fields, coffee plantations, and roads surrounding them, even the forest sites had coffee plantations and roads near to the edge. All of the study sites were near the town of Virajpet. The coffee plantations with greater than 50 % of trees as silver oak were classified as silver oak/ silver shaded coffee plantations.

METHODOLOGY

The study was conducted across four predominant land use types in the study area – the continuous forests (forests), remnant forest fragments (fragments/ sacred groves), coffee plantations with native (Native shade coffee), and exotic shades (Silver shade coffee). The sites were selected such that they represented a similar size class and with similar topographic features. Selected sites were sampled for ants using the below mentioned techniques.

Structural attributes

For computing the structural attributes of each land use, vegetation data (Tree and shrub species, height, and girth) was collected during this study and also compiled from an earlier study (Page et al., 2010). The structural attributes were collected along a 10 X 60 m transect for trees and 5 X 5 m for the shrubs at the beginning and the end of each transect. The canopy cover was evaluated at each ant pitfall location along the transects using the GLAMA application in mobile.

Ant sampling

Leaf litter ants were sampled following the 'Ants of Leaf Litter' protocol (Agosti et al., 2000). Four transects were laid randomly in each site, sometimes using the existing paths to navigate. Transects were laid such that they spread across the site and maximizing the distance between the two nearest transects. Each Transect was 60 m in length and leaf litter ants were sampled at every 20 m. At each sampling point, the ants were sampled using both pitfall traps and wrinkler extraction (Figure 5).

- Pitfall traps consisted of paper cups filled with detergent (like surf excel) water kept inside the ground flushed up to the rim. The traps were kept active for a minimum period of 24 hours and a maximum of 26 hours from deployment. The catch in the pitfall was preserved in 70% ethanol.

- Wrinkler extraction of ants consisted of sampling the leaf litter in 0.5 m^2 area. The leaf litter and the topsoil up to 2 cm were scraped and transferred to a sieve with a mesh size of 1 inch and sieved. The siftate was collected in a white tray and the ants were collected using an aspirator. The catch was preserved in 70% ethanol. This method was modified from the original wrinkle extraction, where wrinkler apparatus is used and the leaflitter dwelling organisms move downwards and are collected in alcohol.
- For quantifying the amount of leaflitter, litter was weighed from the 0.5 m^2 plots after sifting the litter for invertebrates.

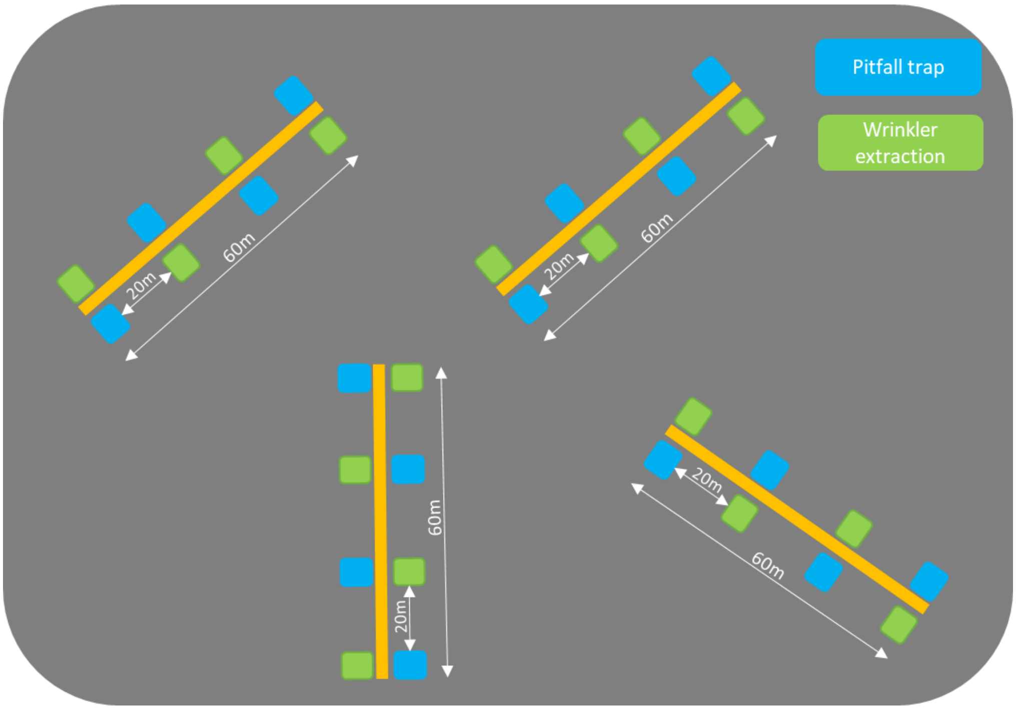

Figure 5: Sampling method of ants at a site.

Table 1: Description of the study sites in Kodagu district, Karnataka, India.

Land use	**Name**	**Location**		**Area (ha)**	**Elevation**	**No of transects**
		Latitude	Longitude			
Forest	Heggala RF	12° 7'49.20"	75°45'56.99"	>1000	910	4
Forest	Kokka RF	12° 5'26.34"	75°50'19.10"	>1000	800	4
Fragment	Arji	12°10'53.25"	75°47'49.13"	8.51	900	4
Fragment	Bettoli	12°11'24.55"	75°47'17.98"	9.72	914	4
Fragment	Kadanoor	12°13'6.23"	75°46'51.70"	9.07	908	4
Native shaded coffee plantation	Bittangala	12° 9'52.66"	75°50'44.09"	8	852	4
Native shaded coffee plantation	Chickpet	12°12'27.94"	75°47'28.82"	10	908	4
Native shaded coffee plantation	Mythadi	12°15'20.51"	75°47'12.20"	10	898	4
Native shaded coffee plantation	Panjarpet	12°10'52.80"	75°48'55.07"	8	903	4
Silver shaded coffee plantation	Bhetri	12°16'10.72"	75°45'24.91"	8.2	905	4
Silver shaded coffee plantation	Kotekoppal	12°13'38.55"	75°48'2.47"	8	893	4

Identification of ants

The collected ants were identified till the genus level using the key provided by Fayle et al. (Fayle et al., 2014). Although the key was developed primarily for ants of Malaysia, however, most of those tropical genera are represented in the Western Ghats it was used in the study. Multiple morphospecies in a single genus were considered as different species under the genus and given a species number in the order of identification. Only the worker caste was identified and considered in this study. In case a species had major and minor workers; the minor worker was considered for the identification. The descriptive images for species collected were drawn for reference (Appendix II).

Statistical methods

Statistical analysis was performed in R and Excel, and visualized using ggplot2 (R Core Team, 2020; Wickham, 2011). Data collected by both methods (pitfall and leaflitter extraction) was pooled into a single sample for further analysis. Species richness was rarefied to the least number of samples across all the sites across land use types. Species richness estimates for each land use were derived using classic Chao I estimates for the land use types using EstimateS,v.9.1.0 (Colwell, 2013). The rank abundance of species across sites was computed in R (BiodiversityR:: rankabuncomp) and plotted using ggplot2 (Kindt and Kindt, 2015). Mantel test was performed on the community data with the environmental variables to understand the variation in communities across sites with the variation in environment (Vegan:: Mantel) (Oksanen et al., 2013).

Generalized Mixed Effect Model’s (GLMM’s) were performed (glmmTMB:: glmmTMB) to understand the factors explaining the observed species richness (Magnusson et al., 2017). The predictor variables were scaled before running the model with a Poisson distribution. Non-metric multidimensional scaling (NMDS) was performed using bray-curtis dissimilarity with three dimensions at 1000 permutations

(Vegan::metaMDS) on transects grouped at land use type to visualize the grouping of transects across land use. The compositional similarity of communities across land use was checked using an analysis of similarity test (ANOSIM, Vegan::anosim). Berta diversity (Whittaker's Beta- $\beta = \gamma/\alpha$) was calculated at transects and site scale. Beta diversity was further decomposed into contributions by differences in richness and turnover [Jaccard index from the Baselga family (adespatial::beta.div.comp)] (Baselga, 2010; Dray et al., 2018). Local contribution of sites to the overall beta diversity (adespatial::LCBD.comp) was calculated to identify the sites that are driving the change in beta diversity across the landscape.

RESULTS

Overview

Eleven sites were sampled in total spanning the landscape around Virajpet comprising 2 sites for the forests, 3 sites for fragments, 4 shades for native shaded coffee, and 2 sites for the silver shaded coffee. A total of 70 species of ants representing 31 genera spanning 7 sub-families were collected during the sampling (Appendix I– Table 1). Mymricinae was the most widely represented subfamily with 29 species from 11 genera. The most species-rich genus was Leptogenys (Ponerinae) with 7 species and the most abundant species is Nylanderia sp. 1 (Formicinae). Nylanderia sp. 1 was the most frequently occurring species found in 24.12% of the 340 individual traps (trap level). Leptogenys sp. 1 and Pheidole sp. 2 were the most frequently occurring species in the transects, and were recorded in 77.27% of the 44 transects sampled.

Structural complexity

We examined multiple attributes of structural heterogeneity to check whether it declined from forests to fragments to coffee plantations, as initially hypothesized. We found that the land use types varied with each measure of the habitat characters assessed. The canopy cover (Figure 6A) and litter weight (Figure 6B) decreased from forests to silver shade coffee plantations, however between the forests and fragments canopy cover was comparable. The mean tree basal area was highest in fragments followed by native shade coffee plantation and then forests and silver shade coffee. The average height of vegetation was highest in forests followed by coffee plantations (both types are similar) and least in fragments (Figure 6D).

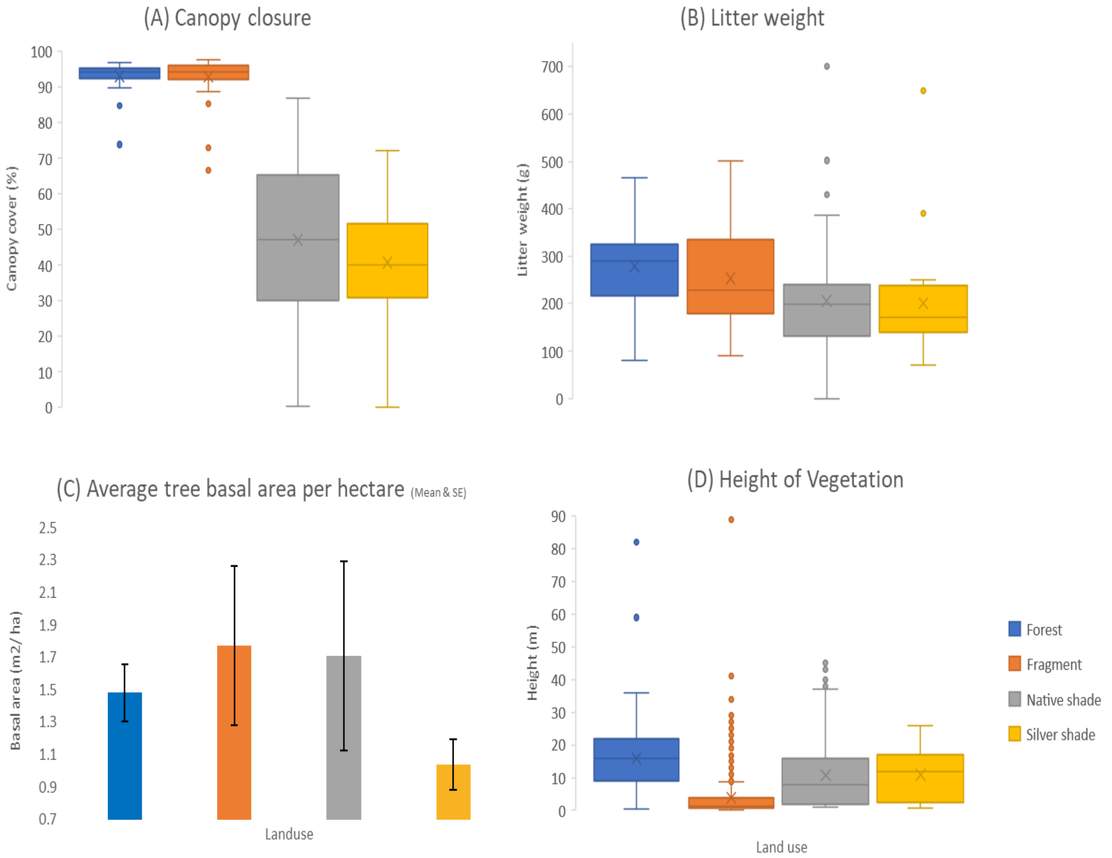

Figure 6: Structural complexity of land use with respect to various habitat characters. A) Canopy closure & B) Litter weight decreased from Forest to coffee plantations, while C) Tree basal area was highest in fragments and least in coffee plantations D) Height of vegetation decreased from forests to coffee plantations and was least in fragments.

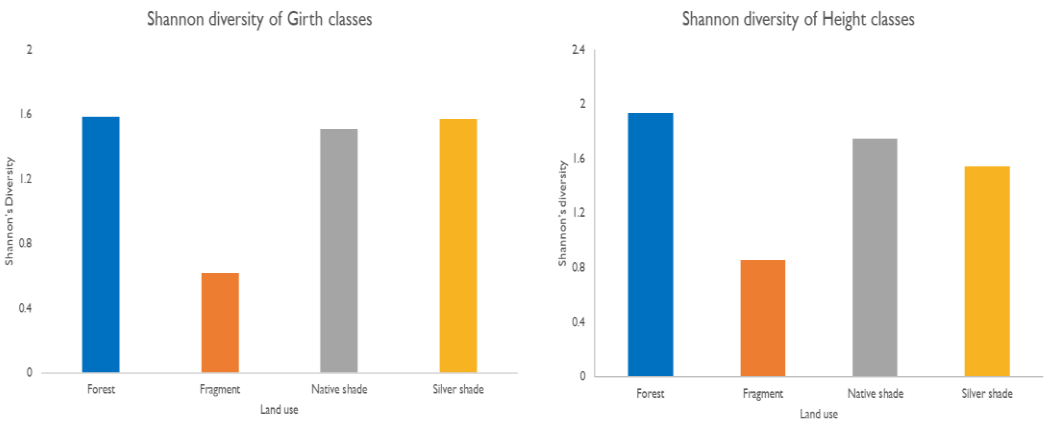

Figure 7: Diversity in Girth and height classes of vegetation didn’t show any trend.

The average species richness observed at the sample and transect levels complies with the hypothesis that forests are the high species-rich land use type and the silver shade coffee with the least and fragments and native shade coffee in between (Figure *8* A&B). The observed species richness was highest in the native shaded coffee followed by silver shade coffee, while the fragments had lower than coffee plantations, the forests represented the least number of species, when it's pooled at land use level (Figure *8*D). Rarefied species richness (to account for the differences in sampling in each land use) estimated at the least samples across land use types (n=32) indicated the native shaded coffee was the most species-rich followed by silver shaded coffee. Rarefied species richness was comparable for forests and fragments and lower than coffee plantations. Estimated species richness also showed a similar trend of consistent decline in species richness from coffee plantations to fragments and forests (Figure *8*).

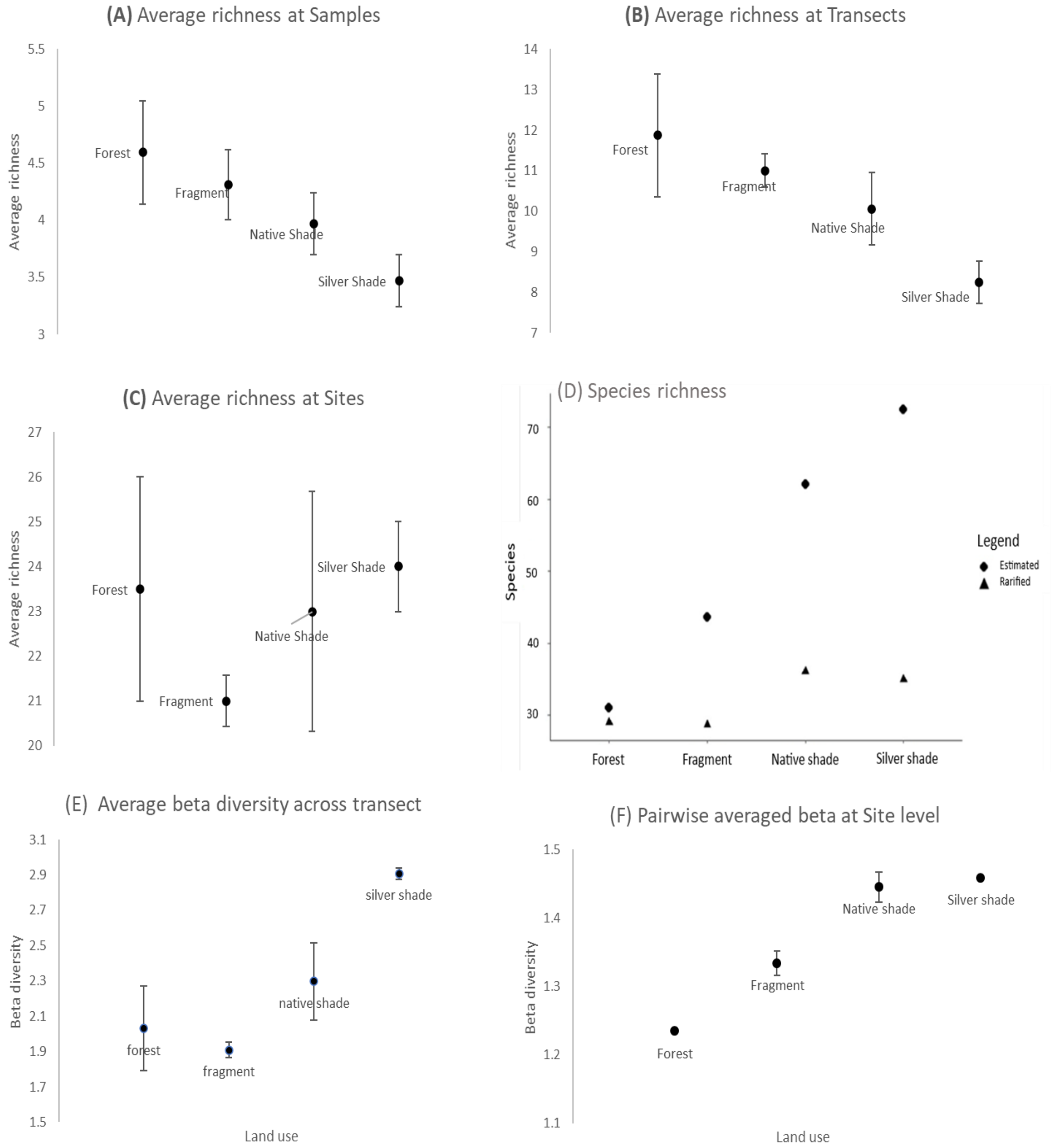

Figure 8: Observed Species richness (Mean & SE) and the line is just to denote the trend. (A- D) The trend observed at sample level, transects vanishes at sites and reverses at land use, D) Rarefied and Estimated species (Chao I) richness across land use, (E- F) The contribution of beta diversity increased from forests and fragments to coffee plantations at both transect and sites.

Factors explaining the species richness

Generalized Linear Mixed Effect Models (GLMM's) were considered to incorporate the effect the randomness in transect might have on the species richness while accounting for habitat variables. The intercept-only model and the global model were not different from each other either (Δ AIC=2.8). The results thus suggested that there was no significant contribution by any of the measured habitat variables in explaining the observed species richness.

Table 2: Intercept only model. The estimates on intercept are significant as they are not overlapping zero.

Family: Poisson (log)					
Formula: species ~ 1 + (1 | transect)					
	AIC	BIC	logLik	deviance	df.resid
	749.7	756.1	-372.9	745.7	174
Random effects:	Groups	Name	Variance	Std.Dev.	
	transect	(Intercept)	0.05135	0.2266	
Conditional model:	Estimate	Std.	Error	z value	Pr(>|z|)
(Intercept)	1.3817	0.0517	26.73	<2e-16	***
Signif. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**					

Table 3: Although the best model explained little variation (marginal R^2 = 0.065), it was within 2 delta AIC units from the intercept only model (Δ AIC=1.5).

Family: Poisson (log)					
Formula: species ~ Stem density + human habitation + (1 | transect)					
	AIC	BIC	logLik	deviance	df.resid
	748.2	759.6	-369.5	738.9	172
Random effects:	Groups	Name	Variance	Std.Dev.	
	transect	(Intercept)	0.03474	0.1864	
Conditional model:	Estimate	Std.	Error	zvalue	Pr(>|z|)
(Intercept)	1.27150	0.07012	18.134	<2e-16	***
Stem density	0.12604	0.05398	**2.335**	0.0195	*
Human habitation	0.24561	0.10702	2.295	0.0217	*

Effect of residence and insecticide

Built-up or residential buildings were categorized as human habitations and were observed across fragments and coffee plantations. The species richness per transect was not significantly different from the native shade coffee plantations (only native shade had human habitations in them) with and without human habitation (t-test- P = 0.1759, t = 1.5232, df = 6.3489). We did not find any significant difference in species richness between plantations which used insecticides and plantations which did not (Native shade coffee -> t-test- P = 0.740, t = -0.33809, df = 13.898; Silver shade coffee -> t-test- P = 0.67, t = -0.44721, df = 5.7692). There was no significant difference in species richness between fragments with human habitations and fragments without human habitation (paired t-test- P = 0.63, t = -0.49835, df = 9.5036).

Species Composition

While *Nylanderia* sp. 1 was one of the abundant species across forests, fragments, and native shaded coffee, *Pheidole* sp. 1 and *Technomyrmex* sp. 1 were abundant across forests, native shaded coffee, and silver shaded coffee. The dominance order of species changed with the change in land use type (Figure 11). The number of rare species also increased in coffee plantations compared to forests and fragments. The Mantel test showed a weak but significant correlation between environmental dissimilarity matrix and compositional dissimilarity matrix (Mantel statistic based on Spearman's rank correlation, r = 0.1786; p = 0.0017). This suggests that change in compositional similarity is associated with change in habitat variables such as canopy, stem density, leaflitter, pH, tree and shrub species richness.

Only18.6% of the total species were shared across the four land use types, while forests shared 22.9% with fragments and 27.1% with silver shade coffee plantations. Native shade coffee plantations shared 32.9% of species with each other, whereas both the native and silver shade coffee plantations shared 37.1% of the species. Coffee plantations shared 56% of species with forest and fragments together.

The community composition visualized from an NMDS plot suggests that there is an overlap of communities of coffee plantations with each other and little with fragments, while forest communities are mostly unique with a little overlap with only fragments. ANOSIM showed that the composition of ants in each land use together doesn't differ much (R: 0.08724). The forested and non-forested land use differed slightly (R: 0.123).

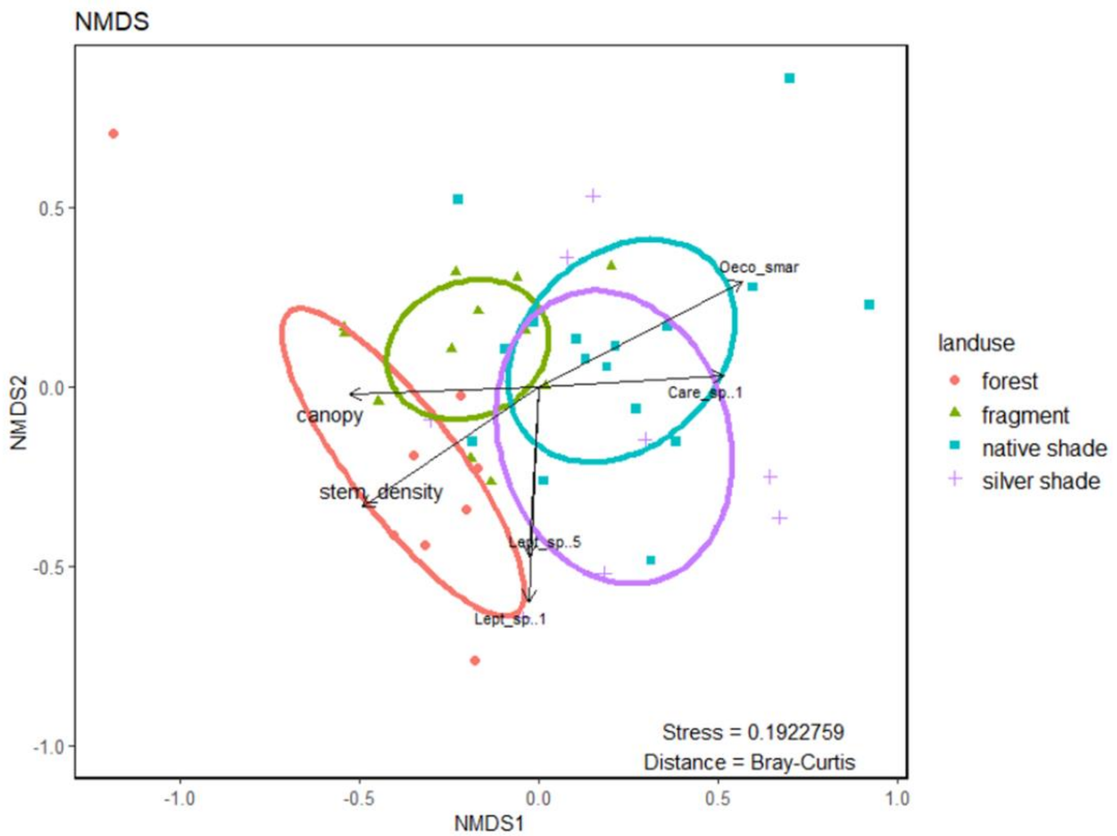

Figure 9: NMDS plot of various land use types. The vectors represented here shows the direction of their increase in the plot and thus the contribution to the sites (vectors represented are those with $p \leq 0.02$).

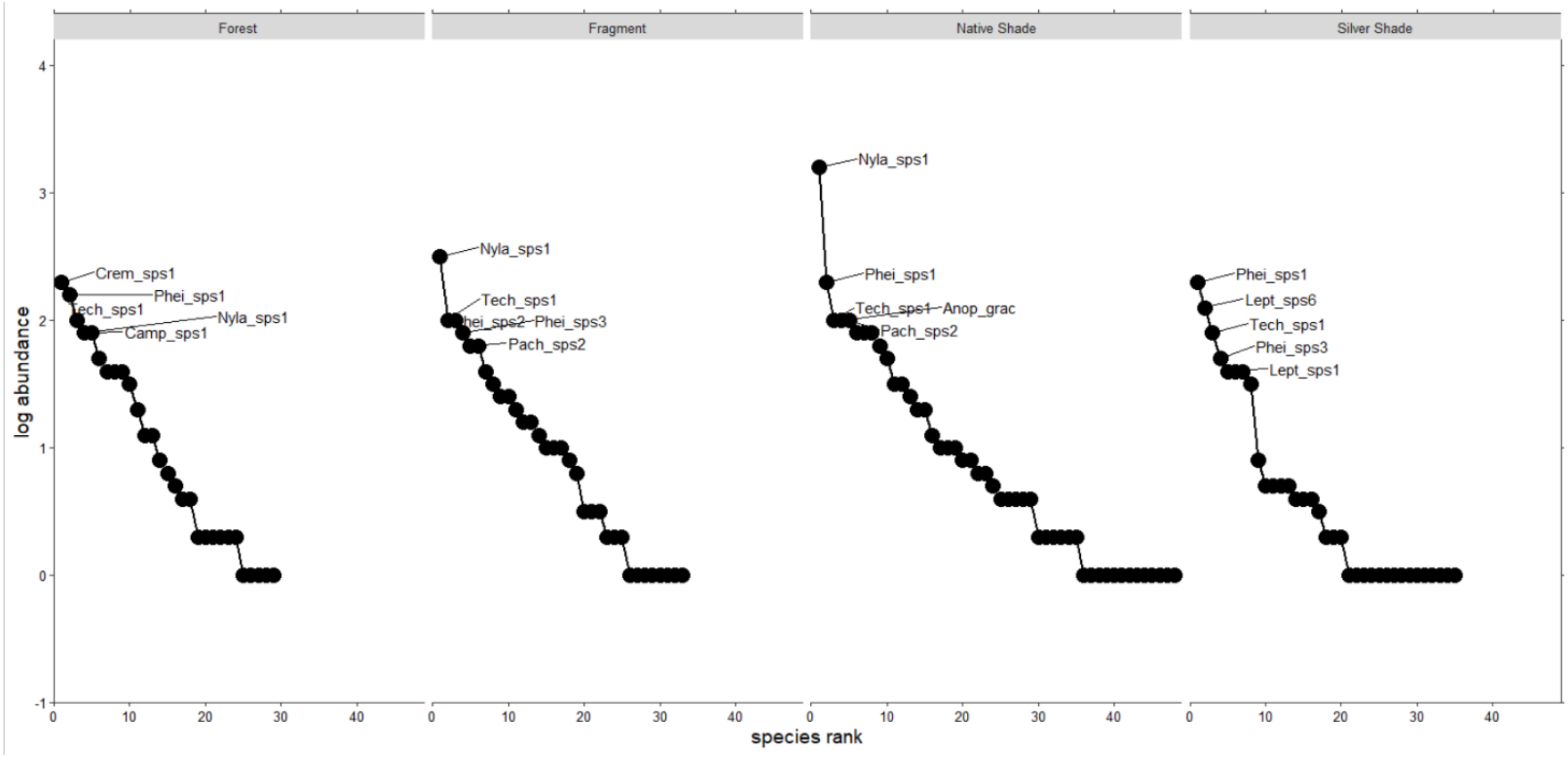

Figure 10: Rank abundance curves across land use types (The top five most abundant species are labelled). Although some species are dominant across other land use their dominance order changed. There is an increase of rare species in coffee plantations.

Beta diversity

Beta diversity of the landscape (across all land uses) is found to be 0.448 when decomposed further into contribution by the difference in richness and due to species replacement. Results show that the contribution to overall beta diversity by replacement (52.6%) was slightly higher than by richness (47.4%) (Table *4*Table *5*). Native shade coffee had the highest beta diversity followed by forests and silver shade coffee, whereas fragments were the ones with the least beta diversity (Table *4*). The contribution by transects from the forest was higher followed by the one in native shade coffee. When beta diversity was calculated for individual land use types, it showed that there was an increase in contribution to beta diversity due to the replacement of species in coffee plantations when compared to forests and fragments (Table *4* & Figure *12*).

Table 4: Table of results of Beta diversity of individual land use and for the landscape

Land use	Beta diversity	Replacement	Nestedness/Richness
Forest	0.449	0.357	0.092
Fragment	0.406	0.359	0.047
Native shade coffee	0.456	0.407	0.049
Silver shade coffee	0.424	0.401	0.023
Entire Landscape	0.448	0.235	0.212

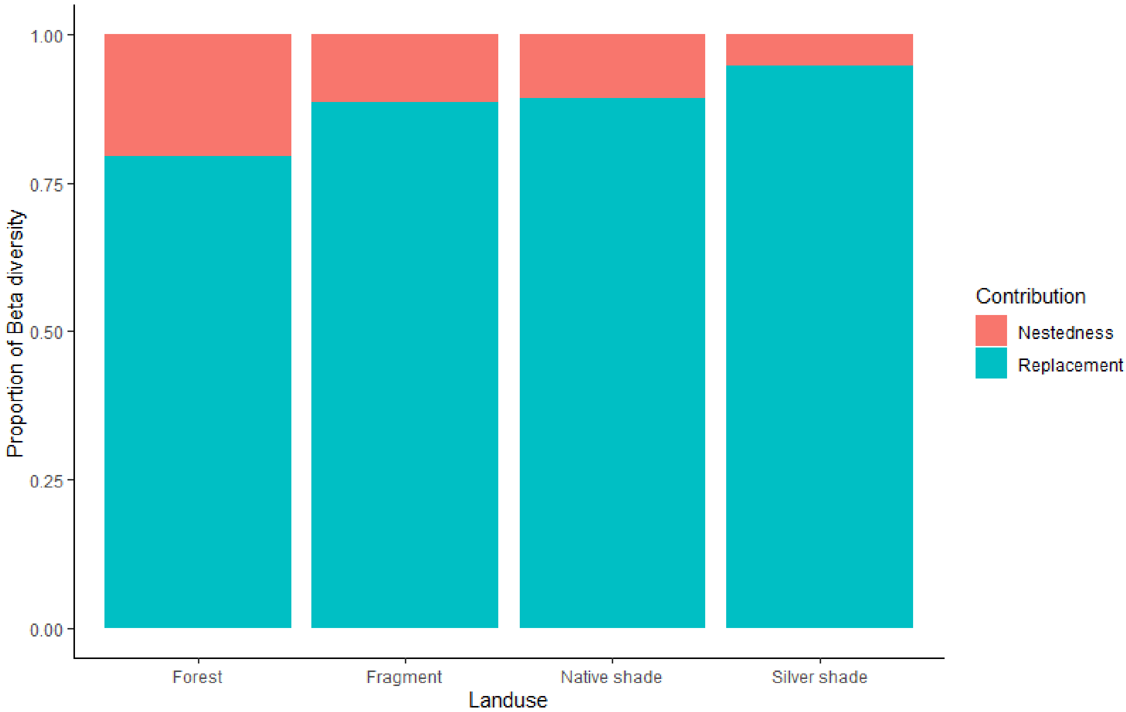

Figure 11: The contribution of replacement and nestedness to the total beta diversity for each land use. There is an increase in contribution by replacement from forest to coffee plantations.

DISCUSSION

This is one of the few studies to investigate the effect of land use change on predominantly leaf litter ant communities in the Western Ghats biodiversity hotspot (Badrinarayanan, 2001; Gadagkar et al., 1993; Rajan and Marathe, n.d.; Vineesh et al., 2007). The land use types examined in the study represent a gradient in structural heterogeneity of vegetation which largely declines from forests to fragments to native shade coffee plantations to and silver oak dominated coffee plantations.

Structural complexity

Our study was based on the premise that structural heterogeneity quantified through vegetation attributes would decrease from forests to fragments to coffee plantations. Our results were partially consistent with this prediction (Figure *6*). Canopy closure and leaf litter weight declined from forests to coffee plantations. A similar trend was observed in a study from a nearby landscape where litter biomass and litter moisture decreased from forests to coffee plantations (Badrinarayanan, 2001). However, mean basal area of trees increased from forests to fragments and native shade coffee plantations and was least in silver shade coffee plantations. Although the vegetation girth and height classes represented a decrease from forests to coffee plantations, the shannon's diversity didn't show any trend, but the fragments were least diverse because of higher number of shrubs. The management strategies followed in coffee plantations leads to opening up of canopies for ensuring adequate light for coffee below. This results in reduction of foliage thus affecting the amount of litter seen. The leaf litter in the coffee plantations is also subjected to continuous removal owing to the management strategies thus contributing to the reduction in litter in plantations as well. Majority of the litter in coffee plantations was contributed by coffee leaves (personal observation). Certain life forms such as lianas and understorey trees and shrubs were entirely missing from the coffee plantations.

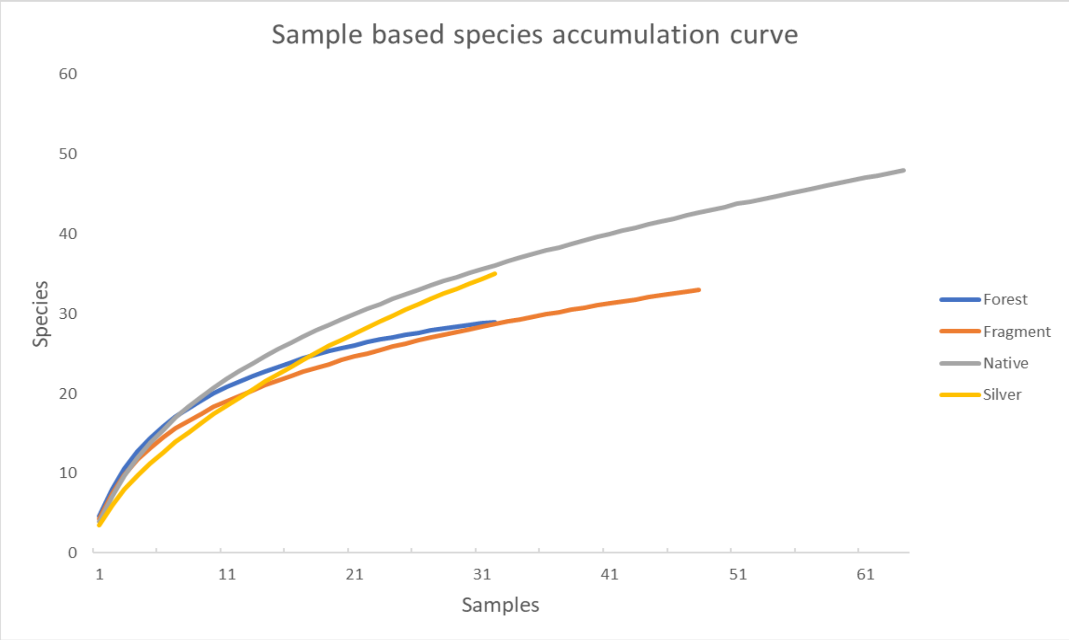

Figure 12: Sample based accumulation curves for each land use. None of the land use reached saturation.

Species richness

Observed species richness at the level of a transect showed a consistent decline from forests to coffee plantations (Figure *8*). The trend is consistent with a number of other studies that have examined the effect of conversion of forests to other land use types (Armbrecht et al., 2005; Bickel and Suparoek, 2005; Mauda et al., 2018; Nazarreta et al., 2020; Perfecto and Snelling, 1995; Philpott et al., 2008). However, this trend disappeared at the scale of individual sites and reversed at the scale of land use type when species richness of different sites within a land use type was pooled together. At this scale, species richness showed a positive trend from forests to coffee plantations (Figure *8*D).

This result was contrary to our expectation that forests with intact structural heterogeneity would show the highest species richness among the four land-use types. The results suggest that coffee plantations together support the highest species richness while the two forests sites together exhibit lowest species richness (Figure *13*). This result was not an artefact of sampling bias as evident from sample-based rarefaction curves (Figure *12*) which shows that the two categories of coffee plantations showed higher rarefied species richness as compared to the forest or the fragments. This is in contrast with the trend observed in other studies that focused on the effect of land use conversion at comparable scales. These studies found a consistent decrease in species richness from forests to the plantations (Fayle et al., 2010; Liu et al., 2016; Pacheco et al., 2009; Ratsirarson et al., 2002). While the study by Badrinarayanan has found similar species richness between forests and coffee plantations (Badrinarayanan, 2001). A similar shift in the pattern of species richness at different scales (landscape and transect level) was also reported by Betselmeyer & Weins from Argentina (Bestelmeyer and Wiens, 1996). Thus, the patterns in species richness observed in our study showed a strong scale dependence.

The increase in species richness with the decrease in habitat complexity has been observed in two studies from Australia, in Sydney sandstone ridge-top woodlands (Lassau and Hochuli, 2004) and in urban green spaces (Ossola et al., 2015). They attributed this pattern to enhanced negotiability on the ground in less complex areas and greater light availability for fulfilling the energy requirements of ants as they are thermophilic. In contrast to this, Nooten et al., (2019) found that among the urban golf courses, those with highly complex habitats were the ones with highest species richness of ants. Comparison of the present study with other studies should be carried out with caution as the measure of habitat complexity was not the same across. That said, none of the habitat variables measured during the study viz., canopy, stem density, and amount of leaf litter explained the variation in species richness, although all these varied with land use **(**Figure *6***).**

Beta diversity

This reversal and strong scale dependence of species richness observed in our study can be attributed largely to higher beta diversity or species turnover in coffee plantations than forest and fragments (Figure *8-E & F*). Average beta diversity showed an increasing trend from forests to plantations with the exception of fragments which exhibited lowest beta diversity. This suggests that, on an average any two transects in silver shade coffee plantations are more dissimilar than those in fragments and forests.

A similar pattern was found when beta diversity was examined across sites. In other words, we found maximum turnover in species composition across sites for coffee plantations as compared to forests and fragments. High beta diversity in coffee plantations is in contrast with studies in agricultural landscapes, where intensification was found to lead to a decrease in beta diversity (Escobar-Ramírez et al., 2020).

The beta diversity when decomposed into contribution by species replacement and nestedness, revealed that there was a steady increase in species replacement from forests to silver shade coffee plantations with a simultaneous decrease in nestedness (Figure 11). A similar trend was observed from a study from South America, where the decrease in similarity of pine plantations with forests was studied (Santoandré et al., 2019). It led to an increase in the contribution by replacement towards beta diversity in plantations with most dissimilarity, attributed to possible environmental filtering. The increase in replacement of species across transects, leads to higher species pool and thus the higher species richness in silver shade coffee when compared to forests.

Insecticides and Human influence

Insecticide's usage has long been known to negatively impact targeted and non-targeted groups when applied to crops, while the human influence/ disturbances negatively impacts native fauna as it brings up tramp species (Perfecto, 1990; Rizali et al., 2010). The reduction in habitat complexity coupled with insecticide usage and human presence could be driving the high replacement/ turnover across transects in coffee plantations. The usage of insecticides in the coffee plantations didn't have any impact on species richness as the plantations with and without insecticide use, have comparable species richness. This finding is inconsistent with an earlier study from the same landscape which found a reduction in species richness due to insecticides (Mone et al., 2014). The trend observed in this study could be because of the way the insecticides are applied in the coffee plantations sampled. It is applied in powdered form and generally dusted on the branches specifically targeting *Oecophylla* and *Crematogaster* sp. to prevent coffee pickers from getting attacked during the picking of coffee. When applied some of it falls on the litter below the coffee plant and might lead to non-targeted killing/ reduction in abundance of the ants in those areas. Reduction of abundance or richness of species due to the use of insecticides coupled with alternation of microhabitat conditions due to canopy opening may facilitate colonisation by species adapted to drier and more open habitats.

The observed patterns in the species richness might also be influenced by the type and quality of the matrix surrounding the coffee plantations and fragments (Perfecto and Vandermeer, 2002). Human presence in terms of residence are known to bring in tramp species and invasives that might displace the native species around their area of influence and contribute to higher turnover across transects (Rizali et al., 2010). Our results also show that coffee plantations with human habitation had a significantly higher species richness than those without any human habitation.

Species Composition

Species like *Meranoplus* sp. which have morphological adaptations to living in drier conditions were found only in coffee plantations (observed in silver shade coffee also but not collected in pitfalls). It indicates a change in the microhabitat characters in coffee plantations which favour these species seen in a study in a nearby landscape where the forests are found to be generally cooler, moist and with little variation in temperatures, while the coffee plantations are drier and have variable climate (Badrinarayanan, 2001). Species like *Strumigenys* sp. which are leaf litter dwelling species were recorded primarily from forests and fragments where the amount, thickness, and diversity of leaf litter was high. Genera such as *Discothyrea, Lophomyrmex, Myrmoteras* were recorded only in the coffee plantations while the invasive ant species *Anoplolepis gracilepis* was encountered only in the native shade coffee plantations.

Results from rank abundance curve (Figure *10*) show that the species dominance changes with a change in land use, for instance, *Oecophylla smaragdina* which is one of the frequently encountered species in coffee plantations is relatively less common in fragments and encountered just once in forests (one individual).

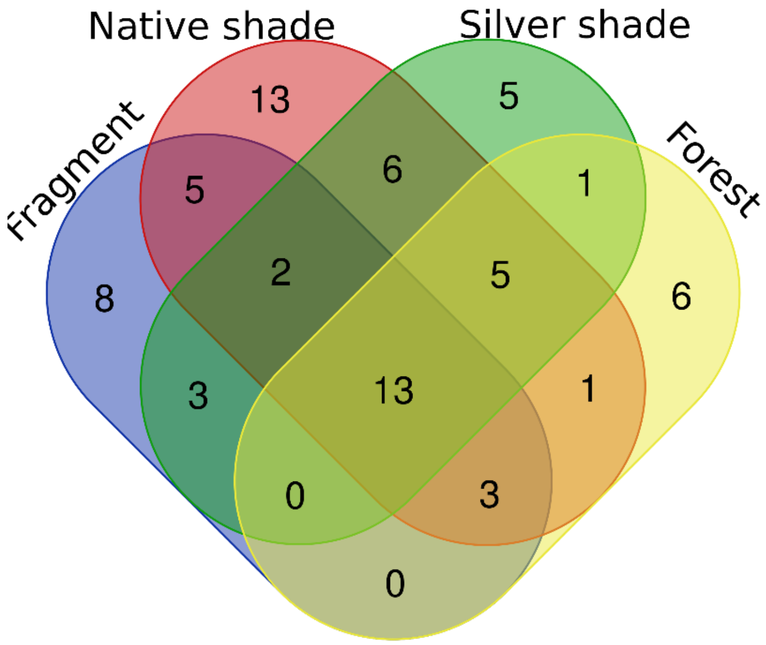

Figure 13: A Venn diagram of species shared between each land use (Total species = 70).

Number of unique species is higher in coffee plantations, a trend observed in a study by Badrinarayanan (Badrinarayanan, 2001). It can be an artifact of insufficient sampling effort in this study (Figure *12*), as some of the species unique to some land uses might have been missed due to their low abundance in other land use types. Coffee plantations, while harbouring some of the species from forests and fragments, also provide refuge to species unique to them. 34% of species were found only in the coffee plantations. This shows that coffee plantations play an important role in maintaining and contributing to the overall diversity of the landscape.

Limitations

- This study was carried out during the late winter, which is not the period of high activity for ants, as compared to the monsoon season.
- Only leaf litter ant communities were sampled in this study. Sampling the canopy dwellers is also required to further enhance the understanding of the ant communities inside these land use types and thus the opportunity to understand the direct effect of reduction in habitat complexity. However, the

number of exclusively arboreal species are very few and hence sampling these is unlikely to change the results of this study.

- It is likely that we have missed a number of rare species as inferred from the species accumulation curve.

CONCLUSION

The findings from our study suggest that responses in ant species richness and composition are not just dependant on structural complexity within a patch but more by the habitat diversity and surrounding heterogeneity collectively represented by a land use type. A number of studies have investigated the role of coffee based agro-forestry in biodiversity conservation. These studies largely advocate the importance of maintaining native tree cover as shade for enhancing the biodiversity value of this land use type as compared to mono-dominant silver-oak shade coffee. Our results suggest that coffee plantations regardless of nature of tree cover are effective in supporting high diversity of ants. However, our results should be taken with caution as this was a short-term study. It was not a complete and comprehensive sampling of ant assemblages in these land use types. It is also important to consider that although the overall richness of coffee plantations was higher, the species composition of ants was observed to be different in different land use types highlighting the importance of each of these individually and also collectively in maintaining the regional species pool of the Kodagu landscape.

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REFERENCES

Agosti, D., Majer, J., Alonso, L.E., Schultz, T., 2000. Ants: standard methods for measuring and monitoring biodiversity. Smithsonian Institution Press.

Almeida, S.M., Silva, L.C., Cardoso, M.R., Cerqueira, P.V., Juen, L., Santos, M.P., 2016. The effects of oil palm plantations on the functional diversity of Amazonian birds. Journal of Tropical Ecology 32, 510–525.

Anand, M., Krishnaswamy, J., Kumar, A., Bali, A., 2010. Sustaining biodiversity conservation in human-modified landscapes in the Western Ghats: remnant forests matter. Biological Conservation 143, 2363–2374.

Andersen, A.N., Hoffmann, B.D., Müller, W.J., Griffiths, A.D., 2002. Using ants as bioindicators in land management: simplifying assessment of ant community responses. Journal of Applied Ecology 39, 8–17.

Arinaminpathy, N., McLean, A.R., Godfray, H.C.J., 2009. Future UK land use policy and the risk of infectious disease in humans, livestock and wild animals. Land Use Policy, Land Use Futures 26, S124–S133. https://doi.org/10.1016/j.landusepol.2009.08.026

Armbrecht, I., Perfecto, I., 2003. Litter-twig dwelling ant species richness and predation potential within a forest fragment and neighboring coffee plantations of contrasting habitat quality in Mexico. Agriculture, Ecosystems & Environment 97, 107–115. https://doi.org/10.1016/S0167-8809(03)00128-2

Armbrecht, I., Rivera, L., Perfecto, I., 2005. Reduced diversity and complexity in the leaf-litter ant assemblage of Colombian coffee plantations. Conservation Biology 19, 897–907.

Asfiya, W., Lach, L., Majer, J.D., Heterick, B., Didham, R.K., 2015. Intensive agroforestry practices negatively affect ant (Hymenoptera: Formicidae) diversity and composition in southeast Sulawesi, Indonesia. Asian Myrmecology 7, 87–104.

Badrinarayanan, S., 2001. The Impact of Land use on Litter Beetle and Ant Communities in a Coffee-Dominated Landscape in Chickmagalur District, Karnataka. Saurashtra University, Rajkot.

Barrera, C.A., Buffa, L.M., Valladares, G., 2015. Do leaf-cutting ants benefit from forest fragmentation? Insights from community and species-specific responses in a fragmented dry forest. Insect Conservation and Diversity 8, 456–463. https://doi.org/10.1111/icad.12125

Baselga, A., 2010. Partitioning the turnover and nestedness components of beta diversity. Global ecology and biogeography 19, 134–143.

Baur, B., Erhardt, A., 1995. Habitat fragmentation and habitat alterations: principal threats to most animal and plant species. GAIA-Ecological Perspectives for Science and Society 4, 221–226.

Berg, Å., Wretenberg, J., Żmihorski, M., Hiron, M., Pärt, T., 2015. Linking occurrence and changes in local abundance of farmland bird species to landscape composition and land-use changes. Agriculture, Ecosystems & Environment 204, 1–7. https://doi.org/10.1016/j.agee.2014.11.019

Bestelmeyer, B.T., Wiens, J.A., 1996. The Effects of Land Use on the Structure of Ground-Foraging Ant Communities in the Argentine Chaco. Ecological Applications 6, 1225–1240. https://doi.org/10.2307/2269603

Bhagwat, S., 2002. Biodiversity and conservation of a cultural landscape in the Western Ghats of India.

Bhagwat, S.A., Kushalappa, C.G., Williams, P.H., Brown, N.D., 2005a. The Role of Informal Protected Areas in Maintaining Biodiversity in the Western Ghats of India. Ecology and Society 10.

Bhagwat, S.A., Kushalappa, C.G., Williams, P.H., Brown, N.D., 2005b. A Landscape Approach to Biodiversity Conservation of Sacred Groves in the Western Ghats of India. Conservation Biology 19, 1853–1862. https://doi.org/10.1111/j.1523-1739.2005.00248.x

Bickel, T., Suparoek, W., 2005. Diversity of leaf litter ant communities in Ton Nga Chang Wildlife Sanctuary and nearby rubber plantations, Songkhla, Southern Thailand. Songklanakarin Journal of Science and Technology 27.

Brambilla, M., Casale, F., Bergero, V., Bogliani, G., Crovetto, G.M., Falco, R., Roati, M., Negri, I., 2010. Glorious past, uncertain present, bad future? Assessing effects of land-use changes on habitat suitability for a threatened farmland bird species. Biological Conservation 143, 2770–2778. https://doi.org/10.1016/j.biocon.2010.07.025

Brühl, C.A., Eltz, T., 2010. Fuelling the biodiversity crisis: species loss of ground-dwelling forest ants in oil palm plantations in Sabah, Malaysia (Borneo). Biodivers Conserv 19, 519–529. https://doi.org/10.1007/s10531-009-9596-4

Brühl, C.A., Eltz, T., Linsenmair, K.E., 2003. Size does matter–effects of tropical rainforest fragmentation on the leaf litter ant community in Sabah, Malaysia. Biodiversity & Conservation 12, 1371–1389.

Bruna, E.M., Vasconcelos, H.L., Heredia, S., 2005. The effect of habitat fragmentation on communities of mutualists: Amazonian ants and their host plants. Biological Conservation 124, 209–216. https://doi.org/10.1016/j.biocon.2005.01.026

Carvalho, K.S., Vasconcelos, H.L., 1999. Forest fragmentation in central Amazonia and its effects on litter-dwelling ants. Biological Conservation 91, 151–157. https://doi.org/10.1016/S0006-3207(99)00079-8

Coffee Board of India, 2021. Coffee Board of India [WWW Document]. Coffee Board of India. URL https://www.indiacoffee.org/coffee-statistics.html (accessed 4.21.21).

Colwell, R.K., 2013. EstimateS: Statistical estimation of species richness and shared species from samples. Version 9 and earlier. User's Guide and application. Published at: http://purl. oclc. org/estimates.

Debuse, V.J., King, J., House, A.P.N., 2007. Effect of fragmentation, habitat loss and within-patch habitat characteristics on ant assemblages in semi-arid woodlands of eastern Australia. Landscape Ecol 22, 731–745. https://doi.org/10.1007/s10980-006-9068-0

Donald, P.F., 2004. Biodiversity Impacts of Some Agricultural Commodity Production Systems. Conservation Biology 18, 17–37.

Draw Venn Diagram [WWW Document], n.d. URL http://bioinformatics.psb.ugent.be/webtools/Venn/ (accessed 6.30.21).

Dray, S., Blanchet, G., Borcard, D., Guenard, G., Jombart, T., Larocque, G., Legendre, P., Madi, N., Wagner, H.H., Dray, M.S., 2018. Package 'adespatial.' R Package 2018, 3–8.

Escobar-Ramírez, S., Tscharntke, T., Armbrecht, I., Torres, W., Grass, I., 2020. Decrease in β-diversity, but not in α-diversity, of ants in intensively managed coffee plantations. Insect Conservation and Diversity 13, 445–455. https://doi.org/10.1111/icad.12417

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.

Fayle, T.M., Turner, E.C., Snaddon, J.L., Chey, V.K., Chung, A.Y.C., Eggleton, P., Foster, W.A., 2010. Oil palm expansion into rain forest greatly reduces ant biodiversity in canopy, epiphytes and leaf-litter. Basic and Applied Ecology 11, 337–345. https://doi.org/10.1016/j.baae.2009.12.009

Fittkau, E.J., Klinge, H., 1973. On biomass and trophic structure of the central Amazonian rain forest ecosystem. Biotropica 2–14.

Gadagkar, R., Nair, P., Krishnappa, C., Bhat, D., 1993. Ant species richness and diversity in some selected localities of Western Ghats. Hexapoda 5.

Gibb, H., Hochuli, D.F., 2002. Habitat fragmentation in an urban environment: large and small fragments support different arthropod assemblages. Biological Conservation 106, 91–100. https://doi.org/10.1016/S0006-3207(01)00232-4

González, E., Buffa, L., Defagó, M.T., Molina, S.I., Salvo, A., Valladares, G., 2018. Something is lost and something is gained: loss and replacement of species and functional groups in ant communities at fragmented forests. Landscape Ecol 33, 2089–2102. https://doi.org/10.1007/s10980-018-0724-y

Hadi, A., Inubushi, K., Purnomo, E., Razie, F., Yamakawa, K., Tsuruta, H., 2000. Effect of land-use changes on nitrous oxide (N2O) emission from tropical peatlands. Chemosphere - Global Change Science, Atmospheric Nitrous Oxide 2, 347–358. https://doi.org/10.1016/S1465-9972(00)00030-1

Indian Meteorological Department, 2021. Customized Rainfall Information System (CRIS) [WWW Document]. Customized Rainfall Information System (CRIS), IMD. URL http://hydro.imd.gov.in/hydrometweb/(S(1i05p43kzmmp2n55s5y0m555))/DistrictRaifall.aspx (accessed 4.21.21).

JingWen, Z., ZhiXing, L., YouQing, C., 2017. Diversity of canopy foraging ant communities in secondary natural forest and plantations in Lüchun, Yunnan. Forest Research, Beijing 30, 823–830.

Kapoor, V., 2008. Effects of rainforest fragmentation and shade-coffee plantations on spider communities in the Western Ghats, India. J Insect Conserv 12, 53–68. https://doi.org/10.1007/s10841-006-9062-5

Kareiva, P., 1987. Habitat fragmentation and the stability of predator–prey interactions. Nature 326, 388–390.

Kindt, R., Kindt, M.R., 2015. Package 'BiodiversityR.' R Proj.

Klein, B.C., 1989. Effects of forest fragmentation on dung and carrion beetle communities in central Amazonia. Ecology 70, 1715–1725.

Kodagu District, Government of Karnataka, 2021. URL https://kodagu.nic.in/en/about-district/ (accessed 4.21.21).

Koh, L.P., 2007. Impacts of land use change on South-east Asian forest butterflies: a review. Journal of applied ecology 44, 703–713.
Kruess, A., Tscharntke, T., 2000. Species richness and parasitism in a fragmented landscape: experiments and field studies with insects on Vicia sepium. Oecologia 122, 129–137.
Kurz, D.J., Nowakowski, A.J., Tingley, M.W., Donnelly, M.A., Wilcove, D.S., 2014. Forest-land use complementarity modifies community structure of a tropical herpetofauna. Biological Conservation 170, 246–255. https://doi.org/10.1016/j.biocon.2013.12.027
Kushalappa, C., 2014. Devakad – Sacred Groves of Kodagu | JLR Explore. JLR Explore. URL https://jlrexplore.com/explore/on-assignment/devakad-sacred-groves-of-kodagu (accessed 4.24.21).
Kushalappa, C., Bhagwat, S.A., 2001. Sacred groves: biodiversity, threats and conservation. Forest genetic resources: status, threats, and conservation strategies. Oxford and IBH, New Delhi 21–29.
Lassau, S.A., Hochuli, D.F., 2004. Effects of habitat complexity on ant assemblages. Ecography 27, 157–164. https://doi.org/10.1111/j.0906-7590.2004.03675.x
Laurance, W.F., Bierregaard, R.O., 1997. Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities. University of Chicago Press.
Leal, I.R., Filgueiras, B.K.C., Gomes, J.P., Iannuzzi, L., Andersen, A.N., 2012. Effects of habitat fragmentation on ant richness and functional composition in Brazilian Atlantic forest. Biodivers Conserv 21, 1687–1701. https://doi.org/10.1007/s10531-012-0271-9
Liu, C., Guénard, B., Blanchard, B., Peng, Y.-Q., Economo, E.P., 2016. Reorganization of taxonomic, functional, and phylogenetic ant biodiversity after conversion to rubber plantation. Ecological Monographs 86, 215–227. https://doi.org/10.1890/15-1464.1
Magnusson, A., Skaug, H., Nielsen, A., Berg, C., Kristensen, K., Maechler, M., van Bentham, K., Bolker, B., Brooks, M., Brooks, M.M., 2017. Package ‘glmmTMB.’ R Package Version 0.2. 0.
Malhi, Y., Gardner, T.A., Goldsmith, G.R., Silman, M.R., Zelazowski, P., 2014. Tropical Forests in the Anthropocene. Annual Review of Environment and Resources 39, 125–159. https://doi.org/10.1146/annurev-environ-030713-155141
Mauda, E.V., Joseph, G.S., Seymour, C.L., Munyai, T.C., Foord, S.H., 2018. Changes in landuse alter ant diversity, assemblage composition and dominant functional groups in African savannas. Biodivers Conserv 27, 947–965. https://doi.org/10.1007/s10531-017-1474-x
Mone, S., Kusha, K.M., Jathanna, D., Ali, M., Goel, A., 2014. Comparison of insect biodiversity between organic and conventional plantations in Kodagu, Karnataka, India. J. Threat. Taxa 6, 6186–6194. https://doi.org/10.11609/JoTT.o3778.6186-94
Mujeeb Rahman, P., Varma, R.V., Sileshi, G.W., 2012. Abundance and diversity of soil invertebrates in annual crops, agroforestry and forest ecosystems in the Nilgiri biosphere reserve of Western Ghats, India. Agroforest Syst 85, 165–177. https://doi.org/10.1007/s10457-011-9386-3

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

Nath, C.D., Pélissier, R., Ramesh, B.R., Garcia, C., 2011. Promoting native trees in shade coffee plantations of southern India: comparison of growth rates with the exotic Grevillea robusta. Agroforestry Systems 83, 107–119. https://doi.org/10.1007/s10457-011-9401-8

Nazarreta, R., Hartke, T.R., Hidayat, P., Scheu, S., Buchori, D., Drescher, J., 2020. Rainforest conversion to smallholder plantations of rubber or oil palm leads to species loss and community shifts in canopy ants (Hymenoptera: Formicidae). Myrmecological News 30.

Newbold, T., Hudson, L.N., Hill, S.L.L., Contu, S., Lysenko, I., Senior, R.A., Börger, L., Bennett, D.J., Choimes, A., Collen, B., Day, J., De Palma, A., Díaz, S., Echeverria-Londoño, S., Edgar, M.J., Feldman, A., Garon, M., Harrison, M.L.K., Alhusseini, T., Ingram, D.J., Itescu, Y., Kattge, J., Kemp, V., Kirkpatrick, L., Kleyer, M., Correia, D.L.P., Martin, C.D., Meiri, S., Novosolov, M., Pan, Y., Phillips, H.R.P., Purves, D.W., Robinson, A., Simpson, J., Tuck, S.L., Weiher, E., White, H.J., Ewers, R.M., Mace, G.M., Scharlemann, J.P.W., Purvis, A., 2015. Global effects of land use on local terrestrial biodiversity. Nature 520, 45–50. https://doi.org/10.1038/nature14324

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O’hara, R., Simpson, G.L., Solymos, P., Stevens, M.H.H., Wagner, H., 2013. Package ‘vegan.’ Community ecology package, version 2, 1–295.

Ossola, A., Nash, M.A., Christie, F.J., Hahs, A.K., Livesley, S.J., 2015. Urban habitat complexity affects species richness but not environmental filtering of morphologically-diverse ants. PeerJ 3, e1356. https://doi.org/10.7717/peerj.1356

Pacheco, R., Silva, R.R., Morini, M.S. de C., Brandão, C.R.F., 2009. A comparison of the leaf-litter ant fauna in a secondary atlantic forest with an adjacent pine plantation in southeastern Brazil. Neotropical Entomology 38, 55–65. https://doi.org/10.1590/S1519-566X2009000100005

Page, N.V., Qureshi, Q., Rawat, G.S., Kushalappa, C.G., 2010. Plant diversity in sacred forest fragments of Western Ghats: A comparative study of four life forms. Plant Ecology 206, 237–250.

Perfecto, I., 1990. Indirect and Direct Effects in a Tropical Agroecosystem: The Maize-Pest-Ant System in Nicaragua. Ecology 71, 2125–2134. https://doi.org/10.2307/1938626

Perfecto, I., Rice, R.A., Greenberg, R., Van der Voort, M.E., 1996. Shade Coffee: A Disappearing Refuge for BiodiversityShade coffee plantations can contain as much biodiversity as forest habitats. BioScience 46, 598–608. https://doi.org/10.2307/1312989

Perfecto, I., Snelling, R., 1995. Biodiversity and the transformation of a tropical agroecosystem: ants in coffee plantations. Ecological applications 5, 1084–1097.

Perfecto, I., Vandermeer, J., 2002. Quality of agroecological matrix in a tropical montane landscape: ants in coffee plantations in southern Mexico. Conservation biology 16, 174–182.

Perfecto, I., Vandermeer, J., Hanson, P., Cartín, V., 1997. Arthropod biodiversity loss and the transformation of a tropical agro-ecosystem. Biodiversity and Conservation 6, 935–945. https://doi.org/10.1023/A:1018359429106

Philpott, S.M., 2005. Changes in arboreal ant populations following pruning of coffee shade-treesin Chiapas, Mexico. Agroforest Syst 64, 219–224. https://doi.org/10.1007/s10457-004-2372-2

Philpott, S.M., Arendt, W.J., Armbrecht, I., Bichier, P., Diestch, T.V., Gordon, C., Greenberg, R., Perfecto, I., REYNOSO-SANTOS, R., SOTO-PINTO, L., 2008. Biodiversity loss in Latin American coffee landscapes: review of the evidence on ants, birds, and trees. Conservation Biology 22, 1093–1105.

Powell, A.H., Powell, G.V., 1987. Population dynamics of male euglossine bees in Amazonian forest fragments. Biotropica 176–179.

R Core Team, 2020. R: The R Project for Statistical Computing [WWW Document]. URL https://www.r-project.org/ (accessed 7.2.21).

Rajan, P.D., Marathe, A.P., n.d. Ant diversity responses to changing land-use forms in the central Western Ghats (Karnataka, India).

Ramesh, T., Downs, C.T., 2015. Impact of land use on occupancy and abundance of terrestrial mammals in the Drakensberg Midlands, South Africa. Journal for Nature Conservation 23, 9–18. https://doi.org/10.1016/j.jnc.2014.12.001

Ratsirarson, H., Robertson, H.G., Picker, M.D., Noort, S.V., 2002. Indigenous forests versus exotic eucalypt and pine plantations : a comparison of leaf-litter invertebrate communities. African Entomology 10, 93–99.

Riemann, J.C., Ndriantsoa, S.H., Rödel, M.-O., Glos, J., 2017. Functional diversity in a fragmented landscape—Habitat alterations affect functional trait composition of frog assemblages in Madagascar. Global Ecology and Conservation 10, 173–183.

Rizali, A., Lohman, D.J., Buchori, D., Prasetyo, L.B., Triwidodo, H., Bos, M.M., Yamane, S., Schulze, C.H., 2010. Ant communities on small tropical islands: effects of island size and isolation are obscured by habitat disturbance and 'tramp' ant species. Journal of Biogeography 37, 229–236. https://doi.org/10.1111/j.1365-2699.2009.02194.x

Roth, D.S., Perfecto, I., Rathcke, B., 1994. The effects of management systems on ground-foraging ant diversity in Costa Rica. Ecological Applications 4, 423–436.

Sala, O.E., Chapin, F.S., III, Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M., Wall, D.H., 2000. Global Biodiversity Scenarios for the Year 2100. Science 287, 1770–1774. https://doi.org/10.1126/science.287.5459.1770

Santoandré, S., Filloy, J., Zurita, G.A., Bellocq, M.I., 2019. Taxonomic and functional β-diversity of ants along tree plantation chronosequences differ between contrasting biomes. Basic and Applied Ecology 41, 1–12. https://doi.org/10.1016/j.baae.2019.08.004

Schoerder, J.H., Sobrinho, T.G., Ribas, C.R., Campos, R.B.F., 2004. Colonization and extinction of ant communities in a fragmented landscape. Austral Ecology 29, 391–398. https://doi.org/10.1111/j.1442-9993.2004.01378.x

Tawatao, N., Lucey, J.M., Senior, M., Benedick, S., Vun Khen, C., Hill, J.K., Hamer, K.C., 2014. Biodiversity of leaf-litter ants in fragmented tropical rainforests of Borneo: the value of publically and privately managed forest fragments. Biodivers Conserv 23, 3113–3126. https://doi.org/10.1007/s10531-014-0768-5

Vasconcelos, H.L., Vilhena, J.M.S., Magnusson, W.E., Albernaz, A.L.K.M., 2006. Long-term effects of forest fragmentation on Amazonian ant communities. Journal of Biogeography 33, 1348–1356. https://doi.org/10.1111/j.1365-2699.2006.01516.x

Vineesh, P., Sabu, T.K., Karmaly, K., 2007. Community structure and functional group classification of litter ants in the montane evergreen and deciduous forests of Wayanad region of Western Ghats, Southern India. Oriental Insects 41, 427–442.

Watt, A.D., Stork, N.E., Bolton, B., 2002. The diversity and abundance of ants in relation to forest disturbance and plantation establishment in southern Cameroon. Journal of Applied Ecology 39, 18–30. https://doi.org/10.1046/j.1365-2664.2002.00699.x

Wickham, H., 2011. ggplot2. WIREs Computational Statistics 3, 180–185. https://doi.org/10.1002/wics.147

Wilson, E.O., 1990. Success and dominance in ecosystems: the case of the social insects. Ecology Institute Oldendorf/Luhe.

Wilson, E.O., Hölldobler, B., 2005. The rise of the ants: A phylogenetic and ecological explanation. PNAS 102, 7411–7414. https://doi.org/10.1073/pnas.0502264102

Appendix 1

Species by site matrix (pooled at sites)

Table 5: Species by site matrix.

Sub family	Species	Acronym used	Forest		Fragment			Native shade coffee				Silver shade coffee	
			fr1	fr2	fg1	fg2	fg3	ns1	ns2	ns3	ns4	si1	si2
Formicinae	Acropyga sp1	Aeni_sp1	0	0	0	1	0	0	0	0	0	0	1
Aenictinae	Aenictus sp1	Aeni_sp2	0	0	0	0	0	0	0	0	0	0	2
Aenictinae	Aenictus sp2	Acro_sp1	0	0	0	0	3	62	0	0	0	0	0
Formicinae	Anoplolepis gracilepis	Anop_grac	0	0	0	0	0	34	70	0	0	0	0
Formicinae	Camponotous sp1	Camp_sp1	3	68	1	0	1	0	0	4	0	0	0
Formicinae	Camponotous sp2	Camp_sp2	0	0	1	0	0	0	0	0	0	0	0
Formicinae	Camponotous sp3	Camp_sp3	3	1	0	0	0	0	0	10	0	1	1
Formicinae	Camponotous sp4	Camp_sp4	0	0	0	0	0	0	0	0	0	5	0
Formicinae	Camponotous sp5	Camp_sp5	1	1	0	0	0	0	0	0	0	0	0
Formicinae	Camponotous spx	Camp_spx	0	0	1	0	0	0	0	0	0	0	0
Myrmicinae	Cardiocondyla sp1	Card_sp1	2	0	0	0	0	1	8	4	12	1	0
Myrmicinae	Carebara sp1	Care_sp1	0	0	0	0	0	38	6	12	6	1	3
Myrmicinae	Carebara sp2	Care_sp2	23	16	0	0	3	1	0	5	4	0	0

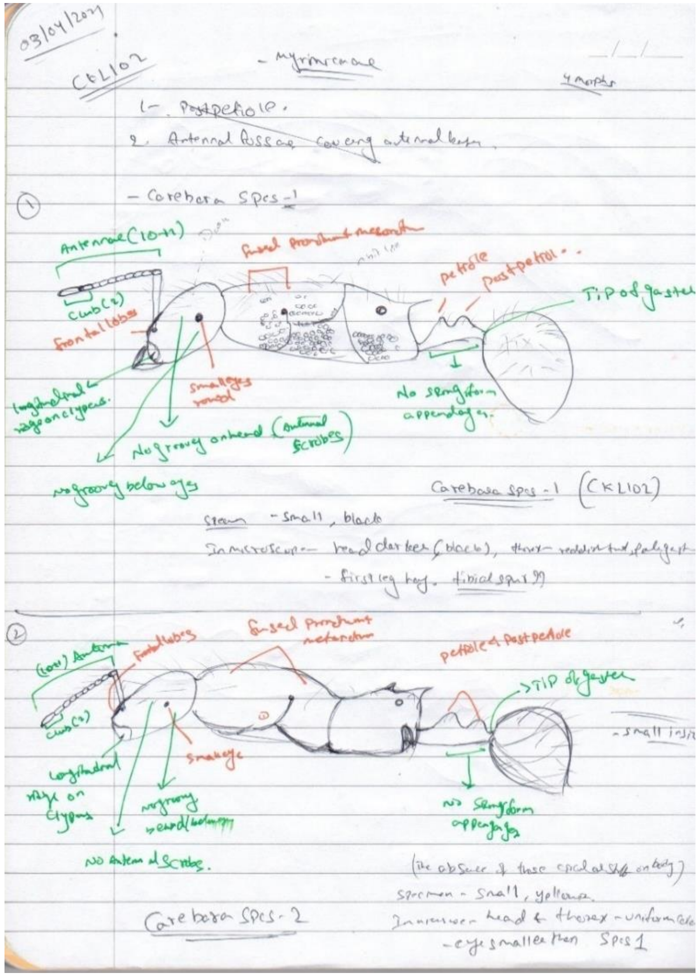
Myrmicinae	Carebara sp3	Care_sp3	0	2	0	0	0	0	0	0	0	0	0
Dorylinae	Cerapachys sp1	Cera_sp1	0	1	0	0	0	0	0	0	0	0	0
Myrmicinae	Crematogaster sp1	Crem_sp1	209	7	3	1	5	1	5	2	0	0	0
Myrmicinae	Crematogaster sp2	Crem_sp2	1	1	1	0	0	0	0	0	1	0	1
Myrmicinae	Crematogaster sp3	Crem_sp3	21	0	0	0	0	0	0	0	0	0	0
Ponerinae	Diacamma sp1	Diac_sp1	0	0	0	0	0	0	0	0	0	1	0
Proceratiinae	Discothyrea sp1	Disc_sp1	0	0	0	0	0	0	0	0	1	0	0
Dorylinae	Dorylus sp1	Dory_sp1	0	0	0	1	0	0	0	0	0	0	0
Ponerinae	Hypoponera sp1	Hypo_sp1	1	5	7	10	0	0	0	2	0	4	1
Formicinae	Lepisiota sp1	Lepi_sp1	0	0	0	0	0	0	0	2	0	0	0
Ponerinae	Leptogenys sp1	Lept_sp1	12	24	9	6	9	3	14	25	5	8	35
Ponerinae	Leptogenys sp2	Lept_sp2	0	0	2	3	1	0	1	3	0	0	0
Ponerinae	Leptogenys sp3	Lept_sp3	0	0	0	0	1	0	0	0	0	0	0
Ponerinae	Leptogenys sp4	Lept_sp4	0	0	0	0	0	0	0	20	0	0	1
Ponerinae	Leptogenys sp5	Lept_sp5	0	14	0	0	0	0	0	5	0	0	5
Ponerinae	Leptogenys sp6	Lept_sp6	0	0	0	0	0	0	0	0	0	114	0
Ponerinae	Leptogenys sp7	Lept_sp7	0	1	0	0	0	0	0	0	0	1	0
Myrmicinae	Lophomyrmex sp1	Loph_sp1	0	0	0	0	0	0	0	0	0	0	1
Myrmicinae	Meranoplus sp1	Mera_sp1	0	0	0	0	0	0	1	1	10	0	0
Myrmicinae	Meranoplus sp2	Mera_sp2	0	0	0	0	0	0	0	0	1	0	0
Myrmicinae	Monomorium sp1	Mono_sp1	0	0	0	0	0	2	1	1	0	0	0

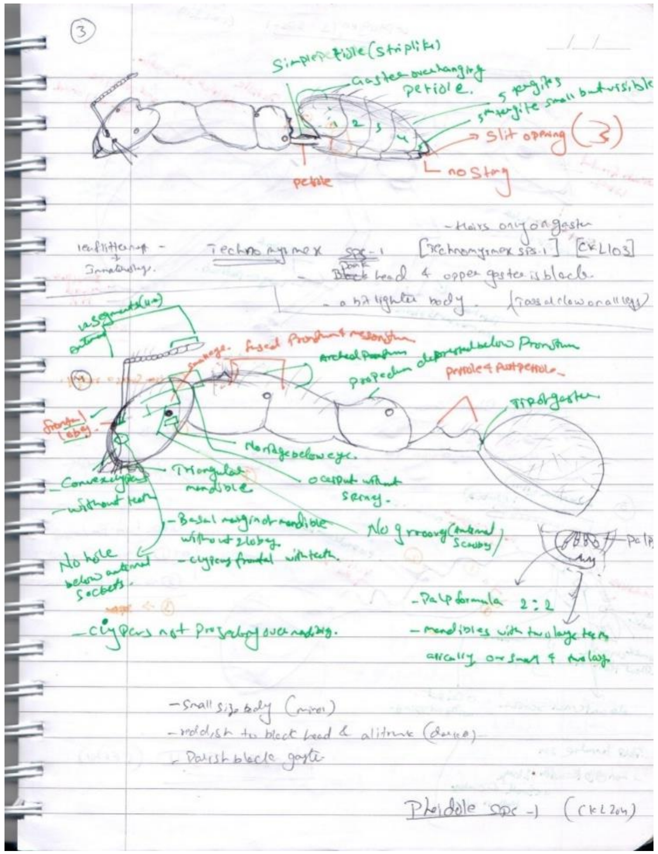
Myrmicinae	Monomorium sp2	Mono_sp2	0	0	0	0	0	0	4	0	3	4	0
Myrmicinae	Monomorium sp3	Mono_sp3	0	0	0	0	1	0	1	0	0	0	0
Myrmicinae	Monomorium sp4	Mono_sp4	0	0	2	20	3	0	0	0	0	0	0
Myrmicinae	Myrmecina sp1	Myca_sp1	0	0	0	0	0	0	0	2	0	0	0
Myrmicinae	Myrmicaria sp1	Myci_sp1	0	0	0	0	0	0	0	1	0	0	1
Formicinae	Myrmoteras sp1	Myrm_sp1	0	0	0	0	0	1	0	0	0	0	0
Formicinae	Nylanderia sp1	Nyla_sp1	22	67	158	23	143	0	0	1611	0	39	1
Formicinae	Nylanderia sp2	Nyla_sp2	0	0	0	0	0	0	2	0	0	0	0
Ponerinae	Odontoponera sp1	Odon_sp1	6	7	3	6	0	3	1	6	1	1	1
Formicinae	Oecophylla smaragdina	Oeco_smar	1	0	3	6	11	18	16	30	22	18	13
Ponerinae	Pachycondyla sp1	Pach_sp1	2	3	2	2	6	1	0	2	1	1	0
Ponerinae	Pachycondyla sp2	Pach_sp2	0	0	12	50	7	5	0	0	85	3	0
Ponerinae	Pachycondyla sp3	Pach_sp3	0	0	1	0	1	0	0	1	0	0	0
Ponerinae	Pachycondyla sp4	Pach_sp4	0	0	0	0	0	0	0	0	87	0	0
Myrmicinae	Pheidole sp1	Phei_sp1	1	174	24	20	0	18	40	133	19	26	169
Myrmicinae	Pheidole sp2	Phei_sp2	18	27	18	27	48	21	12	7	33	21	20
Myrmicinae	Pheidole sp3	Phei_sp3	20	19	15	2	64	0	18	0	0	47	6
Myrmicinae	Pheidole sp4	Phei_sp4	2	6	0	15	0	0	0	4	4	4	0

Myrmicinae	Pheidole sp5	Phei_sp5	0	0	0	2	0	0	0	1	5	0	0
Formicinae	Polyrhachis sp1	Poly_sp1	0	0	0	0	0	0	1	0	0	0	0
Formicinae	Polyrhachis sp2	Poly_sp2	0	0	0	0	1	0	0	0	0	0	1
Formicinae	Polyrhachis sp3	Poly_sp3	0	0	0	0	0	0	0	0	1	1	0
Myrmicinae	Strumigenys sp1	Stru_sp1	0	0	0	2	1	0	0	0	0	1	0
Myrmicinae	Strumigenys sp2	Stru_sp2	0	0	0	66	0	0	0	0	0	0	0
Myrmicinae	Strumigenys sp3	Stru_sp3	1	1	0	0	0	0	0	0	0	0	0
Dolichoderinae	Tapinoma sp1	Tapi_sp1	0	0	0	0	0	0	2	0	0	0	0
Dolichoderinae	Tapinoma sp2	Tapi_sp2	0	0	14	0	0	0	0	0	0	0	0
Dolichoderinae	Technomyrmex sp1	Tech_sp1	3	92	30	15	54	96	5	2	4	80	1
Dolichoderinae	Technomyrmex sp2	Tech_sp2	0	0	8	0	0	0	0	0	1	1	0
Pseudomyrmecinae	Tetraponera rufonigra	Tepo_rufo	0	0	0	0	0	0	0	0	1	0	0
Pseudomyrmecinae	Tetraponera sp1	Tepo_sp1	0	1	0	0	0	0	0	0	1	0	0
Myrmicinae	Tetramorium sp1	Tetr_sp1	13	20	8	4	23	5	5	18	3	2	6
Myrmicinae	Tetramorium sp2	Tetr_sp2	0	0	0	0	0	0	0	1	3	0	1
Myrmicinae	Tetramorium sp3	Tetr_sp3	0	2	0	0	0	0	0	0	2	3	2
Myrmicinae	Tetramorium sp4	Tetr_sp4	0	4	0	0	0	0	0	0	1	0	1
Myrmicinae	Tetramorium sp5	Tetr_sp5	0	1	0	0	0	0	0	0	0	0	0
			fr1	fr2	fg1	fg2	fg3	ns1	ns2	ns3	si1	si2	si3
Species richness			21	26	22	21	20	17	20	28	27	25	23

Appendix- II-

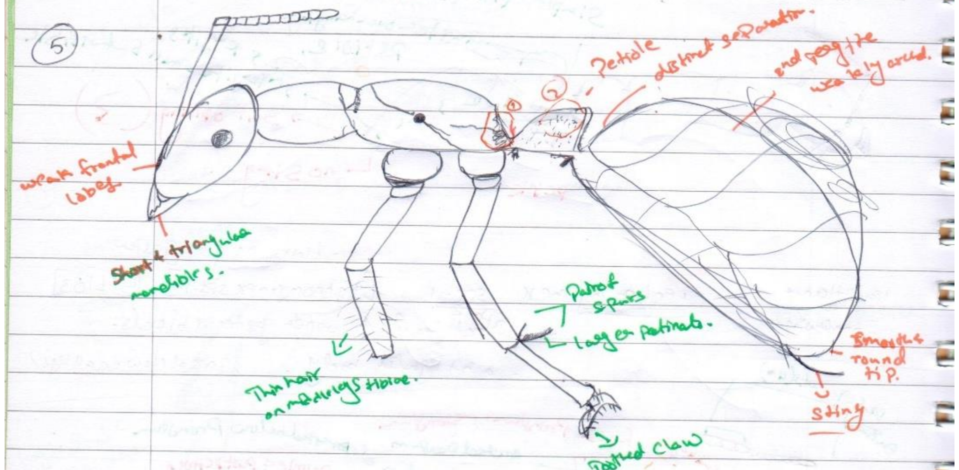
Drawings of the species collected during the study, few common and stand-alone species weren't drawn.





Leptogenys sps-1 (CKL301)

⑤



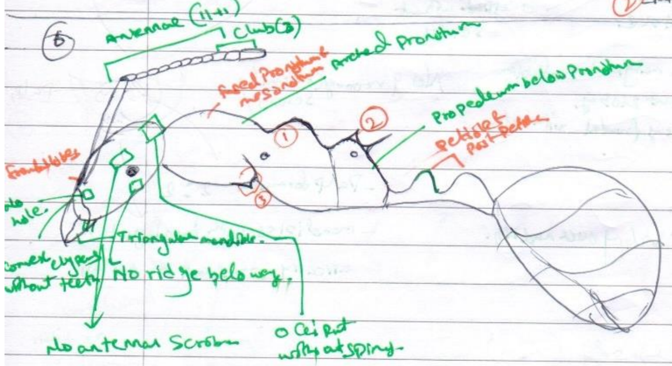
① transverse ridges.

- Big, Black color.
- Large legs,
- gaster - Larger than the alitrunk. big sting.

① Dorsal gradually.

② minute small/patterns on petiole

⑥

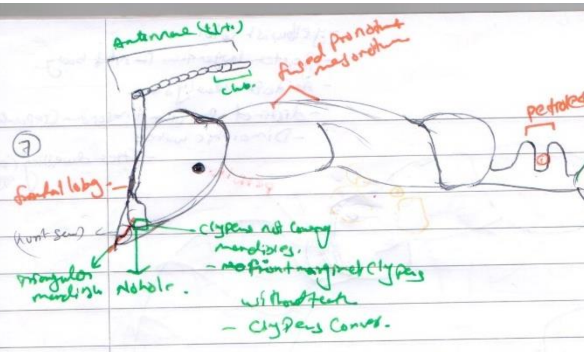


Differs from Pheidole sps 2
by ① → groove on mesonotum
② → Spiny on Propodeum
③ →

- Palp formulae 2:2
- mandible with 2 large, one small & overlap teeth on others

Pheidole - sps-II (CKL301)

⑦



Monomorium sps-I (CKL 303)

(rectangular head)

- (scub antennae) - looks like Pheidole
- darker (blackish red)
- ① - petiole & post petiole, more(or) less similar in size & shape.
(- keeps falling on back or bottom (difficult to keep it on side))

⑧

→ N_2 attached to gaster by more than 1/2

Cardiocondyla

- Propodeal spine

- yellowish color body & dark gaster.

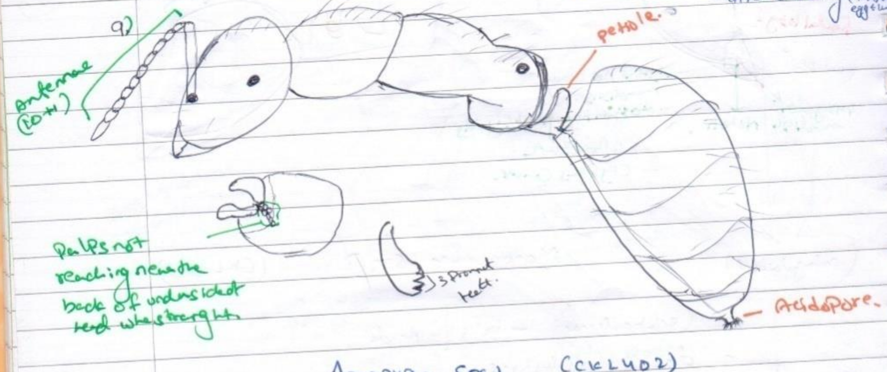
Cardiocondyla sps-1 (CKL401)

(Cardiocondyla worker ??)

01/04/2023

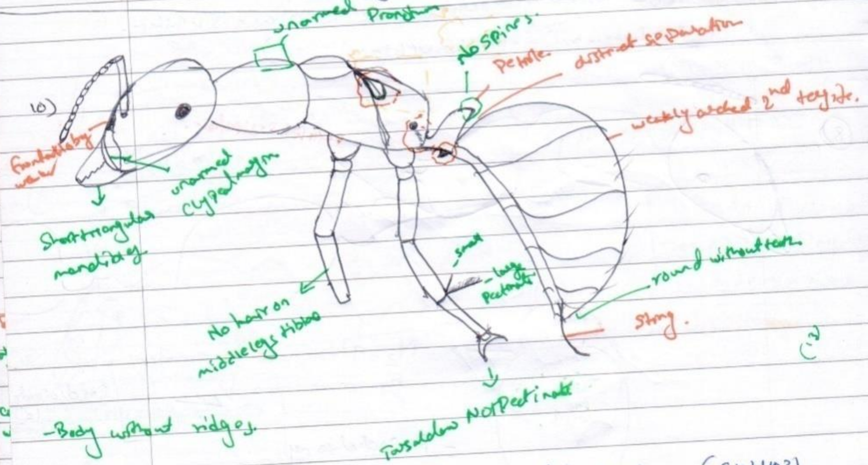
- yellowish color.
- gaster larger than the rest of body.
- Acidopore clearly seen
- distinct Pronotum & mesonotum (separated)
- Dimorphic workers
- litter dwelling (pupae & eggs)

9)



Acropyga sps-1 (CKL402)

10)

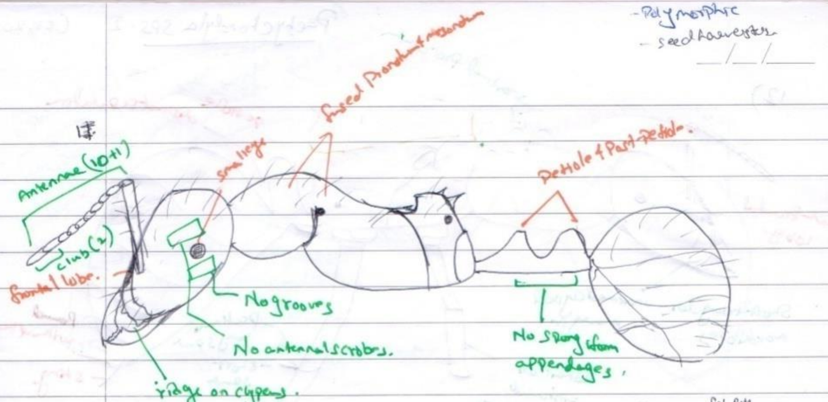


- Body without ridges.

Pachychondyla sps-1 (CKL403)

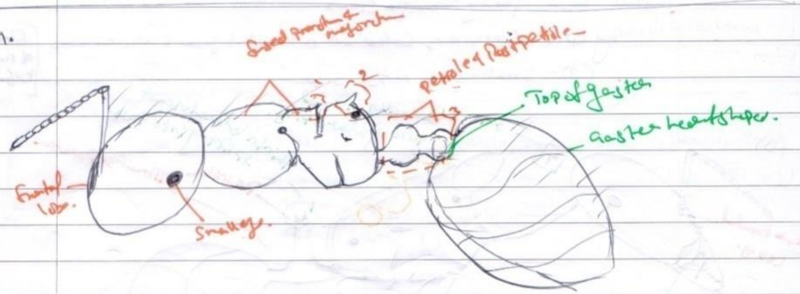
(Brachyponera luteipes)
(with major and disc)

- Polymorphic
- seed harvester



Carebara sps-1 (same as earlier)

11.



- Reddish head, a bit lighter alitrunk, darker gaster.

1 - Spine on mesonotum
2 - Spine on Propodeum
3 - Petiole & Post-petiole distinct + heart shaped from top → double banded.

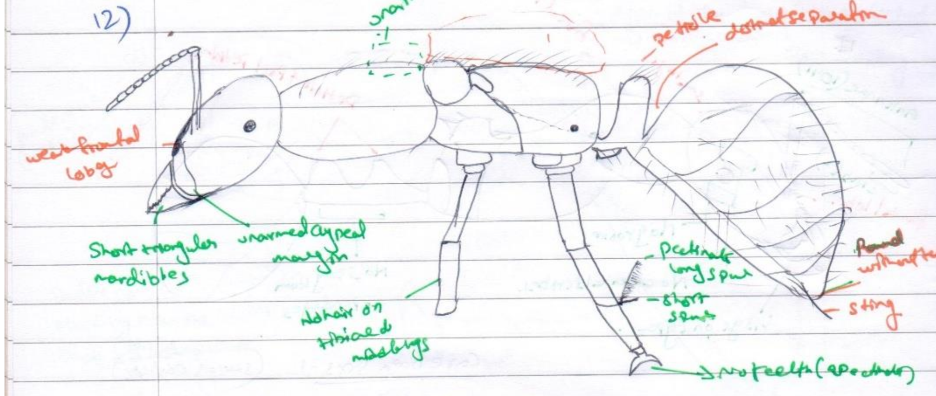
- Dimorphic

[HL104]

Crematogaster sps-1

Pachychondyla sps-2 (ck202)

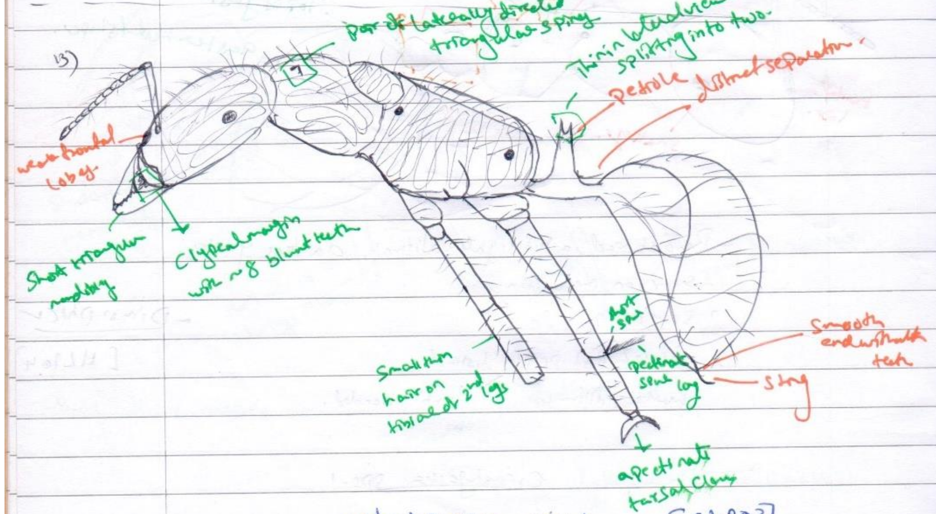
12)



Differs from Pachychondyla sps-I
by ① - Presence of setae on alitrunk & gaster & petiole.
② - small in size ~2/3 size.

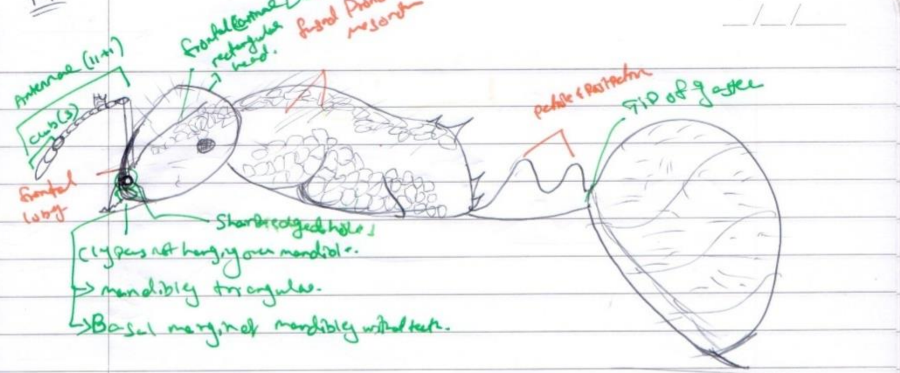
[Check all of them before BZ-2]

13)



odontoponera sps-1 [ck203]

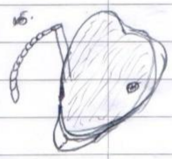
14.



- Tetramorium sps-1 [ck301]

Tetramorium - rectangular head
- 2 pairs Pronotal spines.
- rectangular head
- hole below antennae

15.



- pheidole sps-2 (Subm. 304)

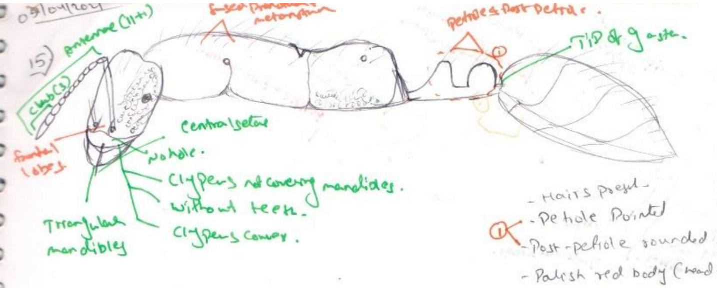
[ck 401]

- yellow color
- spiny meshing
- head with grooves

Anoplolepis gracilipes - Litter dwelling (Purpose in PL|03)

03/04/2024

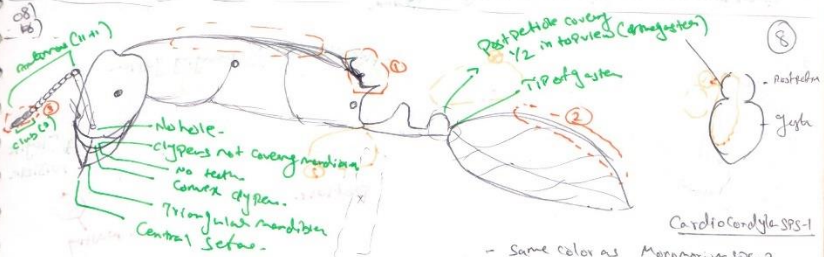
15)



- Hairs present.
- Petiole Pointed (1)
- Post-petiole rounded.
- Palish red body (head & alitrunk)
- darker gaster (black)
- ~~Brownish with black club~~

Monomorium SPS-2 [PL101]

08)



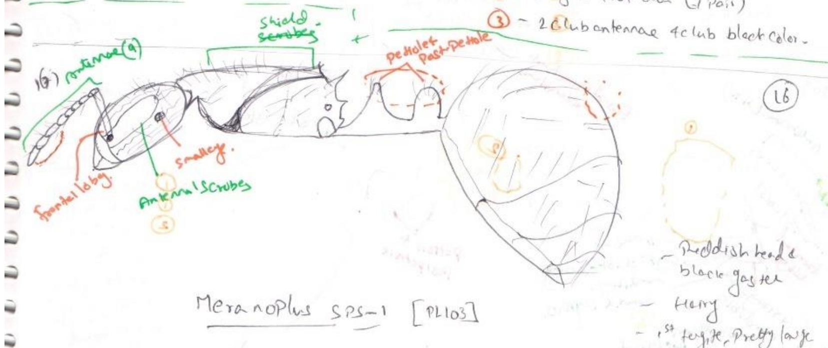
Cardiocondyla SPS-1

- Same color as Monomorium SPS-2 (orangish body & black gaster)
- (4) Smaller size than M. SPS-2
- (2) - No hair/setae on head, alitrunk & gaster.
- (1) - Spiny or Propodeum (1 pair)
- (3) - 2 club antennae & club black color.

Cardiocondyla SPS-1

~~Monomorium SPS-2~~ [PL101]

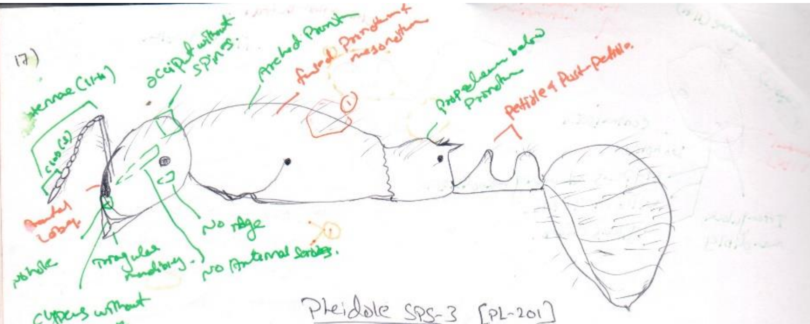
16)



- Reddish head & black gaster
- Hairy
- 1st tergite, Pretty large, what of gaster

Meranoplus SPS-1 [PL103]

17)



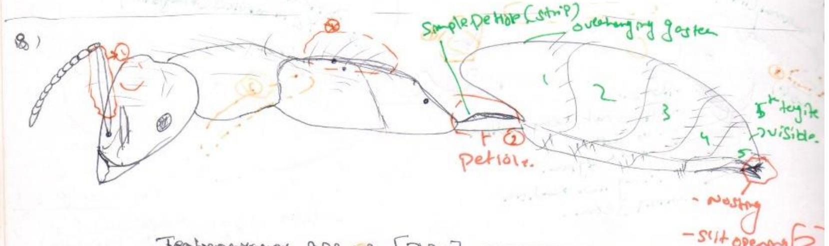
Clypeus without teeth.

Pheidole SPS-3 [PL-201]

- Palp formula - 2:2
- mandible with 2 large, one small & one large @ apex.

- (1) Differs from Pheidole SPS-1 by absence of Suppressed mesonotum (1)

18)



~~Technomyrmex SPS-2~~ [PL301]

Nylanderia SPS-2

- Differs from Nylanderia SPS-1 by (1) having no setae on scape,
(3) Shape of Petiole almost flat like a Technomyrmex petiole. SPS-1 has a bit Pointed

- Small in size

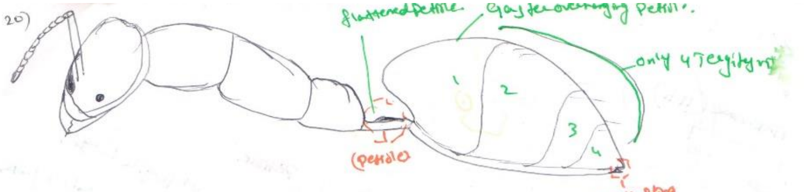
(3) Differs from Technomyrmex SPS-1 by
(1) hairs/setae on head & alitrunk.
(2) Small size (~1/3rd of Technomyrmex SPS-1)
(3) Pale Color.

19)

- Differs from Monomorium SPS-2 by
- (1) Hair on head.
- (1) Smooth head.
- (2) ridges on Propodeum
- => more hairy than Monomorium SPS 2
- larger head

Monomorium SPS-3 [PL303]

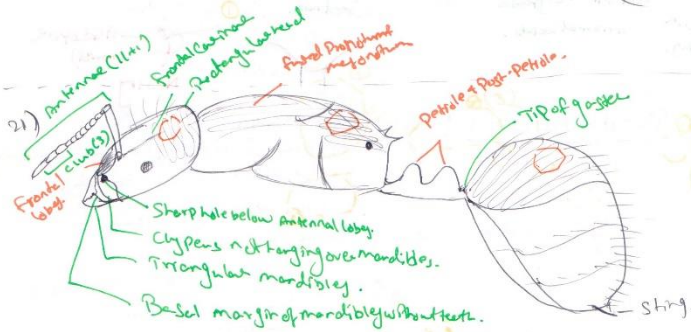
20)



Tapinoma SPS-1 [PL401]

- Pale body
- Small
- hair-orgesterse
- A bit darker head.

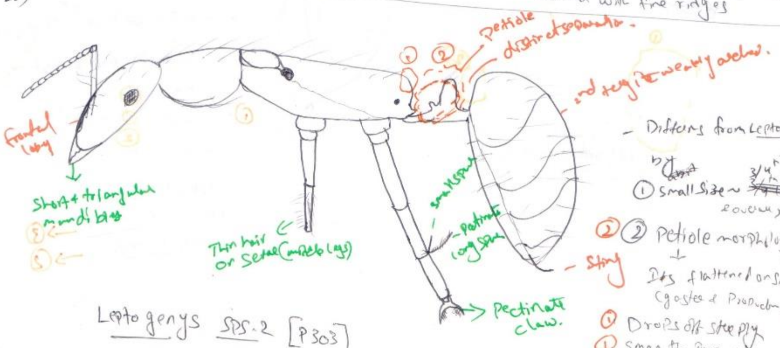
21)



Tetramorium SPS-2 [P203]

- Differs from Tetramorium SPS-1
① by black color (entire body)
② Head, Propodeum & 1st tergite of gaster covered with fine ridges

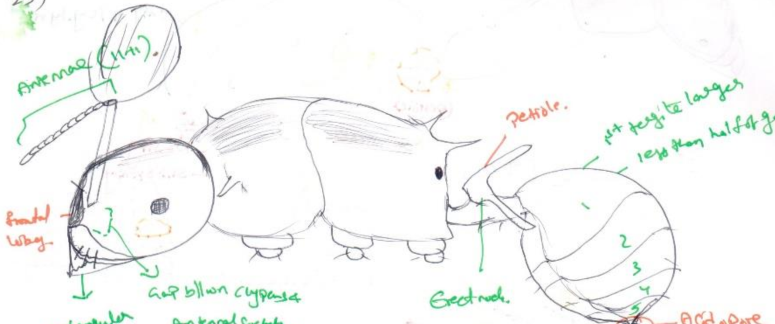
22)



Leptogenys SPS-2 [P303]

- Differs from Leptogenys SPS-1
by
① Small Size ~ 3/4th size of SPS-1
② Petiole morphology
↓
Its flattened on sides (gaster & Propodeum)
① Drops off steeply
① Smooth Propodeum

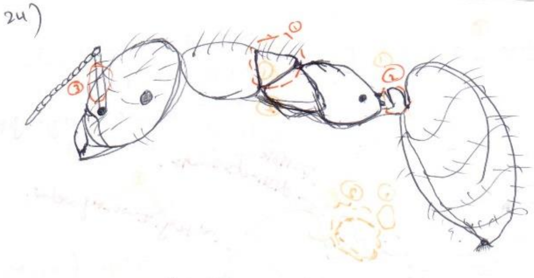
23)



Polyrhachis SPS-1 [P304]

- Black color
- 2 Spines on petiole [Backward pointing]
- 2 on Pronotum & 2 on Propodeum
(forward) Backward.
- Body is covered in smooth & fine ridges.
- Setae
- 3 on clypeus.
- few on [Antennal] frontal lobes.
- Coxae & trochanter
- gaster

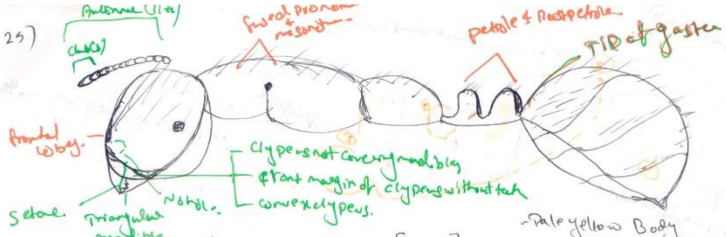
24) [BL103]



Nylanderia SPS-1

- Pale colored & Dark colored Individuals.
- Setae on head, (clypeal also), Promesonotum
- alitrunk (except Propodeum
- Gaster
① Distinct triangle (Dimorphic??)
- Differs from SPS 2 by having Setae on scape → ③
Petiole Shape → ②

25)



Moromorium SPS-4 [B103]

+

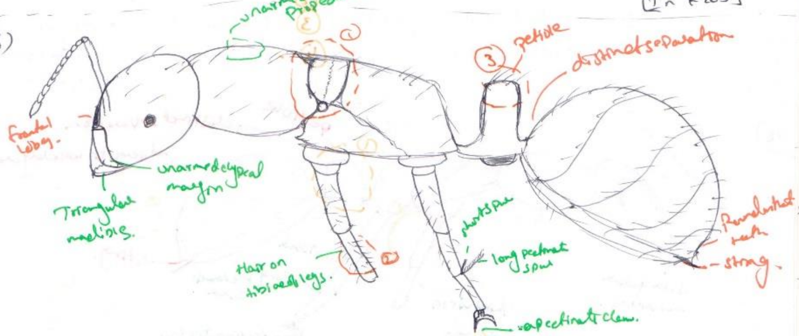
New name

+

Pheidole SPS-4 [attach 1 & 2]

- Pale yellow Body
- uniform color.
- Differs from Monomorium SPS 2 & 3 by Pale body color.
- Havent seen any other morphs
[In K203]

26)



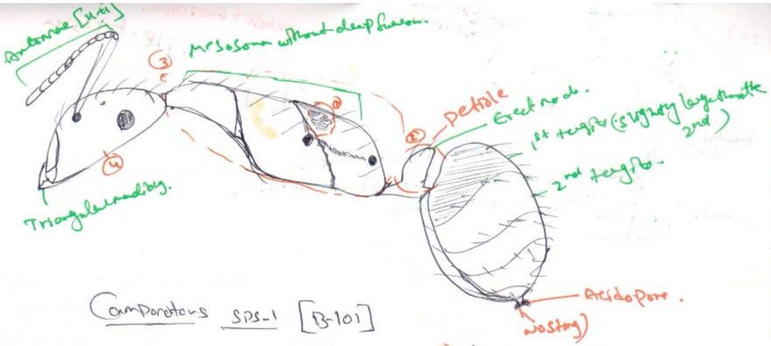
① - Differs from Pachycondyla SPS-2 by absence of clear circular disc on thorax/alitrunk.
- Bigger than P. SPS-2
- more hairy than P. SPS-2
- Same size as P. SPS. 1

② Differs from P. SPS 1 & P-SPS 2 by Presence of hairs on legs also.

③ Shape of petiole - Sandwich type. (- top rounded, sides flat)

Pachycondyla SPS-3

27)



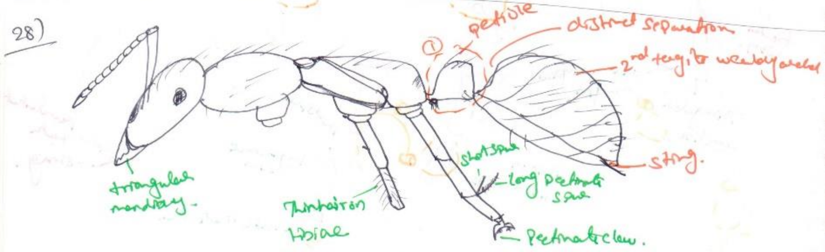
Camponotus SPS-1 [B-101]

- Yellowish body (alitrunk & gaster)
- Reddish / dark head.

① - fine ridges on body
② - shape.
③ - Elongated alitrunk.
④ - Triangular head.

• Setae are large & many than C. SPS - 3

28)



Leptogenys - SPS-3 [B401]

- Small in size than Leptogenys SPS-1
① - differs from L. SPS-2 by petiole shape.
- differs from L. SPS-1 by Plain petiole (no articulations)

2a)

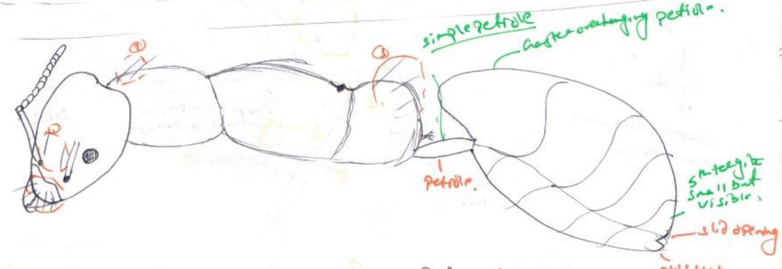
- long mandibles.
- arising from apex of labio-maxillary complex.

- Orangish body
- distinct Petiole & Post petiole (ball like) + fused with gaster

~~Mystrium~~ ~~SPS-1~~ [B401]

Strumigenys - SPS-1

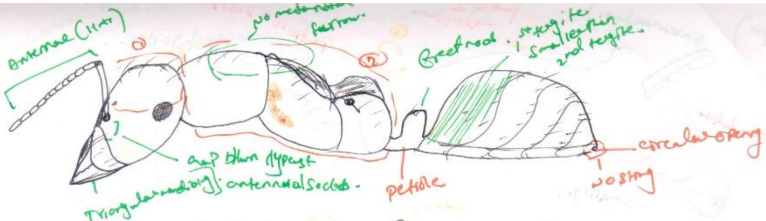
[- litter nesting (below litter) @ BL401 in litter collected]



Technomyrmex SPS-2 (AL103)

- Differs from ~~SPS~~ Technomyrmex SPS-1 by presence of setae on
1. Clypeus & near antennal sockets.
2. Pronotum
3. Propodeum.

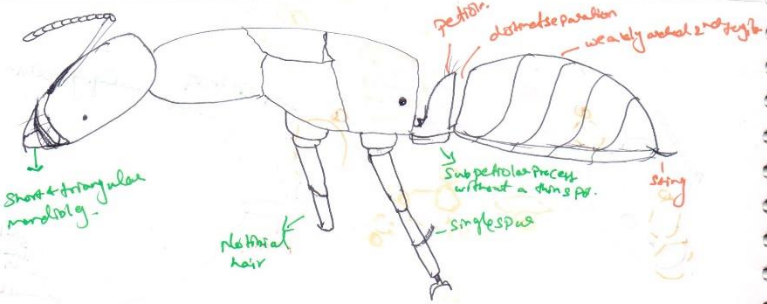
- Darker color.
- One individual showing fungus fruiting body out of it (AL103)



- Camponotus SPS-2 (AL303)

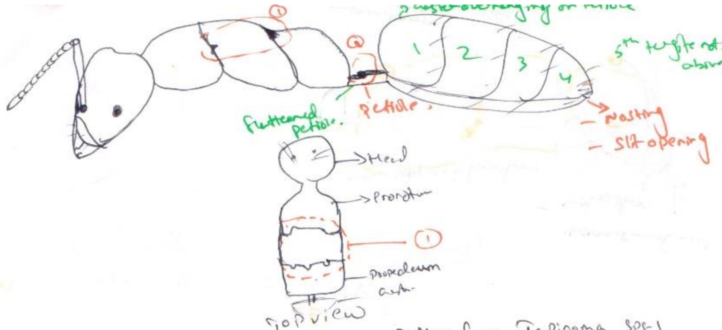
Change it to SPS-3 + description is better there.

- Darker the species
- head & alitrunk same color (dark)
2. - Differs from SPS-1 by not having elongated alitrunk.
1. - Head shape ~ oval.



Hypoponera SPS-1 [AL402]

- very small ant.
- very small eye. (may be hypogaeic ant)
- Reddish yellow.



Tapinoma - SPS-2 [AL203]

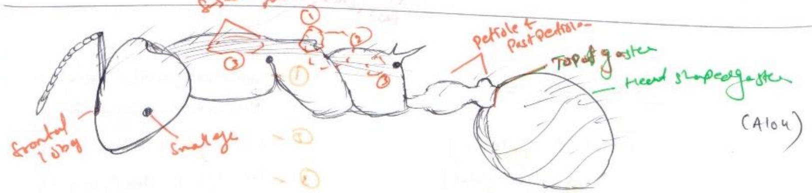
- Differs from Tapinoma SPS-1 by

A -> Big Size

B -> (1) The marginal plates on alitrunk is not uniform & is projected into each other plates.

(2) Petiole shape.
↓
looks like an additional layer on petiole compared to T-SPS-1

- relative eye size is smaller than T-SPS-1 ?



Crematogaster SPS-2 [A104]

- few long setae

- Differs from Crematogaster SPS-1 by

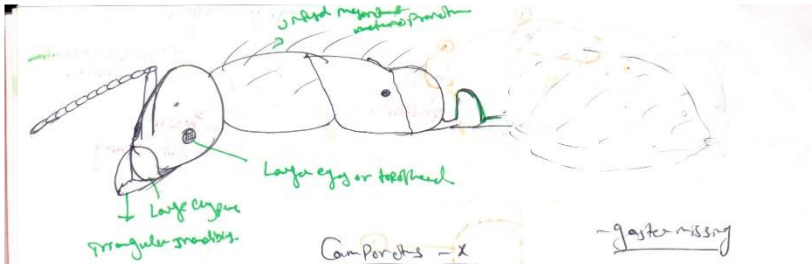
A - Small size.

(1) - B - mesonotal spines are smaller.

(2) - C - Propodeum is below mesonotum (drop can be seen clearly

(3) - D - Carinae on alitrunk prominent

(2) - E - No groove like C. SPS-1

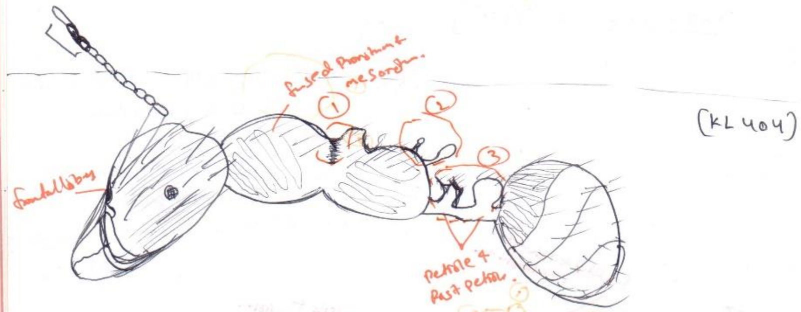


Camponotus - X

[A201]

- gaster missing

- Black color



Pheidole SPS - 5

(Pheidole spathifera)

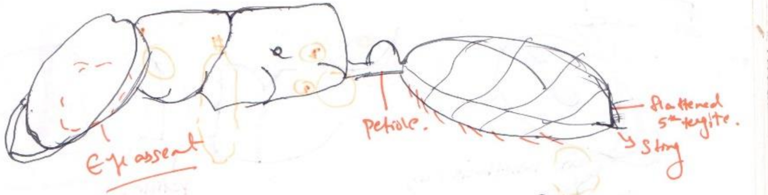
(with queen)

(1) - metanotal groove (??) Prominent Propodeum dips down Pronotum

(2) - Spines forming bulb like @ tip.

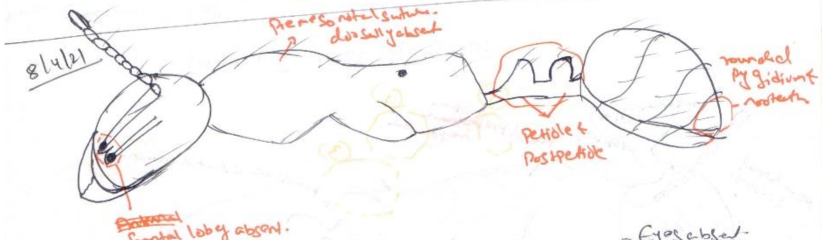
(3) - Petiole looks almost completely the Propodeum -> little fixed on top

- Postpetiole almost fused with gaster + (rounded)



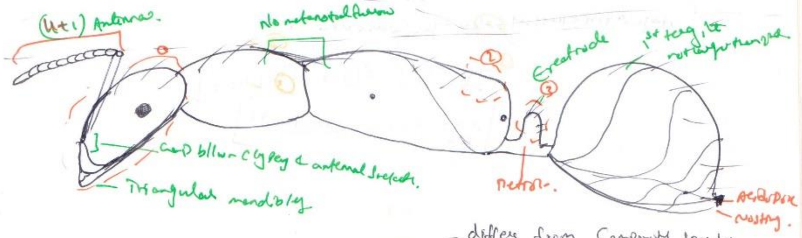
Dorylus SP-1 [KL-303]

8/4/21



Aenictus SPS-1 [K201]

- Eyes absent
- Petiole & Postpetiole.

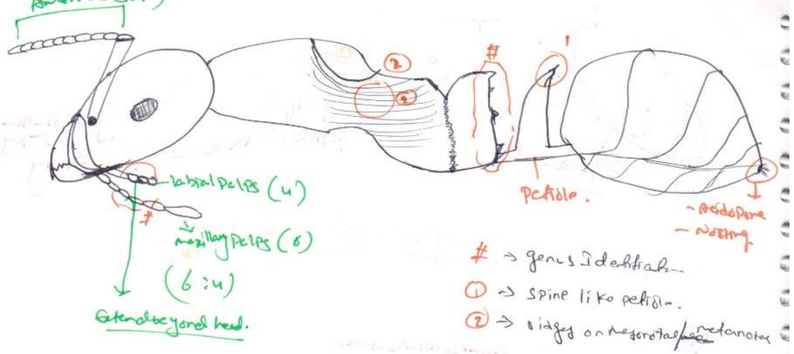


- differs from Camponotus spcs by color

Camponotus SPS-3 [ML401]

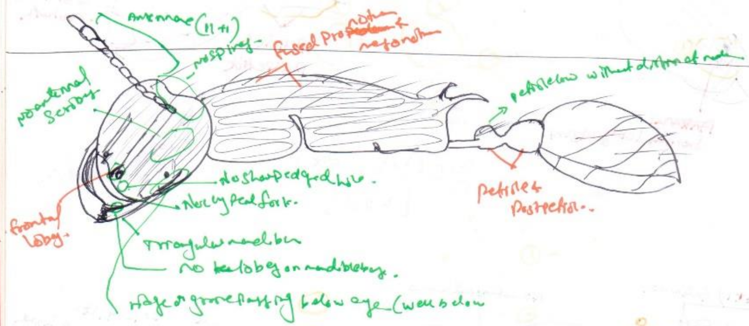
③ - petiole shape.
② - No ridges on body
① - Triangular head.

- Scape are short & few



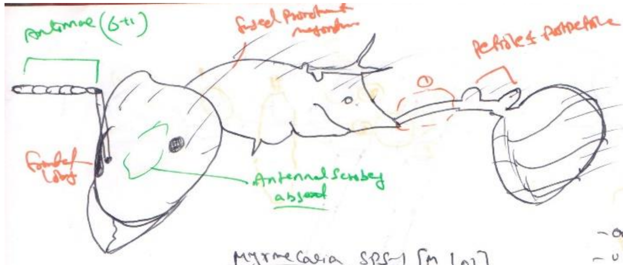
→ genus identification.
① → spine like petiole.
② → ridges on propodeum/metanotum

Lepisiota SPS-1 [ML401]



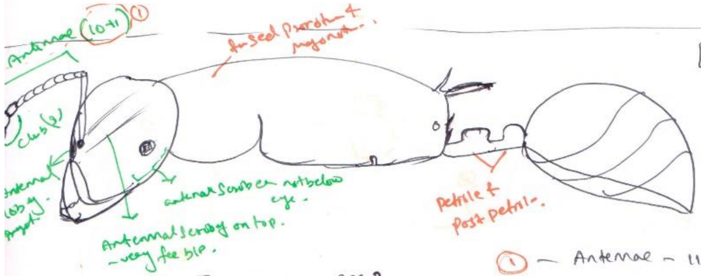
Myrmecina SPS-1 [ML402]

[Myrmecina striata ??]



Myrmecaria SPS-1 [M 101]

- Orangish red Color
- uniform Color.
① - Petiole similar to body altitude by long.....



[M 303]

Tetramorium SPS-3

① - Antennae - 11 segments.
② - Size - bigger than SPS-1
- Same coloratn.
- (check whether it has long setae ?)

[M 401]

Leptogenys SPS-4

- Separated from Leptogenys SPS1 - by ① - fine lines on head.
- Presence of ridges on ...
- Shape of petiole & size.
② Metanotal groove is wide than SPS-1

-> Separated from L. SPS-5 by
~~Square~~ more triangular head
-> Eye Position -> more towards occiput.
-> Smaller size.
③ The metapleural gland is a Projection here, depressed in SPS-5

Check all Leptogenys SP1 & 2

[M 401]

Leptogenys SPS-5

from Leptogenys SP① & ④ by-
① Rectangular head.
② Position of eye.
③ Not Prominent groove @ metanotum ...
④ Metapleural gland is depressed.
- Setae are less in number

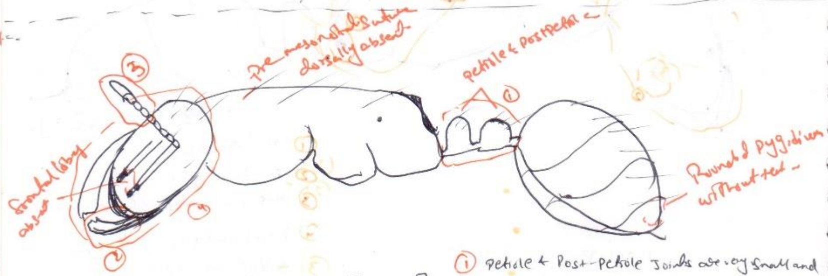
Check all Leptogenys-2 once

5 - Elongated Propodeum as in SPS①

9/4/21

Polyrhachis SPS-2 [BHL402]

- differs from Polyrhachis SPS-1 by -
1. Eye position - more towards occiput.
2. Pronotum spines ~~absent~~ not prominent.
3. Smaller propodeal spines & different shape.
4. Petiole shape & spines number (4 spines)



Aenictus SPS-2 [BH303]

1. Petiole & Post-petiole joints are very small and as almost not there.
2. Broader mandibles.
3. Broader antennae.
4. Head is more rectangular than SPS-1 where it is slightly oval.

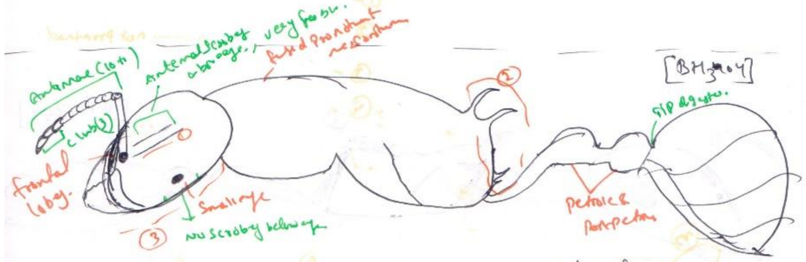
- Dark red color.

[BH304]

Tetramorium SPS-3

- Same size as SPS-2 but color is darker.
1. - Petiole & ~~gas~~ propodeum joints longer & curved downwards.
2. - Spines are long & pointed. (a pair?)
3. - ridges on the alitrunk.

[BH304]



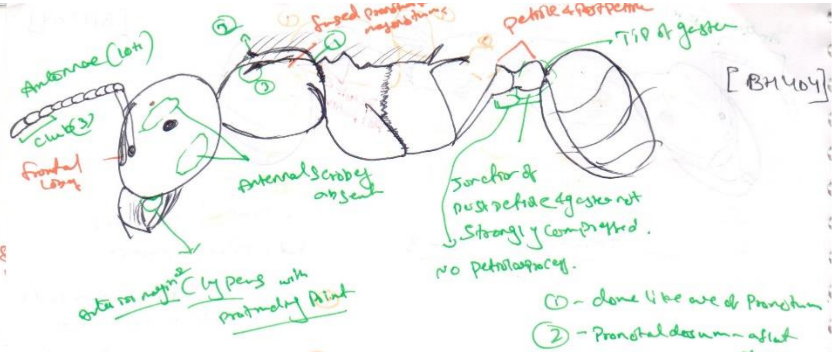
Tetramorium SPS-4

- Differs from SPS-2 by having uniform color.

from SPS-1 by
- T. SPS-1 also
- Body/alitrunk architecture is more/less absent.
- uniform color
- rectangular head.

1. - Antennal scapes not reaching top of head
2. - Spines on propodeum are curved
   2 pairs prominent < Top pair downwards, Bottom pair upwards.
3. - Head shape more broader & oval like.

- from SPS-3 by
2. absence of ridges on body & spines.

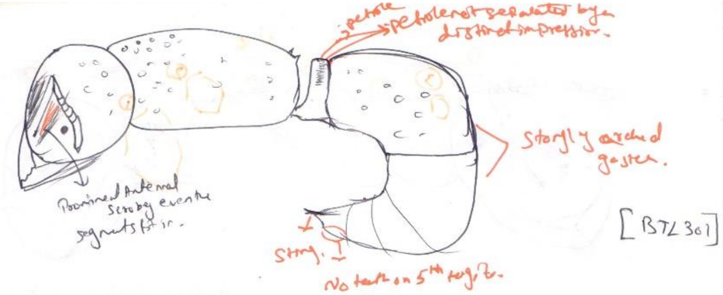


no petiolar process.

① - dome like area of Pronotum
② - Pronotal dorsum - a flat Plateau.
③ - marginate laterally.

Lophomyrmex SPS-1

- yellowish body & dark gaster



Discothyrea SPS-1

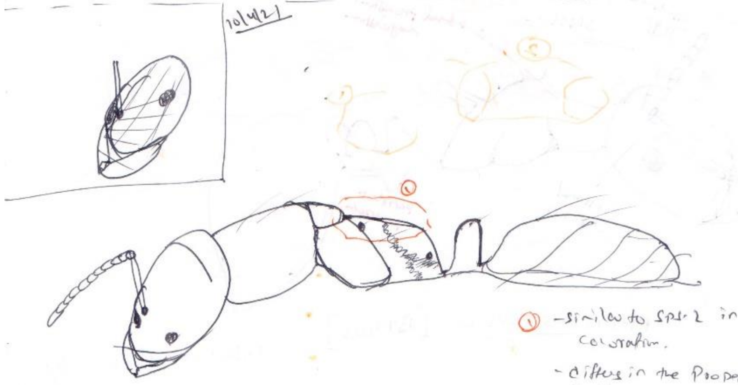
- granulated body

even the legs fit in

Tetraponera SPS-1

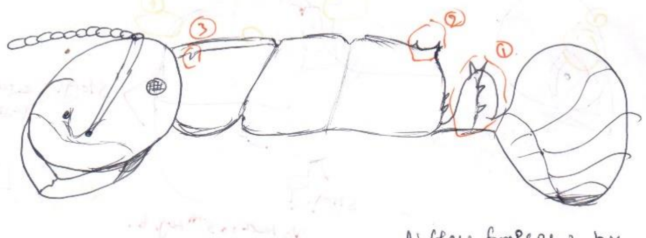
- Black colored Rubrum.
- Small Size.

① - raised Propodeum



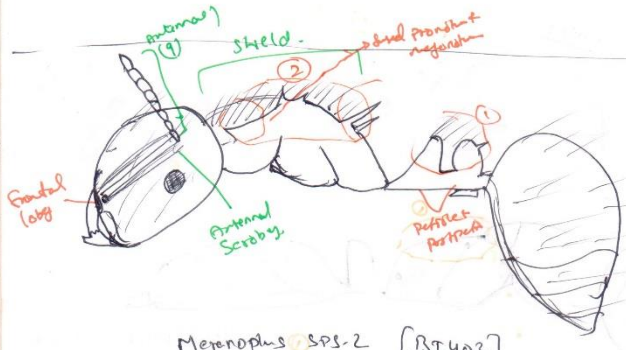
Pachycondyla SPS-4 [BT202]

① - similar to SPS-2 in size & coloration.
- differs in the Propodeum shape & depression angle.
- setae a bit more sparse than SPS 2.
- smaller than SPS ① & SPS ③.
(- more flattened than SPS 2)
+ Step down of Propodeum



Polyrhachis SPS-3 [BT203]

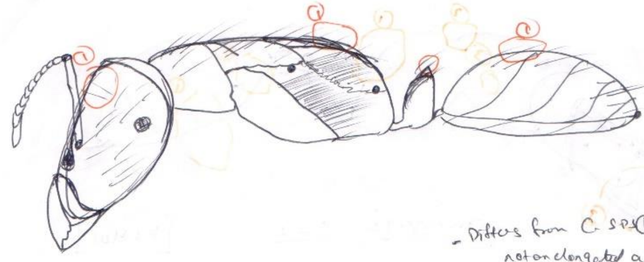
- differs from P. SPS-2 by
- ① – width of petiole & distance in spines + greater.
- ② – spines on propodeum are small & slightly upward.
- ③ – Pronotal apical spines are prominent



Meranoplus SPS-2 [BT403]

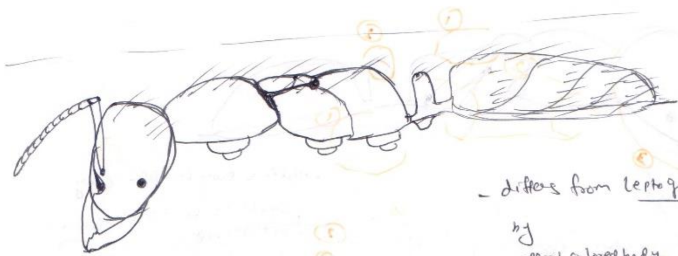
Differs from M. SPS ① by

- having a spine on postpetiole.
- alitrunk spines + pronotal spines & propodeal ...
- Body color + darkened (reddish) - yellowish orange alitrunk & gaster



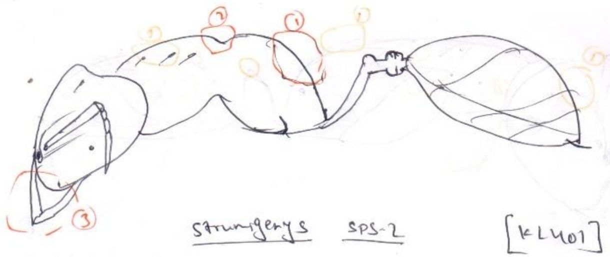
Camponotus SPS-4 [KOL303]

- Differs from C. SPS ① & ③ by not an elongated alitrunk
- ① – long & prominent setae all over the body.
- darker color than C. SPS ①
- very fine griddy over body.



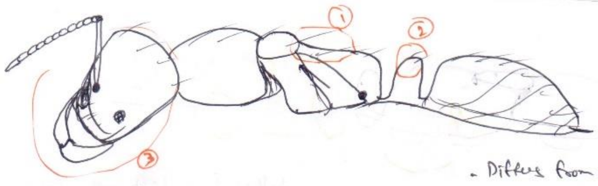
Leptogenys SPS-6 [KO302]

- differs from Leptogenys SPS-5 by
- reddish colored body.
- not so elongated i.e., compressed propodeum
- metapleural gland not prominently seen
- first coxae to second coxae - gap is small.
- a bit bigger



Strumigenys SPS-2 [KL401]

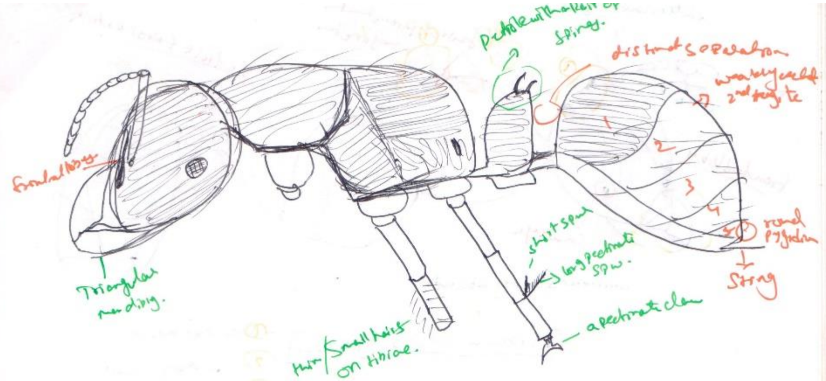
differs from SPS (1) by
(1) – no Propodeal spines.
(2) – depression after Pronotum
(3) – mandibles arent that elongated & teeth are small.
– Hairs like bulbous ends.
– Pale yellow color & uniform



Leptogenys SP-7 [KO404]

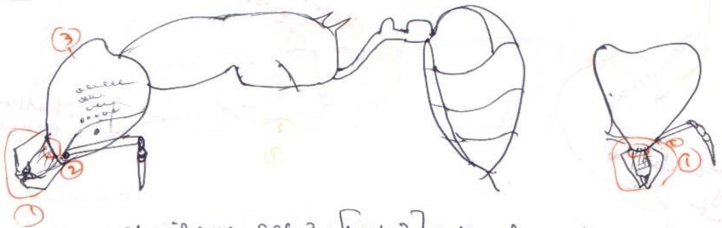
- Differs from L. SPS-6 by
– smaller size & blacker color.
(2) – Petiole shape.
(1) – The drop down of Propodeum is greater here
– Body seems more squarish/rectangle than elongated in SPS-6

– from L. SPS-5 by
– smaller size & more squarish body.
– metapleural gland seen as a depression not as notes in L.SPS 5
– lesser setae.
(1) – depression in Propodeum
(3) – more squarish head than L.SPS.5



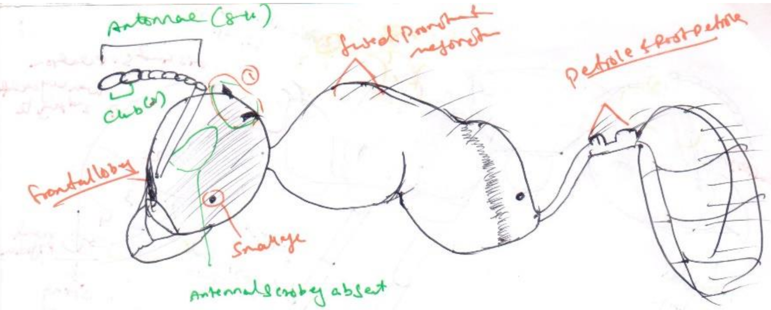
Diacamma SPS-1 [KO403]

- metallic green tint.

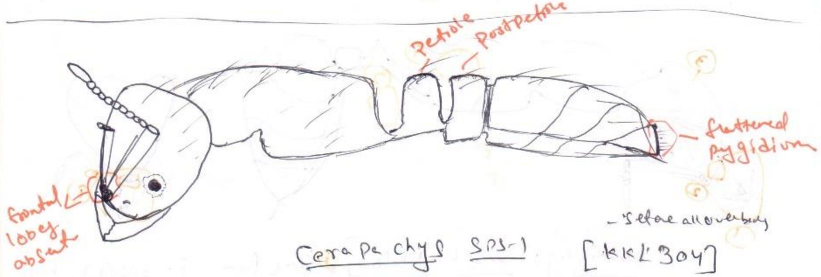


Strumigenys SPS-3 [KK103] differs from S. SPS (1) by.
(1) – having short, stout & broad, mandibles,
(2) – Broader clypeus.
(3) – flatter head,
– a bit bigger.
(2) – Hairs on mandibles

[HL103]

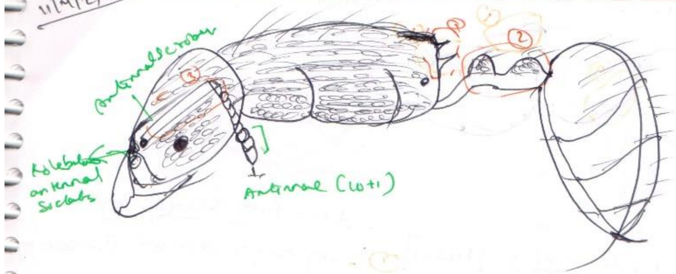


Carebara SPS-3 [KKL202]
- Darker head
- Major worker
- No spines
① - Horns/spikes on occiput



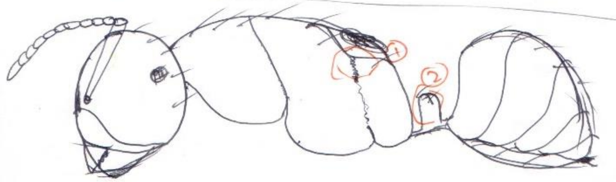
Cerapachys SPS-1 [KKL304]

11/4/21



- only a pair of spines on Propodeum

Tetramorium SPS-5 [KKL401] - Differs from T-SPS-3 by darker body
③ - Prominent Antennal scrobes,
① - Short Propodeal spines (only one pair)
- Prominent body texture.
• - Small numerous setae (SPS-3 has few long)
② - Petiole & Post petiole roughly of same shape & size.
② - Petiole & Propodeum spines small.
- small size



Camponotus SPS-5 [KKL401]
- more rounded body
① - Propodeum dropping below Pronotum
- Darker color.
② - Petiole almost invisible & small when compared to others.
- Big few setae.

Crematogaster SPS-3 [HL304] (1)

- differs from C.SPS-(2) by,
- very strongly depressed Propodeum + mesonotum.
- mesonotum is curved rather than flat in C.SPS-2
- darker color.
- No carinae on head.
- long setae are absent.