SPATIAL PATTERN OF TERMITE MOUNDS AND ITS ASSOCIATION WITH VEGETATION WITH EXPERIMENTAL INSIGHTS ON MOUND REPAIR IN RESPONSE TO ANT DIVERSITY

by

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Under the supervision of

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DECLARATION

I hereby declare that the work conducted under the thesis entitled **“Spatial pattern of termite mounds and its association with vegetation, with experimental insights on mound repair in response to ant diversity”,** is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master’s in Wildlife Science** at the **Academy of Scientific and Innovative Research**. This research work has been carried out under the guidance and supervision of **Sh. Ritesh Kumar Gautam, Scientist-C** of Wildlife Institute of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding, and the particulars given in it are true to the best of my knowledge.

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CERTIFICATE

This is to certify that the thesis by **Vishvavikash I K** entitled **“Spatial pattern of termite mounds and its association with vegetation, with experimental insights on mound repair in response to ant diversity”** is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master’s in Wildlife Science**.

Vishvavikash I K has put one semester of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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1. EXECUTIVE SUMMARY

Termites are considered pests all around the world in Human settlements and agricultural fields. But in Nature, termites are ecosystem engineers, they play a key role in keeping the ecosystem balanced by processing plant material and returning nutrients to the environment. In the African savanna and the Tropical Rainforest of Malaysia, termites are well studied, and termite mounds are considered nutritional hotspots. In the African continent, the genus *Macrotermes* is well studied, and their distribution mainly depends on the colony size. The larger colony size utilizes more space for foraging around the mound and also shows great intra- and interspecific competition between the colonies. In India, very few studies have been conducted on Termites. In this study, we investigated the spatial ecology of Termite mounds (genus *Odontotermes*) in the Sal-dominant Forest of Western Rajaji National Park. To understand the spatial ecology of termite mounds, we assessed their spatial distribution patterns using GPS mapping, mound morphometric characteristics, the influence of surrounding vegetation, and soil chemical properties. We studied the mound repair dynamics of the termites with respect to the predatory pressure exerted by the surrounding mound organisms. We created artificial breaches in termite mounds to monitor repair rates, while pitfall traps around mounds assessed ant diversity and abundance in the surrounding area. The Size classes of the Termite Mound didn't show any kind of territoriality around them. Vegetation around termite mounds (*Odontotermes*) didn't show any type of heterogeneity around the termite mounds. Termite mounds of the small size class show a faster repair rate than the larger termite mounds. The Ant diversity does not dictate the termite mound repair rate.

2. INTRODUCTION

Insects appeared on the Earth much earlier than human beings (Grimaldi & Engel, 2005) and occupied almost all ecosystems on Earth. Almost every ecosystem on Earth relies on insects to function efficiently. With their versatile body plans, insects have effectively colonized a number of habitats (Stork, 2018). The 'insect' term derived from the Latin word "*insectum*" gives the meaning "cut into". They also contribute significantly to the transfer of energy from plants to higher trophic levels in the food chains (Saunders & Rader, 2020). Beyond their ecological roles, insects have a profound cultural impact on human culture and religion, as well as on numerous types of art, folklore, and tradition. (Duffus et al., 2021)

2.1 General Introduction about Termites

Termites are diverse species of social insects having a common ancestor with cockroaches in terms of ecology and evolution (Inward et al. 2007). There have been plenty of discussions on the termite's evolutionary position. According to recent reclassification, termites belong to the insect order Blattodea.

Termites live in colonies and establish eusocial organizations. Eusocial insects make colonies of genetically similar individuals, with various castes found among them. The highest level of social organization can be found among these insects, which leads to cooperative behaviors like defense against predators, food gathering, reproduction, and avoiding abiotic stress (Wilson,1975).

In soil, we can find a wide variety of life forms that make the most complex and species-rich environment. In tropical and subtropical areas, termites are the primary invertebrate decomposers of dead organic materials (Bignell and Eggleton 2000). Termites account for up to 95 % of soil insect biomass and more than 10% of overall animal biomass in tropical ecosystems (Jones and Eggleton 2000). Research estimates 20-70 million termites per hectare in particular biotopes (Jouquet et al., 2011); termite biomass can account for 40-60% of total soil macrofaunal biomass (Dahlsjo et al., 2014).

Termites build arboreal, epigeous, or underground nest systems. Termites can be divided into three broad groups according to their habitat: subterranean, dry-wood, and damp-wood termites (Paul and Rubean 2005). They construct mounds by a fascinating process. The soil is combined with organic ingredients to create the mound nests. Saliva and dirt particles are combined to create the main structural building material. The second substance, called carton, is typically utilized to construct the nest's partitions and is composed of fecal and saliva pellets. Particles of soil are chosen, moved, repositioned, bound together, and combined with organic materials (Wood and Lee 1971).

The morphological differentiation across species of termites with overlapping geographic ranges is notoriously challenging. The outward appearance of soldiers and alates has historically served as the foundation for termite systematics (Snyder 1926). Worker morphology also makes it possible to identify species, particularly in taxa that feed on soil, since each species has a highly modified digestive system that differs morphologically from the others (Noirot 2001).

Termites have a very bad reputation as they are the major pest for household furniture and agriculture that have a significant negative economic impact but these insects are crucial for ecosystems since they recycle a lot of nutrients. Termites are regarded as significant structural pests that cause enormous quantities of damage.(Su and Scheffrahn 1998). Despite having comparable numbers, termites have gotten significantly less attention than ants and bees, which are among the most widely studied of the eusocial species.

2.2 Termites in India

Emerson (1959) asserts that 300 of the 2000 species of termites known to exist worldwide are found in the Indian subcontinent. The genus *Odontotermes* is the most prevalent of the numerous genera found in India; 40 species have been discovered under this genus (Sen Sarma 1962). Sen-Sarma (1974) discussed the biogeography and distribution of different species with respect to vegetation, soil type, and rainfall. With 337 species, termites are highly diverse in India, the largest country in tropical Asia (Chhotani 1997). According to reports, *O. obesus* is the termite that builds mounds most in Northern India. (Roonwal et al, 1987) .Its mounds are a noticeable part of the enormous wet tropical deciduous woods at the foothills of the Himalayas, mostly made up of Sal (Sen-Sarma 1974). Mound-building behaviors of several species from various regions of India have been previously described (Roonwal 1977; Krishna et al. 2013), which include multiple species *O. obesus, O. assmuthi, O. gurudaspurensis, O. redemanni, O. walloensis, O. brunneus, O. feae, O. microdentatus, O. parvidens, Trinervitermes biformis, and Macrotermes convulsionarius*

2.3 Spatial pattern

The phenomenon of scale is one of the most discussed topics in ecological literature. This is due to the fact that most ecological patterns, the processes that accompany them, and how noticeable they are vary according to the scale of the observation (Dungan et al., 2002). To understand population dynamics, community interactions, and ecosystem functioning, one must have a solid understanding of species spatial distribution (Gontijo and Domingos 1991). The spatial patterning of organisms is often linked to the outcomes of competition and predation (Pomeroy 1989; Pomeroy 2005). The spatial distribution pattern of termite mounds has an impact on ecosystem functioning and robustness, especially in arid regions where the effects of climate change would be most apparent (Bonacha et al. 2015).

Termite Mounds may be dispersed uniformly in groups or at random (Pringle et al, 2010). Given the intimate relationship between the pattern and production, knowledge of the spatial distribution of termite mounds may be necessary to maintain an ecosystem. In social insects, intra- and inter-specific territorial interactions that divide the foraging habitats of colonies (Hooldobler et al, 1990; Traniello, 1989). Following contact with other colonies, aggression develops, and thousands of laborers and treetops may be involved during natural encounters seen in *Nasutitermes.* (Adams et al, 1987). Fungus-growing termites like *Macrotermes subhyalinus* and *Macrotermes bellicosus* divide food and space where colonies meet, which appears as a strategy to reduce hostile interactions between colonies (Jmhasly and Leuthold,1998). High mortality (including nest mortality), territorial loss, and the divergence of foraging routes into possibly less productive areas are all outcomes of conflict between two different colonies.(Traneillo,1989)

2.4 Plant diversity around Mounds

As decomposers, termites mostly consume dead plant matter in different phases of decomposition, such as dead wood, leaf litter, dry grass, and soil with different mineral contents (Donovan, Eggleton & Bignell, 2001). Furthermore, they might be in charge of a significant amount of the breakdown of herbivore dung (Freymann et al., 2008). A frequent characteristic of arid and semi-arid savannas is noticeable epigeal termite mounds, which play a crucial role in generating spatial variation in the plant and soil (Silesh et al. 2010). In an otherwise homogenous landscape, termite mounds' elevated soil nutrients produce noticeable heterogenous patches (Fox-Dobbs et al. 2010). Moe et al. (2009) found that termite mounds had a higher level of plant diversity than off-mound control plots. When compared to the surrounding woodland matrix, termite mounds have been shown to include distinct plant species in the majority of the studies. Several studies have demonstrated that termite mounds affect ecological heterogeneity, with tree and shrub densities being higher than the surrounding matrix (Jouquet et al. 2005). The enhanced mound soil chemical and physical characteristics are responsible for the greater variety of plant species found there. Termite mounds increased the amount of water in the soil, which is crucial for plant growth (Mando et al. 1996). Nutrient-rich soil of the mound may influence plant and herbivory spatial patterns Bonachella et al, 2015)

Plant biomass showed several changes with distance from the termite mounds in North-eastern Australia (Spain AV et al.,1988). Woody plants prefer sites mostly around termite mounds in the savannah woodlands of Burkina Faso (Traore et al., 2008). Termite mounds also show a significant contribution to the diversity of plants in Uganda's savannah habitats (Moe SR et al., 2009). Various research indicates that Termites also seem to contribute heterogeneity in tropical forests (Jones CG et al.,1994). Even the chemical composition of soils seems to change because of termites' activities during the nest-building process around the mounds. (Watson JP 1977).

2.5 Ant-Termite Interaction

Ants and termites participate in a wide range of ecological interactions (Bignell &Eggleton, 2000). They occupy a variety of niches above and below ground. They make up between 20 to 52 percent of animal biomass in the tropics, and their high biomass density allows them to dominate many ecosystems (Stork, 1996; Dial, 1971). Ants play a variety of roles in their interactions with other organisms. A variety of animals can be effectively preyed upon by them (Holldobler & Wilson, 1990). Ants have a significant impact on arthropod communities through predation pressure, and they have the power to influence entire insect communities (Floren, Biun & Linsenmair, 2002)

Among the many ways that termites and ants interact are mutualistically, commensally, as competitors for nesting space, and perhaps most importantly, as predators and prey. Ants are the most important and frequent termite predators (Holldobler and Wilson, 1990). Ants and termites usually live in the same ecosystem due to their overlapping global populations, and since many ants prey on a wide variety of insects, it stands to reason that ant-termite predation should be common. With large abundances across a variety of environments and the maximum concentrations seen in the tropics, termites are a rather stable species in space (Eggleton, Williams & Gaston, 1994).

It seems unlikely that termites will prey on ants because they are mostly detritivores. Lipids, proteins, minerals, carbohydrates, and micronutrients are all abundant in termites (Wood & Sands, 1978; Sogbesan & Ugwumba, 2008). Rather than their nutritional worth, termite high density may be the reason for their main source of food (Eggleton, Williams & Gaston, 1994). Furthermore, termite bodies, especially those of worker, are not highly chitinized, making them an acceptable and reasonably priced food source for a variety of species, including ants, despite their defense mechanisms. Even among well-studied termite predators, it is unclear what percentage of the ant diet is made up of termites, although it is likely that termites are a significant food source for ants.

2.6 Knowledge Gap

In India, most of the termite-related studies are related to termites' effect on agriculture (Rana et al, 2021). In moist deciduous forests of Northern India, termites play a significant role in the diet of most of the birds and mammals. The Termite mounds have become one of the characteristics of the Sal forests. Ecological studies on termites and their interaction with other insects are very rare in India. Knowledge of termites and their ecological role in soil redistribution in different environments will help us to understand the productivity of the particular habitat. Expanding research in this field helps us understand termites as more than just pests.

3. AIM OF THE STUDY

Objective 1

To investigate the spatial pattern of Termite mounds (*Odontotermes*) in Sal Forest.

Hypothesis

Larger termite mounds control more space around them, keeping other mounds farther away. Medium-sized mounds have less territory than larger ones, while small mounds have very little space and are surrounded by other mounds.

Question

Whether Termite mounds in Sal-Dominant Forest distributed randomly?

Larger mounds spaced farther away from other mounds?

What kind of distribution pattern is found in different mound classes?

Objective 2

To assess Vegetation patterns associated with Termite mounds (*Odontotermes*).

Hypothesis

Habitat heterogeneity around the termite mound will be High because of the termite activity by re-allocation of nutrients.

Question

Do Termite mounds promote the growth of specific plant species or inhibit others?

Does plant species richness vary along the gradient extending from termite mounds?

Objective 3

To investigate the relationship between the repair rate of termite mounds (*Odontotermes*) and ant diversity.

Hypothesis

Termites are highly responsive to damage and rapidly repair the breaches, and the presence of a lot of predators around mounds shows a faster repair rate.

Question

What are the Ant genera present around the mounds (*Odontotermes*) in Sal Forest?

Is there any relationship between repair rate and Mound size (Colony size)?

Do the various mound size classes drive any changes in ant genus composition around the mounds?

4. METHODOLOGY

4.1 Study Area

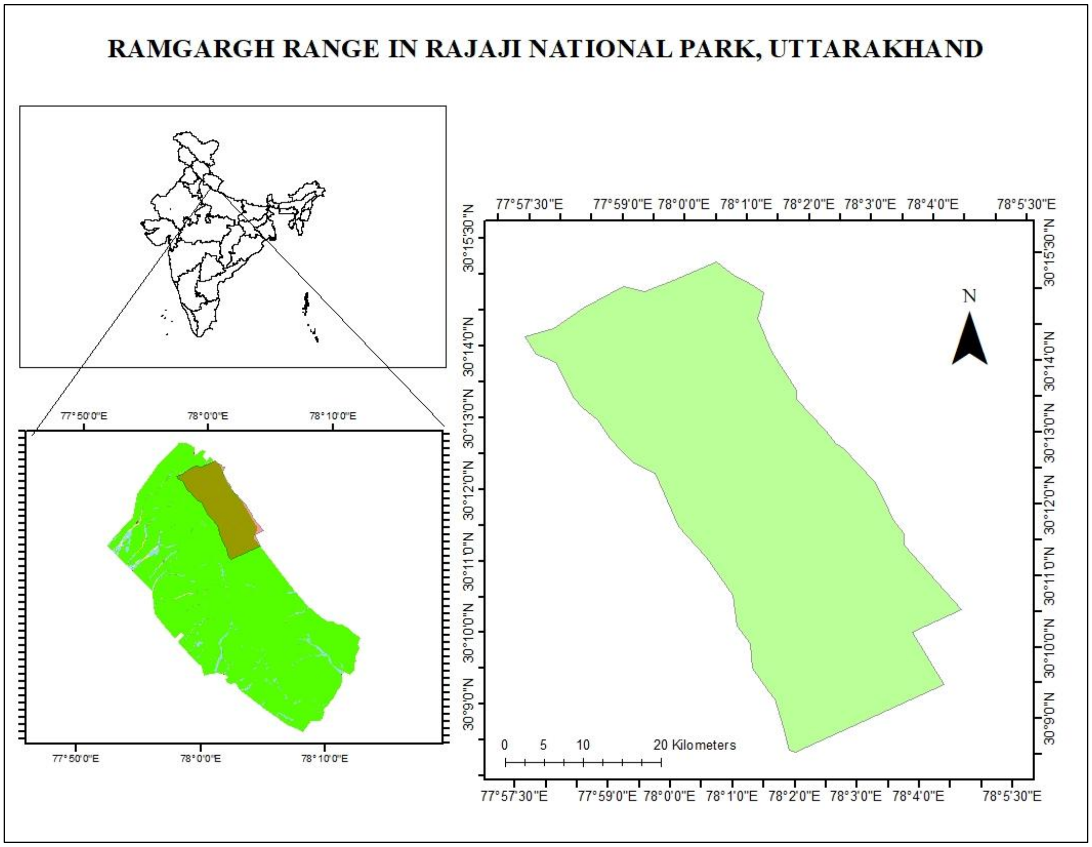


Figure 1: Study Area map for Spatial pattern and Vegetation association

Rajaji National Park, situated in the districts of Haridwar, Pauri Garhwal, and Dehradun in Uttarakhand, India. Rajaji National Park is both a National Park and a Tiger Reserve. It bears the name of Rajagopalachari, India's first and last Governor General. The Park is located in the Shivalik Hills, home to a variety of Flora and Fauna, including pine forests, riparian vegetation, grasslands, and shrublands. The Shivalik, which are between 10 and 20 million years old, are made up of sedimentary rocks such as sandstones and clay. The Hill ranges range from 1000 meters to 200 meters. Rajaji is located in the upper Gangetic plains biogeographic zone Rodgers et al., 2002). Tropical moist deciduous forests make up the majority of the region. The Ministry of Environment, Forests and Climate Change, Government of India, declared Rajaji National Park as a Reserved area for “Project Elephant” in 1983.

For my 1 and 2 objectives, the study area was the Ramgarh Range of Rajaji National Park. For my third objectives, the study area was the Sal Patch behind the Wildlife Institute of India Campus.

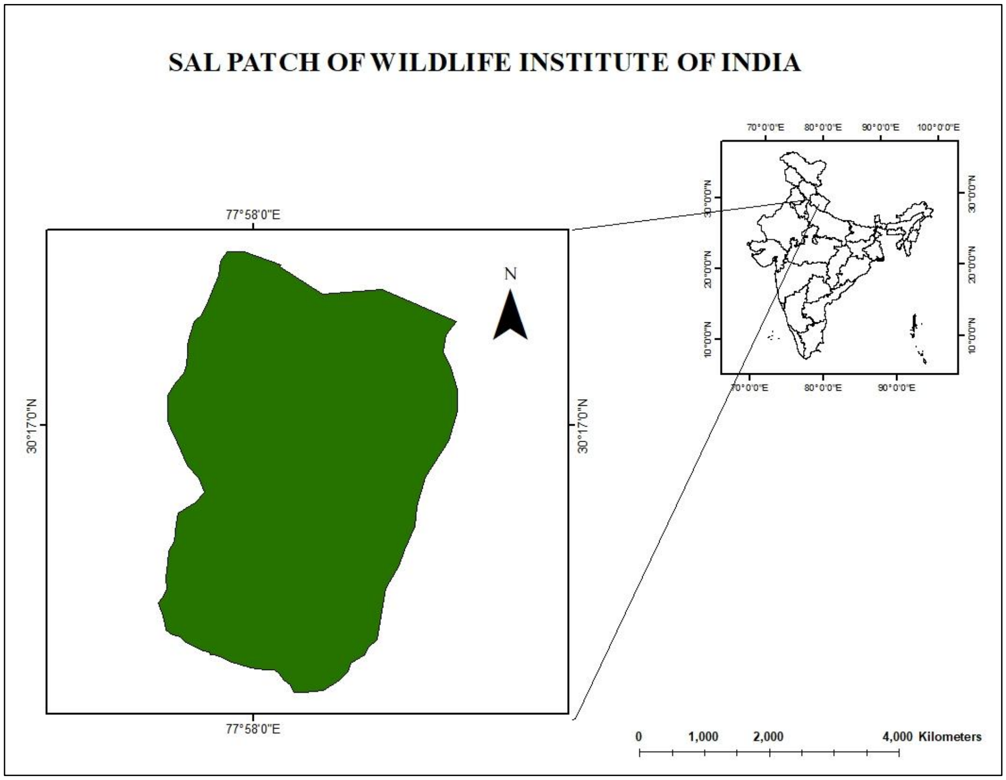


Figure 2: Study area map for the Repair rate and ant diversity

4.2 Objective 1

4.2.1 Field Methods

Mound Location Survey

Three Different plots of 0.5 sq km were taken in the Sal Forest, Rajaji National Park. The plots are farther away by more than 3 km. Each plot is sampled by transects to locate all the mounds inside a particular plot. Two observers walked the transect to locate all the mounds inside the plot. The termite mound location was taken using Locus Map. The Height and the Diameter of every mound inside the plot were noted. The location data was collected with additional canopy cover above the mound using a canopy Spherical Densiometer. Termite mounds condition whether it is active or inactive also noted with what kind of vegetation is on the mounds.

4.2.2 Analytical Methods

All Statistical analysis was performed in R, version 4.2.1, and visualized using ggplot2 (R Core Team, 2022). Ripley's K function is used under the package spatstat. geom and spatstat.explore

Size Classification

To classify termite mounds based on their size, a volume-based method is used. Termite mounds are conical in shape; the volume was calculated by formula

$$V=\frac{\pi}{12} \times Diameter^2 \times \text{Height}$$

This helps us for a meaningful estimation of the mound size rather than relying solely on diameter or height separately.

K-means Clustering for Size Classification

K-Means clustering algorithm applied to group termite mounds into various size categories based on the volume. Standard K-Means clustering (kmeans()) was performed on mound volume using three clusters (k=3) to categorize mounds as small, medium, and large. A random seed (set.seed(123)) is set to ensure reproducibility of cluster assignments. Termites' mounds are assigned to the cluster with which they are more closely related with.

Ripley's k function

Termite mound coordinates were extracted using st_coordinates(), and an observation window for these data is defined based on the dataset's bounding box, st_bbox(), and converted to an observation window with as.owin(). Merging observation window to make sure that the analysis is restricted to the study area, the boundary window (win_1) and the termite mound data's bounding box window (win) are combined using intersect.owin(). The combined window (win_combined) represents the merged spatial data.

Creating the Point Pattern Object (ppp)

The x and y coordinates from the mound data are put in a point pattern object using the ppp() function from the spatstat.geom package. An attribute (SizeClass) is used as a mark for each point. The object (mound_ppp_1) forms the basis for spatial point pattern analysis, including the to assess Ripley's K function.

Computing Ripley's K Function

Ripley's K function, used to evaluate clustering or dispersion in a spatial point pattern. Kest() function from the spatstat.explore package is used to compute the entire dataset. The K function is separately estimated for all of the data by filtering based on mound size category (e.g., Large, Medium, Small) to compare spatial patterns among these groups.

To assess spatial clustering patterns across different size classes of termite mounds, confidence envelopes were generated for Ripley's K function using spatstat.explore package in R. The envelope function was applied to the point pattern dataset to indicate that the observed clustering deviated significantly from a random spatial distribution. The termite mound dataset was filtered into three categories based on mound size (Small, Medium, Large) using the subset() function with spatstat.geom

Monte Carlo Simulations for Envelope Estimation

Confidence envelopes generated using the envelope function with nsim = 99, 99 Monte Carlo simulations of a random point distribution were used to compare against the observed pattern. This tests whether the mounds are significantly clustered or dispersed beyond what would be expected under complete spatial randomness (CSR). This Methodology was applied to additional plots(mounds_ppp_2) and (mounds_ppp_3) to understand whether spatial clustering patterns differ in other plots.

Observed K Function and Theoretical Expectation

$K_{obs}(r)$ be the observed cross-type Ripley's K function at distance r. Under complete spatial randomness (CSR), the theoretical expectation for a univariate point process

$$k_{theor}(r) = \pi r^2$$

Global Test of Spatial Interaction

To assess the spatial interaction between the termite mounds of different size classes, we compared the observed cross-type Ripley's K function, $K_{obs}(r)$, to the theoretical expectation under complete spatial randomness, $k_{theor}(r) = \pi r^2$.

$$D_{obs} = \max_{r \in [r\ min, r\ max]} | Kobs\ (r) - \pi r^2 \ |$$

This represents the maximum absolute departure of the observed functions from their expected reference. To evaluate the significance of D_{obs}, 99 Monte Carlo simulations of the spatial regime obtained from simulated k functions $K_{sim}^{(i)}$ (r) for i= 1, ….,99 . For simulation, the deviance was computed as

$$D_{sim}^{(i)} = \max_{r \in [r\ min, r\ max]} | K_{sim}^{(i)}(r) - \pi r^2 \ |$$

The Monte Carlo p-value was then calculated as

$$p = \frac{\#\{D_{sim}^{(i)} \geq \text{Dobs}\} + 1}{99+1}$$

4.3 Objective 2

4.3.1 Field Methods

To investigate termite mound influences on vegetation and soil properties, we selected 30 large termite mounds (over 200 cm in Height and similar in diameter) across the Ramgarh Range of Rajaji National Park. These mounds were chosen based on their isolation, ensuring a 50 m distance from other mounds to maintain a clear gradient. Studies have shown that the structure and composition of plants up to 16 meters from the termite mounds can be impacted. We still don't have data about mounds in India .

Vegetation Sampling was conducted along a single direction from each mound, ensuring no other termite mounds were present within the sampling path. We established 3x3 m plots for assessing shrubs and 1x1 m plots for herbs at specified intervals of 5m, 10m,15m,25m, 30m, and 35m from the mound. Additionally, soil samples were collected from 10 termite mounds at regular intervals of 5m,10m, and 15 m, providing insight into soil chemical properties across the gradient.

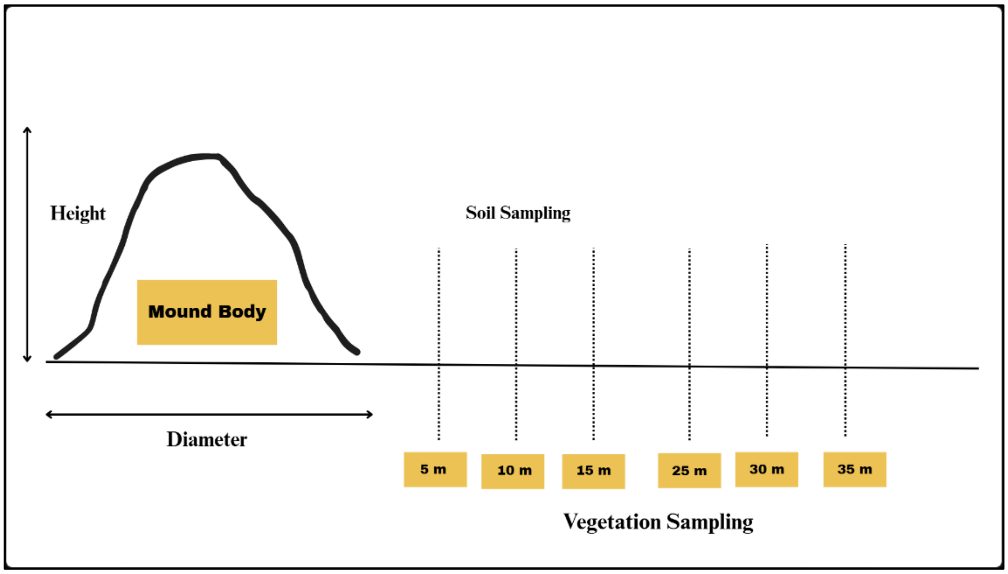


Figure 3: Study design for Vegetation association

4.3.2 Analytical Methods

All Statistical analysis was performed in R, version 4.2.1, and visualized using ggplot2 (R Core Team, 2022). An Indicator species analysis was done using the 'multipatt' function in R with the IndVal association Method. It has a significance level of $\alpha = 0.05$. To see the relationship between species diversity, we calculated the Shannon diversity index and the distance from the termite mound, and a linear model was used. The effect of the termite mound on species richness was assessed using GLM, employing Poisson distribution in R to model count data. PERMANOVA was applied using the adonis() function in the Vegan package, ensuring statistical comparison of community structure across sampled plots. For understanding the relationship between soil parameters and distance from termite mounds, GLMs were used.

4.3.3 Lab Methods

The soil pH was measured using a Digital pH meter, and the pH meter was calibrated with standard buffer solutions (pH of 4.0,7.0, and 10.0) before taking readings of samples. The total Organic carbon in the soil was calculated by (Walkley-Black method 1934). Na and K were measured using a flame photometer. Phosphorus in soil was analyzed using a spectrophotometric method.

4.4 Objective 3

4.4.1 Study Area

The study area for this study is the Sal patch near the Wildlife Institute of India Campus. This habitat is a Sal-dominant area with mainly *Clerodendrum viscosum, Carissa opaca*, *Ardisia solanacea*, *Pyrus pashia*, *Murraya koengii*, *Jasminium multiflorum,* and *Mallotus philippensis*. There is no presence of mammals like Sloth bears or Pangolin, which are the main predators of termites, and they can damage the mound, and Pangolin also predate ants. This area was chosen mainly because the Habitat represents the Natural setup of a salt-dominant forest and its accessibility for this experimental kind of study. Before beginning the Experiment, we have no idea about the repair time of termite mounds. There is no presence of mammals like Sloth bears or Pangolin, which are the main predators of termites, and they can damage the mound, and Pangolin also predate ants.

4.4.2 Field Methods

Termite mounds were selected based on height. Both size classes are the two extreme ends, small (<50 cm) and large (>130 cm). To find the presence of ants around termite mounds, we placed pitfall traps 1 m from the mound in four cardinal directions for seven consecutive days, and we collected ant specimens, which were stored in ethanol for further identification. For the Repair rate, we used a chisel to put a hole in the mounds. Most of the time it perfectly put a hole, but sometimes the mound got broken more. The photograph of every hole was taken to further quantify the area of breaches. It was done for 30 mounds, which consist of 15 small and 15 Large mounds. This work was replicated three times for each mound.

4.4.3 Analytical Methods

All Statistical analysis was performed in R, version 4.2.1, and visualized using ggplot2 (R Core Team, 2022). Image J software was used to quantify the hole measurements. Fayle (2014) key used for the identification of ants.

Predatory Index

This represents the contribution of each genus to the overall predatory character of the community.

S.no	**Genus**	**Behavior**	**Score**
1.	*Odontoponera*	SP	2
2.	*Oecophylla*	OP	1
3.	*Technomyrmex*	NP	0
4.	*Camponotus*	NP	0
5.	*Lophomyrmex*	SP	2
6.	*Brachyponera*	SP	2
7.	*Strumigenys*	SP	2
8.	*Pseudoneoponera*	SP	2
9.	*Crematogaster*	OP	1
10.	*Monomorium*	NP	0
11.	*Tapinoma*	NP	0
12.	*Leptogenys*	SP	2
13.	*Tetramorium*	SP	2
14.	*Polyrachis*	OP	1
15.	*Anochetus*	SP	2
16.	*Dorylus*	SP	2
17.	*Harpegnathos*	SP	2
18.	*Tetraponera*	NP	0
19.	*Pheidole*	NP	0

Predatory index is used to capture the overall predatory potential of an ant community around the termite mound. Each Ant Genus has Various traits, and they may be predatory or may not. We allocated scores to various genera according to their predatory behavior for each mound, the ant genus abundance multiplied by its allotted predator score.

SP- Specialized predator

OP- Opportunistic predator

NP- non-predator

$$\text{Weighted score} = \text{abundance} \times \text{score}$$

$$\text{Predator Index}= \frac{Total\ Weighted\ score}{Total\ Abundance}$$

Plate 1. *Odontotermes* mound (top), Termites Repair breaches in mounds

5. RESULTS

5.1 Objective 1

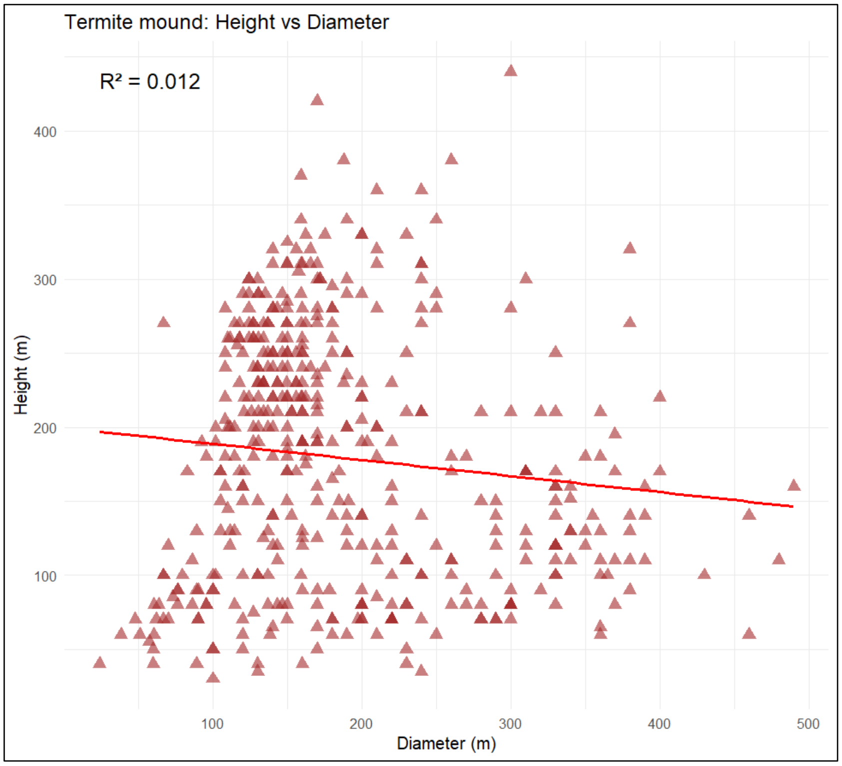


Figure 4: Relationship between Height and Diameter of the termite mound across all plots

Termite mounds are plotted as a red triangle. The Red trend line indicates a weak negative correlation between height and Diameter. This shows that the taller termite mounds tend to have slightly smaller diameters. The R-squared value is 0.012 suggests that the linear relationship between these two variables is quite weak. Diameter alone does not predict the height of a mound.

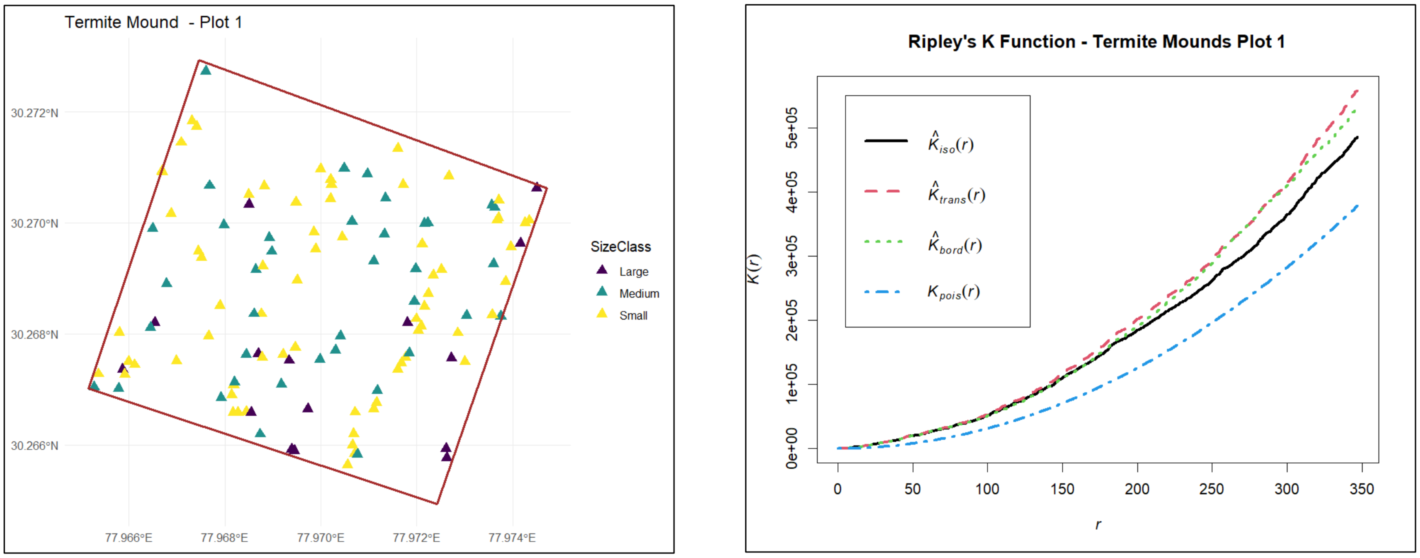


Figure 5: Various Size classes and Ripley's k function across plot 1

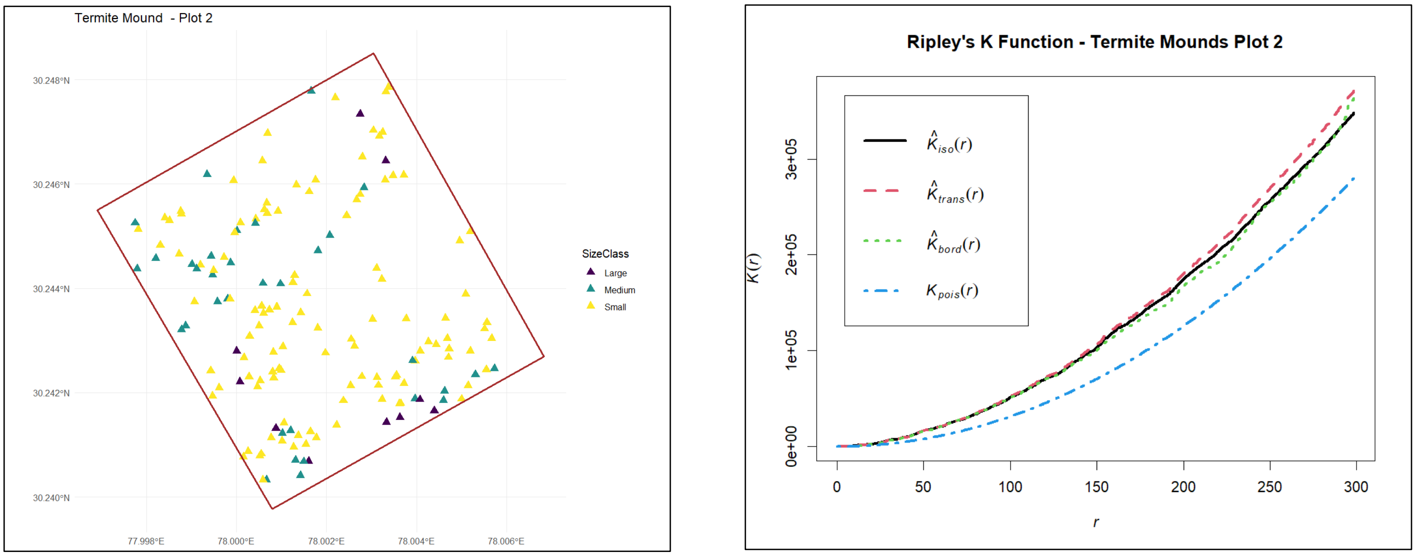


Figure 6: Various Size classes and Ripley's k function across plot 2

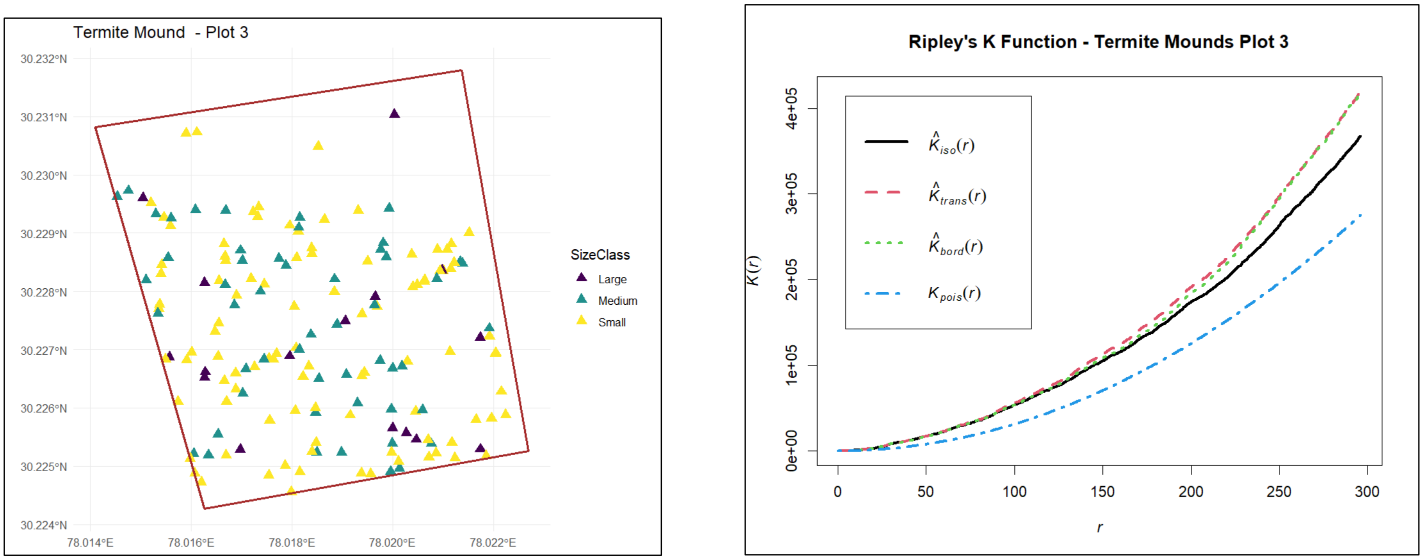


Figure 7: Various Size classes and Ripley's k function across plot 3

The X-axis (Distance r), the horizontal axis, indicates a range of distance being analyzed from 0 to 350 (meters here). It indicates at what scale we are examining the clustering or dispersion.

Y-axis (K Function K(r)), the vertical axis, which represents a cumulative measure of adjusted overall density. Basically, here, it is running a total of neighbors that each event gathers at the search radius increases.

Estimators

$K_{iso}(r)$, an isotropic or rotation-invariant Correction, assumes that the pattern looks the same in every direction.

$K_{trans}(r)$, translational correction that compensates for uneven edges in the study area.

$K_{bord}(r)$, a border correction that minimizes bias by considering points sufficiently far from the boundary.

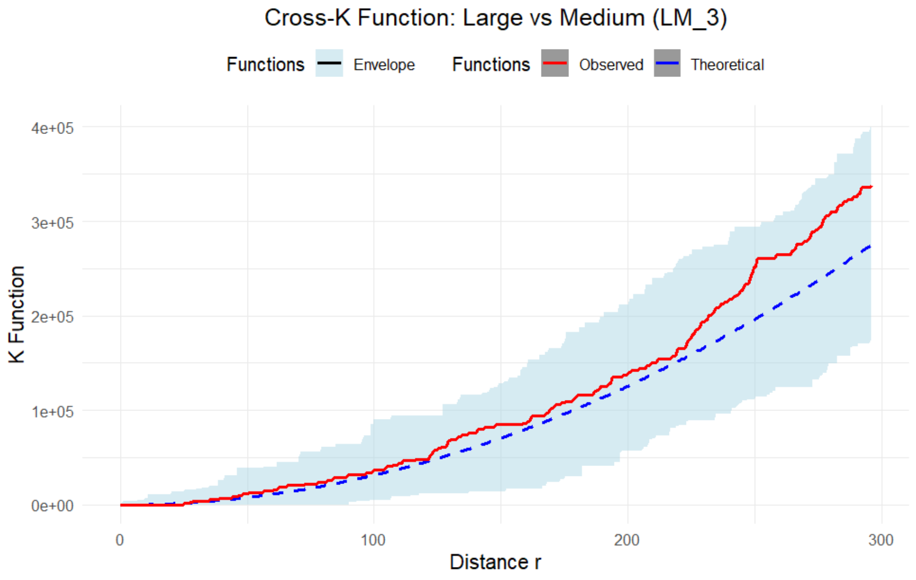
$K_{pois}(r)$, Expected k function under complete spatial randomness (Poisson distribution).

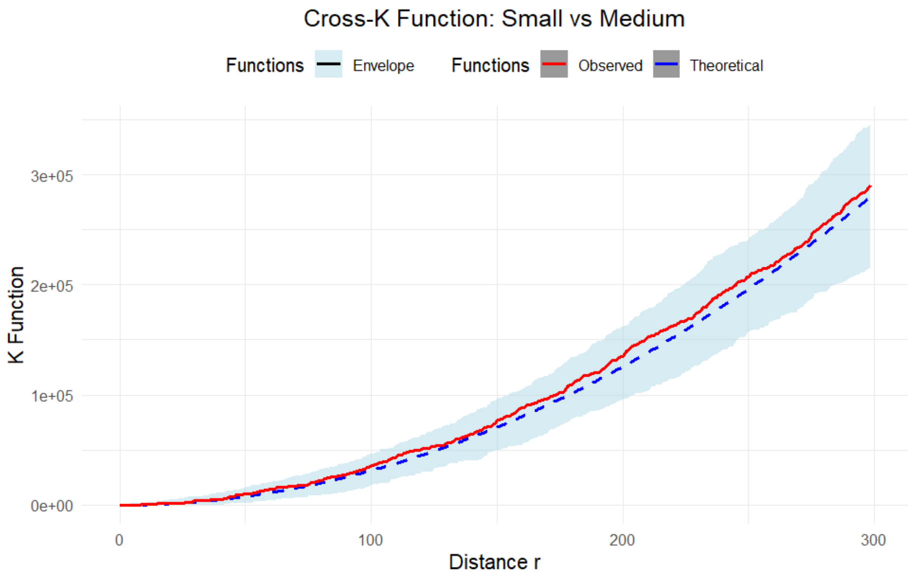
Clustering

If the observed k function $k_{(r)}$ is consistently higher than $k_{pois\,(r)}$ over certain distance ranges, there is more clustering than expected under randomness.

Dispersion

If the observed k function falls below $k_{pois\,(r)}$ over some distance, it signals a more regular or dispersed pattern than a random distribution.


Cross-K Function: Large vs Medium (LM_3)
Functions
Envelope
Functions
Observed
Theoretical
K Function
4e+05
3e+05
2e+05
1e+05
0e+00
0
100
200
300
Distance r


Cross-K Function: Small vs Medium
Functions
Envelope
Functions
Observed
Theoretical
K Function
3e+05
2e+05
1e+05
0e+00
0
100
200
300
Distance r

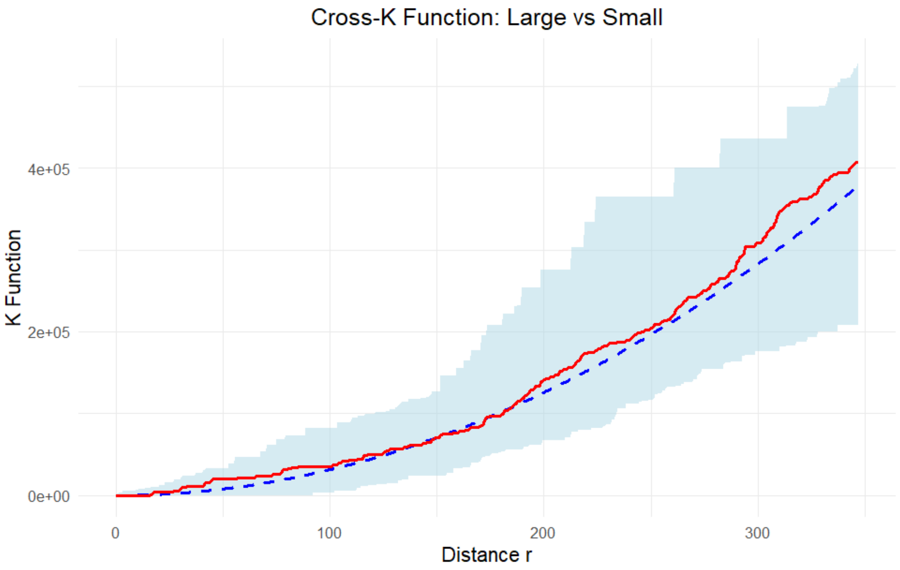


Figure 8: 9999 Sim Envelopes by Size Class

From the observed values of K-Function with the simulated confidence envelopes, we can determine that the mound location exhibited significant clustering or dispersion at varying spatial scales. Deviations above the envelope indicate that the clustering is beyond randomness, while values below suggest that spatial dispersion

The Average global deviation is as follows for the Termite mound across all plots

Interaction	D_{obs}	p
Between Large and Small	55 079.96	1.00
Between Large and Medium	59 202.01	1.00
Between Small and Medium	33 445.92	1.00

Table 1: Global deviation across all plots for termite mounds

A p-value of 1.00 indicates that nearly all the simulated deviations were greater than or equal to the observed deviation. This suggests that the observed spatial deviation is fully consistent with what would be expected under null model (spatial randomness or independence between types). The Size classes of Termite Mound didn’t show any kind of Territorial accusation around them.

5.2 Objective 2

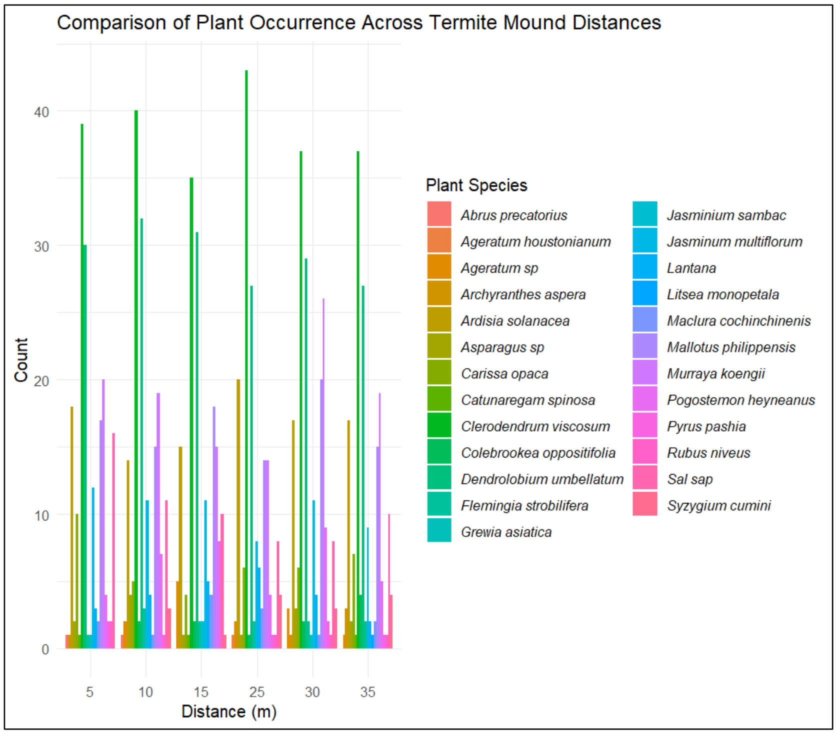


Figure 9: Comparison of plant Occurrence Across the termite mound Distance

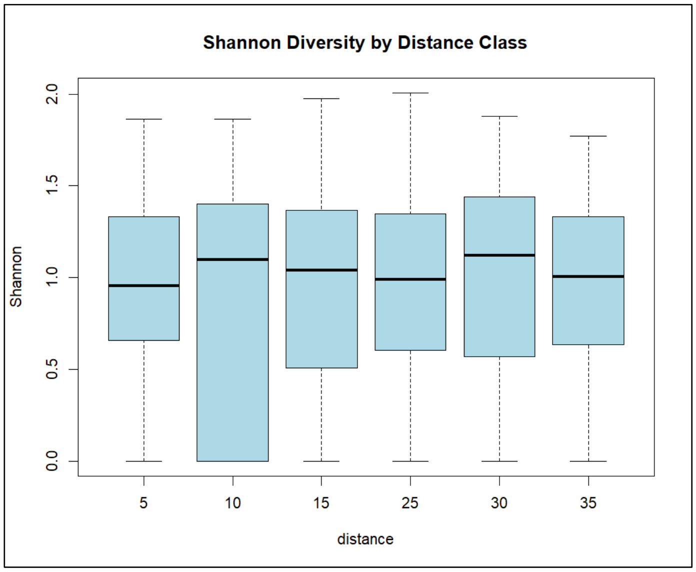


Figure 10: Relationship between Shannon Diversity and Distance from the termite mound

From the Boxplot, it is evident that the Shannon index is relatively consistent among the different distance classes. There is no strong trend between the distance from termite mounds and the Shannon diversity index.

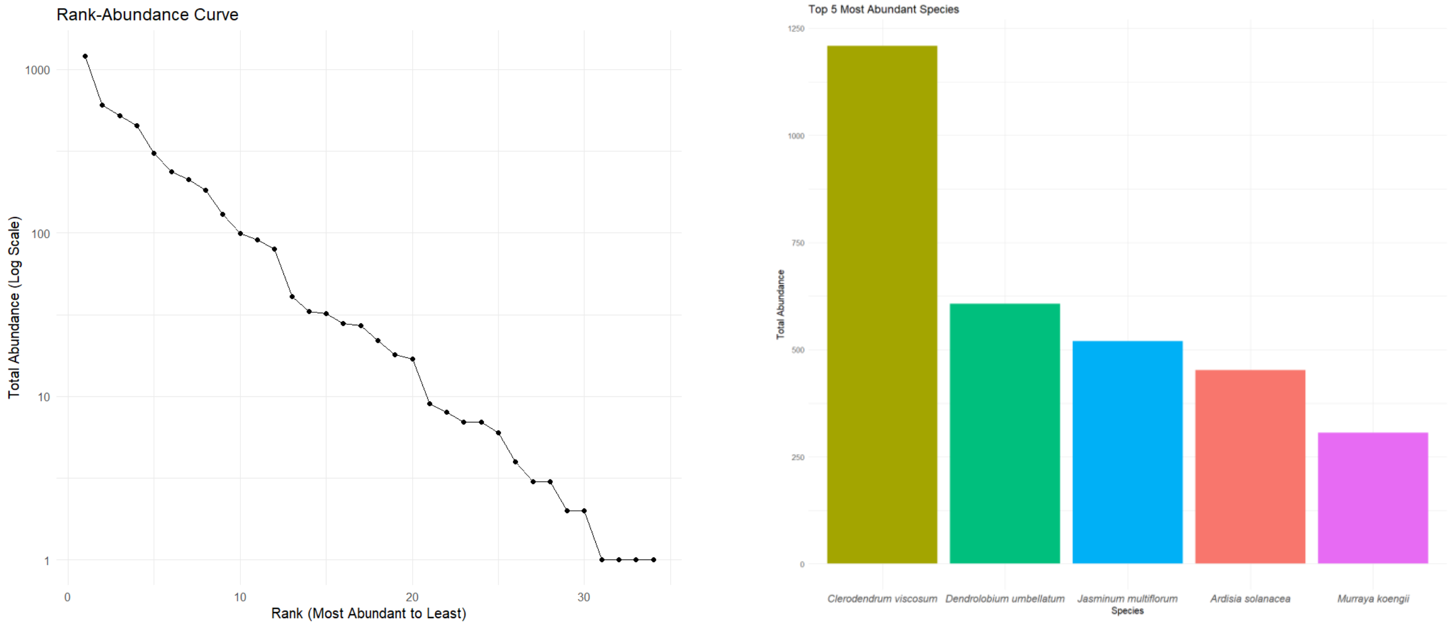


Figure 11: Rank-Abundance and Most Abundant Plant Species in Study Area

Indicator Species Analysis

An Indicator species analysis done which was performed using the 'multipatt' function in R with the IndVal association Method, with a significance level set at α = 0.05. This analysis aimed to determine whether any of the 34 plant species in our dataset were associated significantly with particular distance groups from termite mounds.

Total number of Species included	34
Selected no of species associated with any group	0
No of species associated with 5m,10m,15m,25m,30m,35m	0 for all combinations

Table 2: Indicator species analysis

No species were identified as significant indicators of any specific distance from termite mounds ; these suggests that the spatial distribution of the plant species does not show any kind of clear pattern of association or avoidance.

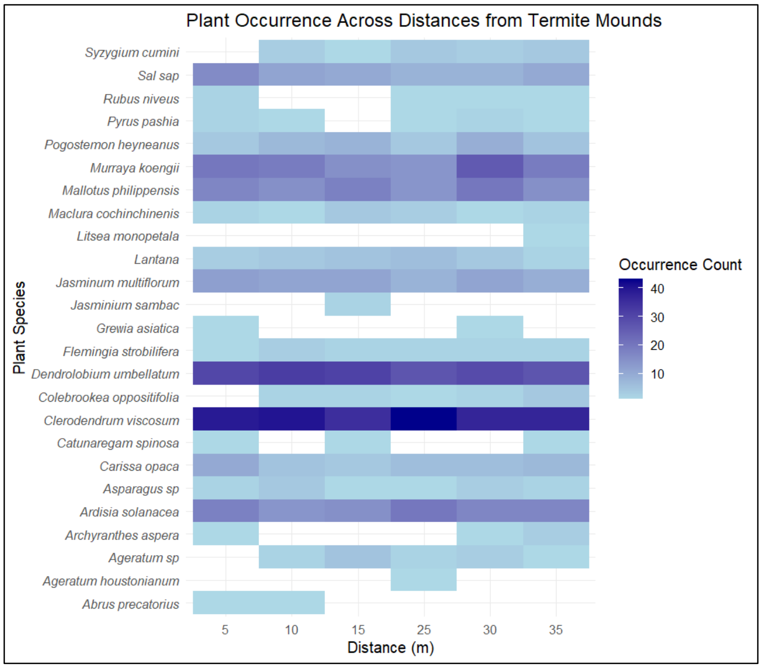


Figure 12: Heatmap of Plant Occurrence Across Distance from Termite Mounds

<table>
<tr><td colspan="5">Model_lm <- lm(Shannon~ distance , data = data_veg_clean)</td></tr>
<tr><td></td><td>Estimate</td><td>Std. Error</td><td>t value</td><td>Pr (>|t|)</td></tr>
<tr><td>(Intercept)</td><td>0.939467</td><td>0.077169</td><td>12.058</td><td><2e-16 ***</td></tr>
<tr><td>distance10</td><td>-0.026748</td><td>0.109628</td><td>-0.244</td><td>0.807</td></tr>
<tr><td>distance15</td><td>-0.041507</td><td>0.110667</td><td>-0.375</td><td>0.708</td></tr>
<tr><td>distance25</td><td>-0.009916</td><td>0.111776</td><td>-0.089</td><td>0.929</td></tr>
<tr><td>distance30</td><td>0.03752</td><td>0.111776</td><td>0.336</td><td>0.727</td></tr>
<tr><td>distance35</td><td>-0.025023</td><td>0.111776</td><td>-0.224</td><td>0.823</td></tr>
<tr><td colspan="5">Multiple R-squared: 0.001924 ,Adjusted R-squared: -0.01412 ,P-value: 0.9879</td></tr>
</table>

Table 3: Output of LM predicting the relationship between Shannon and Distance

glm(formula = richness ~ distance, family= poisson, data = data_veg_clean)				
	Estimate	Std.Error	Z value	Pr(>|z|)
(Intercept)	1.555814	0.06131	25.413	<2e-16***
distance10	0.01802	0.08671	0.208	0.835
distance15	0.01674	0.08755	0.191	0.848
distance25	0.01942	0.08836	0.220	0.826
distance30	0.08976	0.8679	1.034	0.301
distance35	0.03149	0.08809	0.357	0.721
AIC : 1409.5 , McFadden's R square =0.0009				

Table 4: Output of Glm taking distance as predictor variable of Richness.

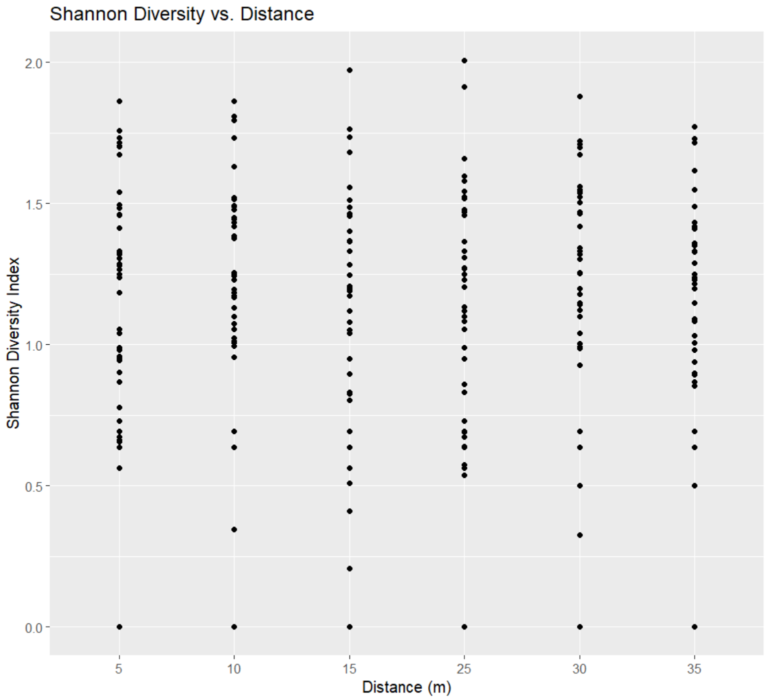


Figure 13: Relationship between Shannon diversity and distance from the mound

This table suggests that distance explains very little variance in species richness. The result of both the models suggest that richness and Shannon index not changing significantly across the distance gradient. From this we can assume The Termite mounds of *Odontotermes* not exhibiting similar way as its African relatives.

Soil Parameters

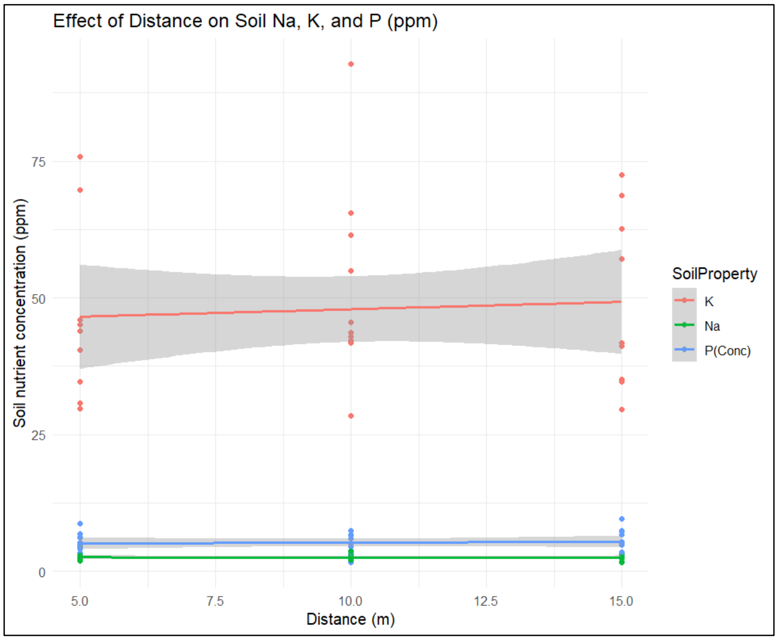


Figure 14: Relationship between Soil K, Na, and P and distance from Termite mounds

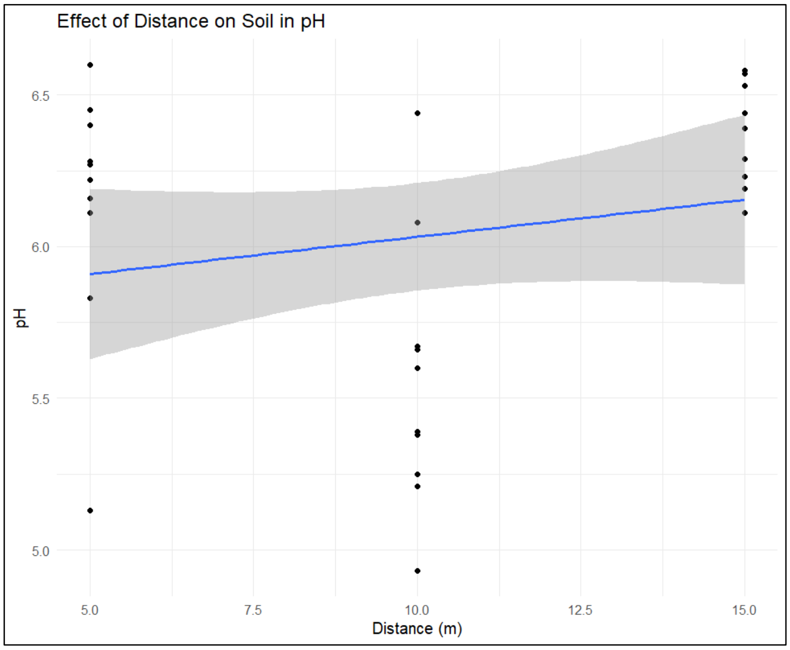


Figure 15: Relationship between soil pH and Distance

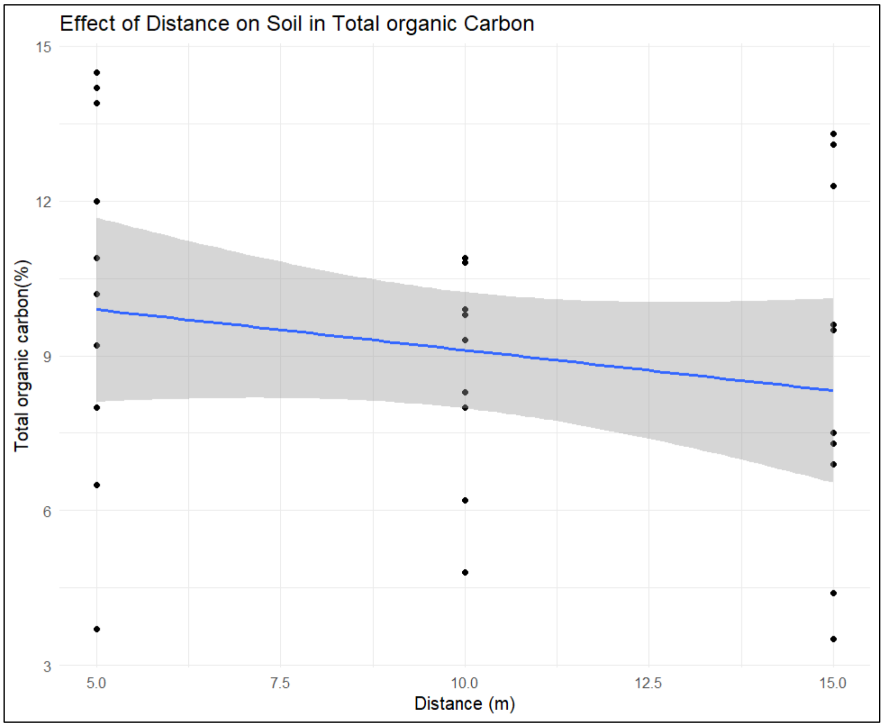


Figure 16: Relationship between Soil and Total Organic Carbon

glm (formula =Na ~ distance, family = gaussian, data = soil_da)				
	Estimate	Std. Error	t value	Pr (>| t |)
(Intercept)	2.58267	0.28322	9.119	7.08e- 10
distance	-0.00370	0.02622	-0.141	0.889
AIC: 57.033				

glm (formula = pH ~ distance , family = gaussian, data = soil_da)				
	Estimate	Std. Error	t value	Pr (>| t |)
(Intercept)	5.78700	0.023954	24.159	<2e-16***
distance	0.02450	0.02218	1.105	0.279
AIC: 46.982				

glm(formula = k~ distance, family = gaussian, data = soil_da)				
	Estimate	Std. Error	t value	Pr (>| t |)
(Intercept)	45.2147	8.1248	5.565	5.94e-06***
distance	0.2708	0.7522	0.360	0.722
AIC :258.42				

glm(formula = OC ~ distance, family = gaussian, data = soil_da)				
	Estimate	Std. Error	t value	Pr (>| t |)
(Intercept)	10.6800	1.5243	7.007	1.28e-07***
Distance	-0.1570	0.1411	-1.113	0.275
AIC: 158.02				

glm(formula = P_Conc ~ distance, family = gaussian, data = soil_da)				
	Estimate	Std. Error	t value	Pr (>| t |)
(Intercept)	4.94551	0.91286	5.418	8.87e-06 ***
Distance	0.03030	0.08451	0.359	0.723
AIC : 127.25				

Table 5: Output of GLM for various soil parameters

From all this model, there are no significant changes in the distance gradients for the soil parameters analyzed.

5.3 Objective-3

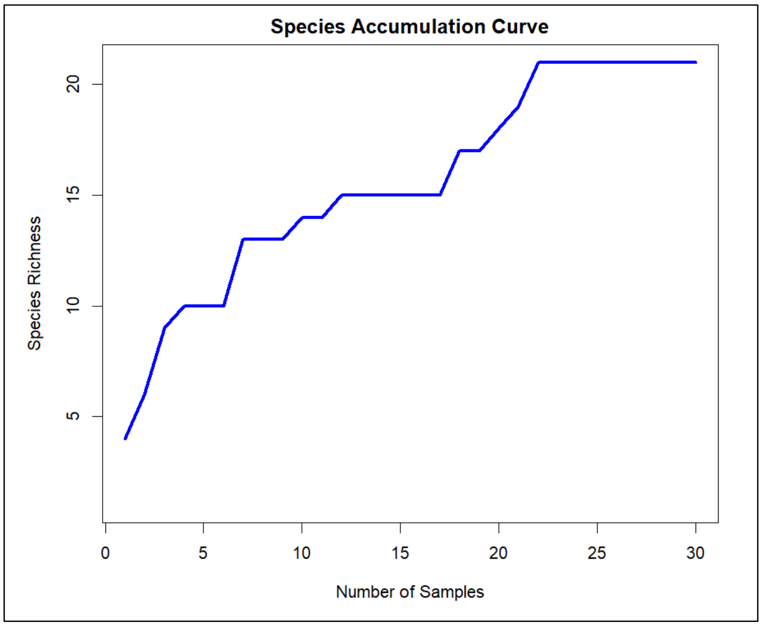


Figure 17: Species Accumulation Curve for Ant Genera around Termite Mounds

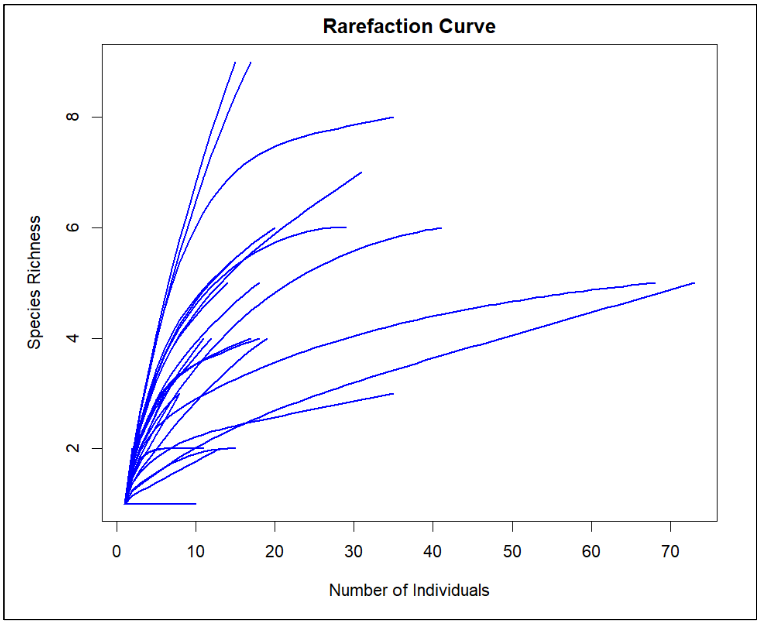


Figure 18: Rarefaction Curve of Ant Genera from 30 Termite Mounds

This graph shows the cumulative number of ant genera from the 30 Termite mounds in the Sal-patch. Initially, many new ant genera were encountered as additional mounds were sampled, which resulted in a steep rise in the curve. The Plateau suggests that our sampling effort was sufficient, as most of the ant genera in the study area were detected. This Rarefaction curve shows the relationship between the number of individuals sampled (x-axis) and the cumulative number of ant genera observed (y-axis) across 30 termite mounds. The curve rises steeply and then begins to level off, which indicates the community is well characterized, notably two lines continue to grow slightly, where further sampling is needed.

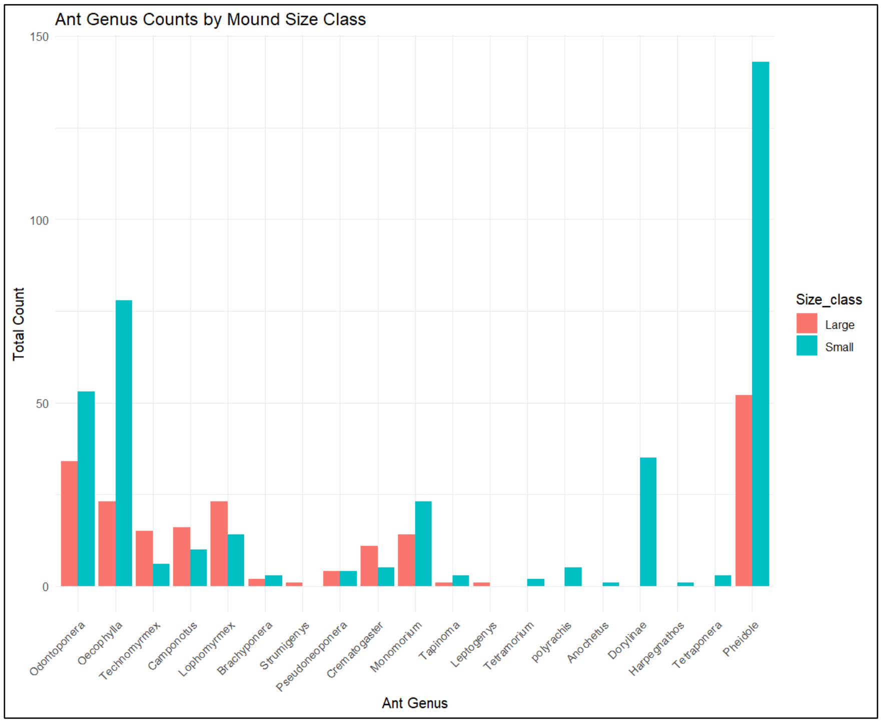


Figure 19: Ant Genus abundance by termite mound size class (Large vs Small)

This Bar Graph, the X-axis represents the different ant genera, and the Y-axis represents the abundance of genera across the two mound size classes. Some genera like *Oecophylla*, *Pheidole,* and *Odontoponera* are more abundant in small mounds.

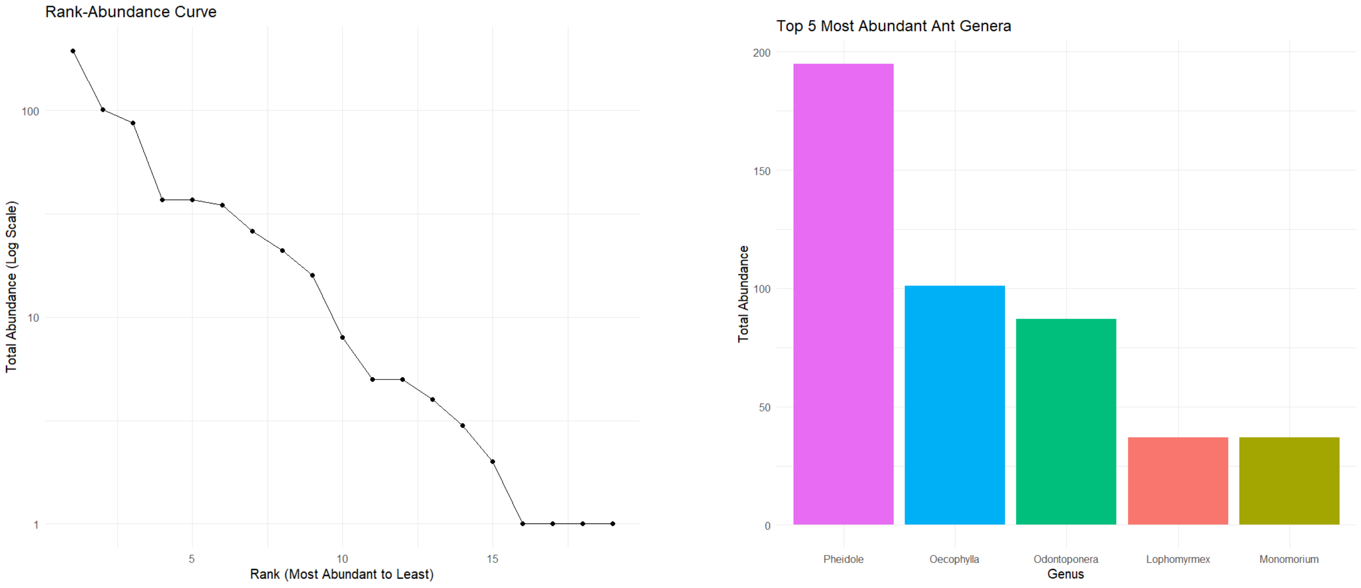


Figure 20: Rank-Abundance and Most Abundant Ant Genus

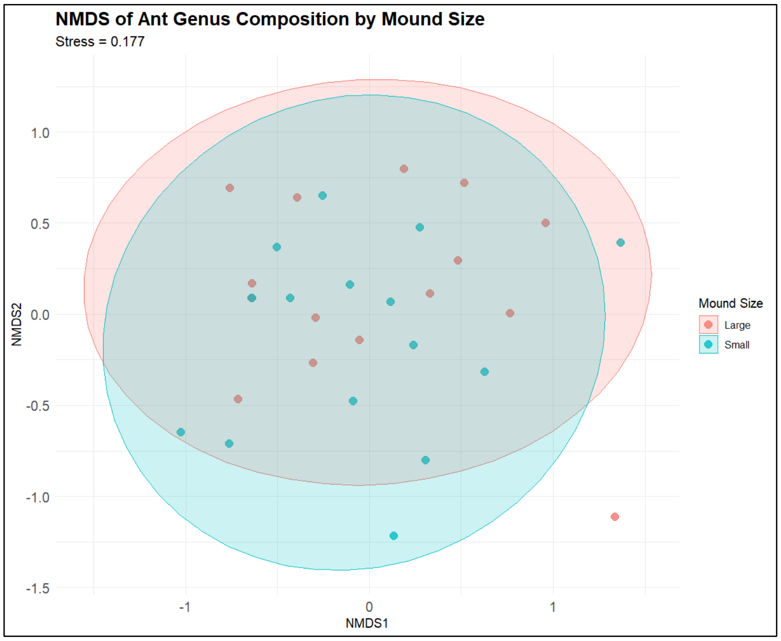


Figure 21: NMDS plot of Ant Genus Composition across Size Classes

The NMDS plot helps to visualize different ant genera distributed based on termite mound size. This takes us back to the question "Do ant communities differ across termite mound size class?". Groups of points clustering together indicate that both size classes share a similar Ant genus. The stress value in NMDS represents how well the plot represents the actual differences in ant genera composition. Here, the Lower stress value 0.177 falls in the moderate range (0.1-0.2), that the plot captures the main patterns in the data with minor inaccuracies.

PERMANOVA results for Ant Community composition by Termite Mound Size Class

<table>
<tr><td colspan="6">adonis2 (formula = community_matrix ~ Size_class , data = obj_ant, method = “bray”)</td></tr>
<tr><td>Source</td><td>Df</td><td>Sum of Sqs</td><td>R^2</td><td>F</td><td>Pr (>F)</td></tr>
<tr><td>Model</td><td>1</td><td>0.4030</td><td>0.04691</td><td>1.378</td><td>0.184</td></tr>
<tr><td>Residual</td><td>28</td><td>8.1886</td><td>0.95309</td><td>-</td><td>-</td></tr>
<tr><td>Total</td><td>29</td><td>8.5916</td><td>1.00000</td><td>-</td><td>-</td></tr>
</table>

Table 6: PERMANOVA result

The variation in Ant communities between the mound classes is not statistically significant at the 0.05 level (p = 0.184). Although mound size might have some influence, it only explains about 4.7% of the variation in ant community composition. This implies that factor other than this might have more influence in structuring these communities.

Figure 22: Shannon Diversity by Mound Size Class

	Df	Sum Sq	Mean Sq	F value	Pr (>F)	R^2
Size_class	1	0.021	0.0214	0.064	0.803	0.0023
Residuals	28	9.418	0.3364			

Table 7 : Shannon Diversity across Mound Class using LM

Mound Size explains only 0.021 units of variation, while the Residual variation is 9.418, suggesting that the mound size class has little impact on Shannon diversity. F value indicates, there is very little difference in Shannon diversity between mound size classes. P value is 0.803 (P> 0.05) is not statistically significant. There is no strong evidence that mound size influences Shannon diversity.

Model_nb2 < glm.nb(repair_time ~predatory_index+ hole_area+ Size_class, data = ant_data_1)					
	Estimate	Std.Error	Z value	Pr(>|z|)	AIC
(Intercept)	3.93713	0.13321	29.555	<2e-16***	780.63
Preadtory_index	-0.10050	0.08456	-1.189	0.23463	
hole_area	0.01518	0.01691	0.898	0.36933	
Size_classsmall	-0.28264	0.09294	-3.041	0.00236**	

Table 8 : Glm model for repair rate relationship between predatory index, hole area and size class

We built a Negative Binomial regression model to predict Repair time using three predictors like predatory index , A numerical measure of predator ant pressure. Hole area , area of the opening breached during sampling and Size class , a categorical variable indicating the size class. Since

Repair time is positively skewed and showed Overdispersion. We used a Negative Binomial model with a log link.

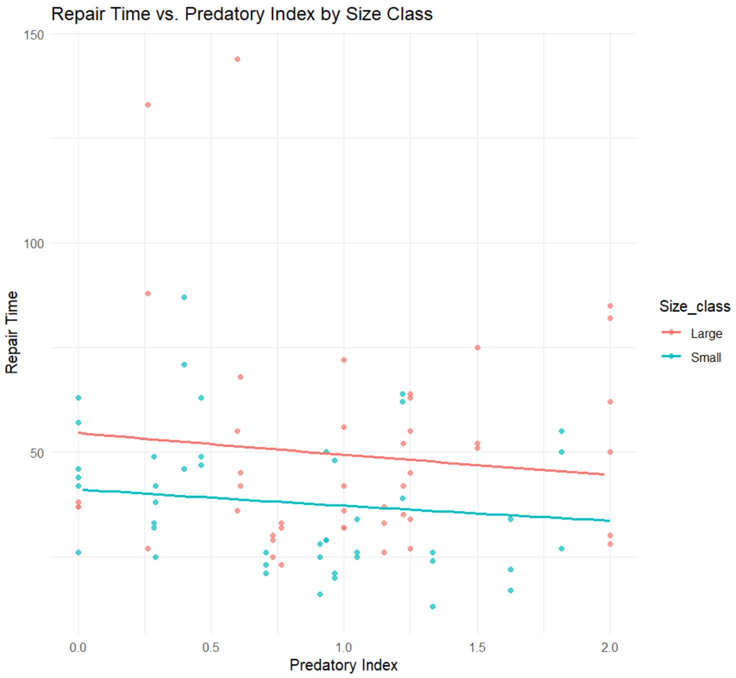


Figure 23: Repair Time vs Predatory Index by Size Class

The Predatory index, p-value (~0.235), means this effect is not statistically significant at the usual 0.05 level. From this result, we don't have enough evidence to prove that the changes in predators affect repair time.

Small size class, explains that the coefficient is statistically significant ($p<0.01$). Compared with the Larger size class, mounds of the smaller size class have a lower log(Repair time) by about 0.28 units, which means mounds that are smaller in size appear to repair faster than the larger ones, holding other factors constant.

6. DISCUSSIONS

Spatial Pattern

Larger termite mounds occupy more space around them because of their large colony size, but the results do not support our hypothesis. For the interaction between large and small mounds, the average global deviation, was D_{obs} is 55079 with a p-value of 1.00. Similarly, for large vs medium and small vs medium interactions D_{obs} values are approximately 59,202 and 33,445 respectively, with a p-value of 1.00. The p-value indicates that the observed pattern of termite mounds in the landscape is spatial randomness, and there is no spatial interaction between various size classes of the mounds.

From our results, we can tell that there is no clear evidence that large mounds of *Odontotermes* maintain more territory compared to the other size classes. *Macrotermes* mounds show regular spatial distributions and size-related spatial repulsions, and also large mounds spaced out regularly due to competition (Wildermuth et al., 2022). But the *Odontotermes* mound in the Sal-Dominant Regions was not actively spaced out by the size classes.

Unlike *Macrotermes* mounds, which tend to show regular spatial distributions and size-related spatial repulsion*,* *Odontotermes* mounds exhibit different spatial arrangements, like clustering and random patterns, irrespective of their size differences. These show that the Termite mounds (*Odontoterme*s) may not show Territoriality like the *Macrotermes* in Africa. By studying the *Odontotermes* in other parts of India, we can confirm the lack of Territoriality behaviou*r* in

Odontotermes. There is also a reason that the Habitat is more productive because they don’t need to form a territory in order to thrive.

Termite Mounds and vegetation

Our purpose of study was to understand how the termite mounds provide heterogenous around them by assessing the plant diversity. We examined how species richness varied along a distance gradient from termite mounds (5,10,15,25,30,35 m). The results indicated there are no significant changes between these gradients. In the linear model, the Shannon diversity index as responsible variable. The LM explained overall only 0.19% of the variability in the Shannon index. The P-value = 0.9879 confirmed that distance has no significant effect on the Shannon index. The overall diversity of the plant community remains essentially constant, indicating that *Odontotermes* exhibit a different relationship with the plant community in that particular ecological setup.

Soil Parameters and Termites

We also examined the soil to find any changes in the soil parameters at 5m,10m, and 15m. By analyzing the samples, we found that there is no significant trend seen in those distances. It all comes back to the biology of *odontotermes* and its interaction with the Environment.

Repair Rate dynamics and the Ant assemblages surrounding Termite mounds

Our Hypothesis suggested that Termite mounds exhibit a faster repair rate under High Predator Pressure (Predator characteristic ants) was not supported by the GLM results. Interestingly, larger mounds generally host larger colonies (Korb and Linsenmair 2001), but our observation indicates that the smaller mounds tend to repair breaches faster than the larger mounds.

Our Reasonable explanation behind this is that the smaller mounds, which are often associated with younger or less established colonies, will invest more heavily in rapid repairing as a survival strategy. During the initial period of the colony, the mound is vulnerable to external environmental factors because of its structural disadvantage. Faster Repair rate in smaller mounds might be considered a response for better survival. In contrast, larger mounds host more established colonies that can tolerate minor damages without immediate repair.

Task Prioritization

In larger colonies, which are generally associated with larger mounds, the available workforce is distributed among several tasks like brood care, fungus garden maintenance, Foraging, and Defense. This division may lead to a relatively slower repair response because the urgency is distributed among multiple functional needs. Smaller colonies may prioritize repair over other activities to survive. Even a short-term structural damage can totally bring down their survival.

7. CONCLUSION

Termites are considered as pests because of various invasive species spread over human settlements over the last three decades. our study demonstrates that *Odontotermes* mounds do not exhibit clear territoriality or spatial repulsion between various size classes. The Spatial pattern of termite mounds we saw in the Sal-dominant Forest was random, which may be mainly due to chance events in time or other factors like *Odontotermes* Behavior related or may also be the Habitat of abundant resources.

The observed Plant community diversity also remains mostly the same across various distances, which clearly indicates that there is no Influence of termite mounds on the overall plant community, and it also does not attract or repel any particular species of that region. For the Soil parameters, we also sampled not see any particular effect according to our sample size.

Higher predator pressure around termite mounds would lead to faster repair rates around mounds, also can’t prove this by our study. But a Faster repair rate of smaller mounds is a new ecological finding that defines that smaller mounds are more vulnerable to the external biotic and abiotic factors, so in order to cope with the environment, they developed this kind of survival mechanism.

8. LIMITATIONS

There are several limitations to this study; by understanding these limitations properly, we can contribute to future research.

Sample Size

Soil samples were taken from 5 m to 15 m from the termite mounds . In that, also soil taken from only 10 termite mounds This sample size may not be enough in order to see the variations in the soil .The limited number of sample size is one of the limitations and by increasing the soil samples to further can help the study.

Species Level Identification

Ant community data were identified to the genus level only. Even in my study area *Pheidole* genus most of them are non-predators but species like *megacephala* considered as predator. So, it is essential in order to understand the Species level variation also. Species level identification can give more input in this kind of study. Our Results clearly defines that mound characteristics such as size class may have more influence on repair rate.

Measurement of Predator Pressure

The current measure of predator pressure, which is based on the overall predatory index based on ant diversity, might not tell the whole story of the complex interactions between ants and termite defense behaviors. Some ant genus might prefer termites as their main prey that the presence of that particular Ant species may put more pressure , while it is also necessary to know the ant species present in the study area before this kind of study.

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10. APPENDIX

Plate 1. Top left – right: Alates (Fertile Termites) protected by soldiers before first flight, Amts attacking Alates in the Wildlife Institute of India Campus. Moss prefers growing on Mound base (down left) and (Down Right)Forest guards placed naturally fallen antlers inside a tree trunk, they absorbed by the surrounding mound, observed in Rajaji National Park.

Weight Calculated and Predatory Index for Each Mound

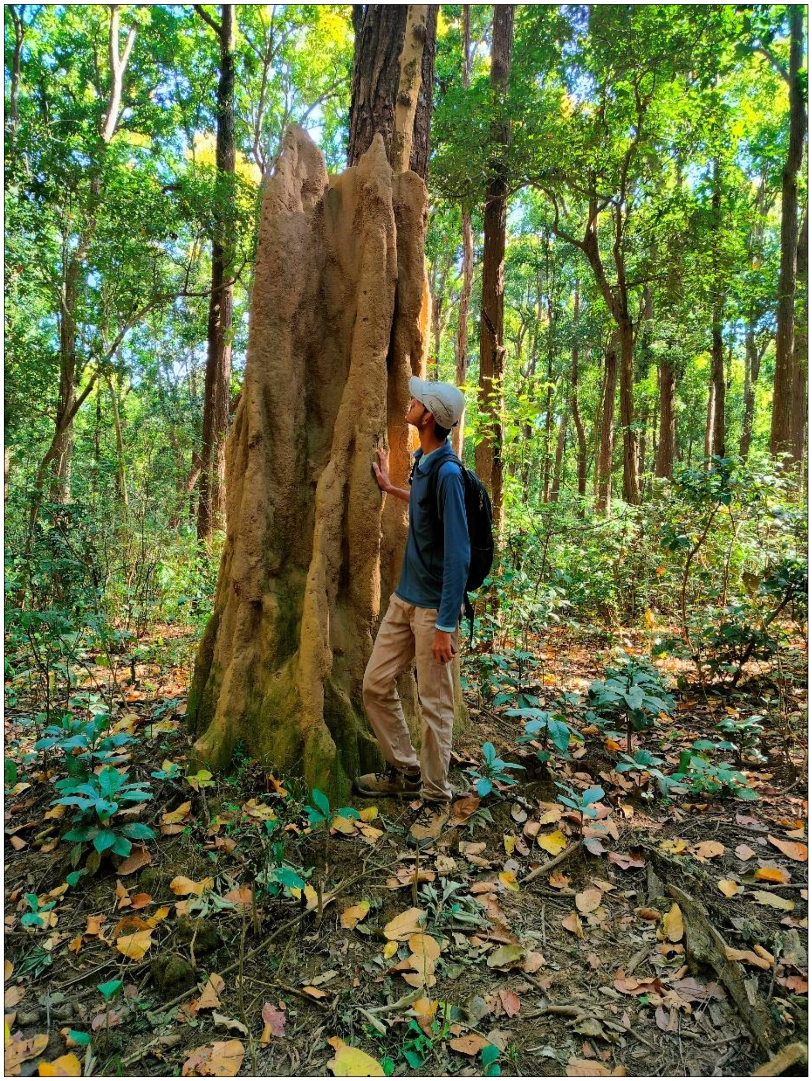
Mound	total_abundance	total_weighted	predatory_index
1	12	15	1.25
100	41	19	0.463414634
101	1	2	2
12	2	2	1
125	19	5	0.263157895
127	8	10	1.25
16	15	11	0.733333333
32	8	13	1.625
33	20	23	1.15
4	4	6	1.5
45	14	4	0.285714286
5	18	11	0.611111111
55	31	9	0.290322581
56	11	10	0.909090909
68	35	14	0.4
72	35	21	0.6
74	73	68	0.931506849
82	18	22	1.222222222
86	13	0	0
91	17	13	0.764705882
93	8	16	2
99	15	0	0
LL	7	7	1
s1	29	28	0.965517241
s2	11	20	1.818181818
s3	68	83	1.220588235
s4b	17	12	0.705882353
s4d	20	21	1.05
ss1	6	8	1.333333333
ss2	10	0	0

Repair Rate data on Hole area and Time taken by each mound

Mound	Replicates	Size_class	start_time	end_time	repair_time(Hr.Min)	hole_area(Cm$^{2)}$
72	1	Large	9.38	11.32	1.94	2.426
72	2	Large	4.26	5.02	0.76	2.384
72	3	Large	4.16	5.11	0.95	2.886
82	1	Large	9.42	10.34	0.92	10.484
82	2	Large	4.31	5.06	0.75	3.797
82	3	Large	3.31	4.13	0.82	2.65
33	1	Large	10.51	11.17	0.66	2.55
33	2	Large	3.36	4.09	0.73	7.203
33	3	Large	5.55	6.32	0.77	6.642
1	1	Large	9.13	10	0.87	6.241
1	2	Large	9.24	10.28	1.04	6.598
1	3	Large	12.24	1.27	13.03	2.098
4	1	Large	9.17	10.32	1.15	14.964
4	2	Large	9.27	10.19	0.92	4.995
4	3	Large	12.26	1.17	12.91	2.707
5	1	Large	9.19	10.04	0.85	2.741
5	2	Large	9.29	10.37	1.08	5.474
5	3	Large	12.27	1.09	12.82	9.815
91	1	Large	9.36	10.08	0.72	2.354
91	2	Large	9.41	10.14	0.73	2.653
91	3	Large	11.39	12.02	0.63	2.564
93	1	Large	9.39	10.41	1.02	2.207
93	2	Large	9.43	11.08	1.65	2.994
93	3	Large	11.42	1.04	13.62	2.928
12	1	Large	9.41	10.37	0.96	8.081
12	2	Large	9.45	10.12	0.67	2.815
12	3	Large	11.43	12.15	0.72	2.801
16	1	Large	9.43	10.13	0.7	2.494
16	2	Large	9.46	10.11	0.65	3.003
16	3	Large	11.45	12.14	0.69	2.712
125	1	Large	10.49	12.17	1.68	5.653
125	2	Large	11.14	1.29	14.15	5.771
125	3	Large	9.14	9.41	0.27	2.194
127	1	Large	10.52	11.47	0.95	2.588
127	2	Large	11.17	11.44	0.27	3.493
127	3	Large	9.17	9.51	0.34	1.291
LL	1	Large	12.22	12.54	0.32	3.607

LL	2	Large	11.53	12.35	0.82	8.38
LL	3	Large	10.12	10.48	0.36	2.739
101	1	Large	12.27	12.57	0.3	2.694
101	2	Large	12.36	1.26	12.9	1.446
101	3	Large	10.18	10.46	0.28	2.373
86	1	Large	3.26	4.03	0.77	2.266
86	2	Large	4.02	4.39	0.37	3.975
86	3	Large	3.24	4.02	0.78	2.97
s3	1	Small	9.22	10.24	1.02	2.771
s3	2	Small	5.12	5.51	0.39	4.263
s3	3	Small	3.23	4.27	1.04	3.233
45	1	Small	9.24	9.56	0.32	3.054
45	2	Small	3.29	4.18	0.89	10.066
45	3	Small	5.13	5.46	0.33	4.34
55	1	Small	9.3	10.12	0.82	2.638
55	2	Small	3.25	4.03	0.78	12.438
55	3	Small	5.09	5.34	0.25	3.419
56	1	Small	9.31	9.59	0.28	14.558
56	2	Small	3.26	3.42	0.16	2.621
56	3	Small	5.09	5.34	0.25	2.499
68	1	Small	4.2	5.32	1.12	3.664
68	2	Small	4.23	5.09	0.86	3.951
68	3	Small	9.35	11.02	1.67	3.188
74	1	Small	9.4	10.3	0.9	1.975
74	2	Small	4.28	4.57	0.29	6.85
74	3	Small	4.15	4.44	0.29	1.745
32	1	Small	10.48	11.22	0.74	2.582
32	2	Small	3.32	3.49	0.17	2.667
32	3	Small	5.39	6.01	0.62	2.665
s2	1	Small	9.23	10.18	0.95	2.851
s2	2	Small	9.31	10.21	0.9	2.165
s2	3	Small	12.29	12.56	0.27	3.57
s1	1	Small	10.54	11.14	0.6	2.092
s1	2	Small	11.21	11.42	0.21	3.693
s1	3	Small	9.21	10.09	0.88	3.813
ss1	1	Small	10.55	11.21	0.66	3.257
ss1	2	Small	11.18	11.31	0.13	5.539
ss1	3	Small	9.2	9.44	0.24	3.288
ss2	1	Small	10.57	11.23	0.66	2.622
ss2	2	Small	11.19	12	0.81	3.265
ss2	3	Small	9.19	10.05	0.86	2.732
s4d	1	Small	12.2	12.45	0.25	2.982
s4d	2	Small	11.49	12.15	0.66	2.605

s4d	3	Small	9.23	9.57	0.34	2.55
99	1	Small	12.24	1.21	12.97	8.435
99	2	Small	11.57	12.41	0.84	4.118
99	3	Small	10.14	11.17	1.03	5.957
100	1	Small	12.25	1.13	12.88	2.629
100	2	Small	12.35	1.24	12.89	2.136
100	3	Small	10.16	11.19	1.03	3.204
s4b	1	Small	3.28	3.5	0.22	7.083
s4b	2	Small	4.02	2.25	22.23	5.045
s4b	3	Small	3.32	3.58	0.26	2.567



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