One Man's Trash is another Man's Treasure: A Study on the Effects of Roads on the Brazilian Nut Ecosystem in the Madre de Dios Region, Using Homemade Arthropod Traps

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Abstract

Infrastructure development is essential for community welfare, especially in remote areas where better transportation and resource access can drive economic growth and improve quality of life. In the Amazon rainforest, road network expansion offers a chance to support local livelihoods but brings potential risks to biodiversity. Roads often fragment habitats, create edge effects, and increase human disturbances—factors that typically reduce biodiversity. The Brazil nut forest, an ecosystem dominated by *Bertholletia excelsa*, holds significant ecological and economic value, yet its response to road proximity is underexplored. This study investigates the effect of road proximity on biodiversity within Brazil nut forests, using arthropod populations as an indicator group for ecosystem health. Contrary to expectations, no significant differences were observed in biodiversity, abundance, or dominant arthropod families across plots with varying distances from a road. However, a notable exception was found in one plot containing a native food forest, which exhibited lower biodiversity levels. This finding may be linked to the reduced plant diversity within the food forest, suggesting that certain food forest types may support biodiversity more effectively than others. The results underscore the importance of further research into food forests that bolster biodiversity, as well as targeted studies on how specific roads affect biodiversity under various ecological conditions. These insights can guide policymakers and planners in balancing infrastructure development with conservation goals, ultimately fostering sustainable growth in regions like the Amazon.

Keywords: Biodiversity, Brazilian nut, Arthropods, and Human disturbance, Agroforestry

Introduction

A robust infrastructure forms the foundation of prosperous communities, facilitating efficient transportation, access to essential resources, and fostering progress across multiple sectors. Improving infrastructure in remote areas is, therefore, a critical step toward enhancing welfare. The Amazon rainforest and its surrounding regions are examples of areas where infrastructure improvements could positively impact welfare. Currently, this process involves expanding the existing road network in these areas (Gallice et al., 2017; Vilela t al., 2020). While road expansion promises to bring benefits to the communities, it also presents certain drawbacks. Roads are known to decrease biodiversity across various ecosystems, a trend that also appears in the Amazon rainforest (Barber et al., 2014; Gallice et al., 2017). However, while these general trends provide an initial understanding, more specific knowledge about the diverse ecosystems within the Amazon and the impacts of roads on each is essential. Although many of the Amazon's ecosystems have been extensively studied in this context, certain areas—such as the Brazil nut ecosystem, characterized by its abundance of Brazil nut trees—are still relatively understudied. Filling these knowledge gaps is crucial to guide where future road expansion should and should not occur.

A high level of biodiversity is a key driver of ecosystem stability, which in turn supports essential ecosystem services, climate regulation, and resilience against environmental degradation. One indicator of a stable ecosystem is functional redundancy, where multiple species can fulfill similar ecological roles. This redundancy ensures that if one species declines or dies out, others can continue to perform critical functions, maintaining ecosystem balance (Biggs et al., 2020; Londe, 2021). Another sign of a stable, biodiverse system is the presence of sustainable populations, where species have adequate population sizes to reproduce effectively and avoid inbreeding, thus allowing long-term persistence within the ecosystem (De Bello et al., 2021). Stable ecosystems offer numerous benefits to humankind. They provide ecosystem services that create economic value, prevent environmental degradation, and mitigate natural disasters (Albert et al., 2023; Borma et al., 2022). Furthermore, stable ecosystems can influence the global climate. The Amazon rainforest, as one of the world's largest carbon sinks, stores an estimated 180 gigatons (Gt) of carbon within its vegetation and soils (Albert et al., 2023; Gallice et al., 2017). A decline in biodiversity could destabilize this ecosystem, reducing its carbon storage capacity. Carbon that is not retained within the ecosystem is released into the atmosphere as carbon dioxide, contributing to the enhanced greenhouse effect and climate change. For these reasons, maintaining stable ecosystems is crucial, and this can only be achieved by preserving adequate levels of biodiversity.

Roads can reduce biodiversity through several mechanisms: fragmentation, the edge effect, and increased exposure to human disturbances. Fragmentation occurs when roads act as barriers that many species are unable to cross. The extent to which a road fragments an area for a given species depends heavily on both traffic density and road width. This division of habitats creates smaller, isolated areas with reduced carrying capacities. When the carrying capacity of a habitat becomes too low, it can no longer sustain viable populations of certain species, leading to their eventual disappearance from the ecosystem (Barber et al., 2014; Heraldo & Bruna, 2012; Meza-Elizalde & Armenteras-Pascual, 2021; Muñoz et al., 2014). A second impact of roads is the ecological edge effect, where the edges near a road foster different species than the interior. The edge effect occurs naturally where biomes transition but also occurs artificially where roads are located. This artificial edge further reduces the effective habitat size for species adapted to interior conditions (Heraldo & Bruna, 2012; Maynard et al., 2016; Meza-Elizalde & Armenteras-Pascual, 2021; Laurance et al., 2000). Lastly, roads lead to increased human disturbance due to traffic but also by increasing activities like recreation, logging, mining, and the creation of side roads that reach deeper into forests. Each of these activities can further decrease biodiversity (Gallice et al., 2017; Maynard et al., 2016). Thus, roads introduce multiple factors that collectively diminish biodiversity within an ecosystem.

The Brazil nut forest is one of the diverse ecosystems within the Amazon and is characterized by the dominance of the

Brazil nut tree (*Bertholletia excelsa*). This ecosystem occurs in parts of Peru, Brazil, and Bolivia. Brazil nut seeds are naturally dispersed by Agoutis (*Dasypus azarae*), which are crucial for the regeneration of these trees (Tuck Haugaasen et al., 2010). Brazil nut trees typically mature in forest gaps where ample light supports their growth (Brouwer et al., 2021; Moll-Rocek et al., 2014). The seeds, or nuts, produced by these trees hold significant commercial value for surrounding communities. In Madre de Dios, Peru, approximately 22% of the local residents rely on the economic value of the Brazil nut in some capacity (Alarcón-Aguirre et al., 2023; Moll-Rocek et al., 2014). Due to the tree's economic and ecological importance, the government has implemented special concessions to protect Brazil nut trees. These regulations prohibit cutting or burning Brazil nut trees and restrict the use of their timber in any product or construction. However, harvesting the nuts is permitted once they fall naturally. An unintended benefit of these rules is the creation of semi-protected areas around the trees. Since Brazil nut trees cannot be cleared, the surrounding vegetation is often preserved, as this land is deemed less suitable for agriculture. This protection offers a promising approach to rainforest conservation, especially as Brazil nut forests are recognized for their high biodiversity (Alarcón-Aguirre et al., 2023; Willlem et al., 2019). Preserving biodiversity in these forests also benefits the Brazil nut trees, as a stable ecosystem minimizes damage from environmental and biological stressors. In turn, this stability can increase the yield of Brazil nut harvests (Alarcón-Aguirre et al., 2023; Brouwer et al., 2021; Jansen et al., 2021). Therefore, studying potential impacts—such as roads—on this ecosystem is crucial, not only for conservation efforts but also for the economic well-being of local communities.

Measuring biodiversity levels is a complex task, especially in rich ecosystems like the Brazil nut forest. Using an indicator group can streamline this process by offering insights into biodiversity without the need to measure every species present. Arthropods are particularly effective as an indicator group due to their remarkable diversity— with insects alone accounting for approximately 75% of global fauna biodiversity (Heraldo & Bruna, 2012; Sankarganesh, 2017). Additionally, arthropods typically occupy the first or second trophic levels in most food webs, making them crucial for ecosystem stability. Many species in higher trophic levels rely on arthropods for sustenance, making their presence essential for a well-functioning ecosystem. Analyzing arthropod abundance and diversity within a system can provide valuable insights into that system's carrying capacity and complexity (Heraldo & Bruna, 2012). Arthropods are also highly abundant in ecosystems, which increases the likelihood of encountering them in field studies. Their small size further facilitates their capture using simple traps. These qualities make arthropods a practical choice for biodiversity studies, offering a representative picture of ecosystem health and diversity.

This study will examine the effect of a road on biodiversity levels in the Brazilian nut ecosystem located in the Amazon rainforest. The research area will be divided into four plots at varying distances from the road. Different groups within the phylum Arthropoda will be utilized to assess biodiversity levels in each research location. The study aims to answer the following research questions:

- How does the abundance of captured arthropods differ among the various research plots?

- What are the dominant arthropod groups or species in the different research plots?

- What is the relationship between distance from the road and biodiversity levels?

Given the disturbances that roads introduce into ecosystems, it is expected that areas further from the road will exhibit greater biodiversity and higher levels of abundance. The reduced disturbance deeper in the forest allows for the presence of plants that typically grow only in primary forest conditions. These factors are anticipated to contribute to higher abundance and biodiversity levels further from the road. Moreover, it is expected that the most dominant group closest to the road will consist of highly mobile species, such as flying insects. This is based on the premise that roads act as less of a barrier for more mobile species, allowing them to traverse the area affected by the road more quickly and reach parts of the ecosystem where they can thrive.

Methods

Study Site

All data was collected in the surrounding area of the research station Finca Las Piedras, located in the Madre de Dios region of Peru. Finca Las Piedras is situated at the edge of a Brazil nut concession and is well-suited for comparative studies (Figure 1). The study site itself was located in a Brazil nut forest south of Finca Las Piedras. A dirt road runs along the west side of the study site, while the remaining surrounding area consists of Brazil nut forest, agricultural land, and a native food forest. The coordinates of the research area's corners are as follows:

- Northwest corner: -12.22850654412387°, -69.11489637225669°.
- Northeast corner: -12.22798249183°, -69.11310690006°.
- Southwest corner: -12.22890998120288°, -69.11489637225669°.
- Southeast corner: -12.228393207419°, -69.1129727676275°.

Figure 1: Location of research station Finca Las Piedras.

This figure displays a map of the location of research station Finca Las Piedras. The station is located in the Madre de Dios region of Peru.

The total research area is divided into four quadrants: Plot A beside the road, Plot B near the road, Plot C in the forest, and Plot D deep in the forest. Each quadrant has a different distance from the road: Plot A is 0–50 meters, Plot B is 50–100 meters, Plot C is 100–150 meters, and Plot D is 150–200 meters away (Figure 2). Plot D includes both Brazil nut forest and an overlapping area with a native food forest.

Data Collection

Species from the Arthropod phylum were captured using three different kinds of traps. Using various traps provided a wider array of arthropods, offering more insight into biodiversity levels. The traps used were as follows:

Pitfall Trap

The pitfall traps used in this experiment were made from plastic bottles

Figure 2: Map of the study site.

This figure shows a map of the study site. The bold red line represents the road running adjacent to the study area. The colored squares indicate different plots, each located at varying distances from the road. The symbols within the figure mark the different trap locations.

of approximately the same shape and size. The bottles were cut in half, and both halves were used as pitfall traps (Figure 3). Half of the pitfall traps were covered with large leaves to create a dark environment in the trap (Figure 4). The other half were left uncovered, allowing light to enter. Two types of bait were used: fermented banana and sugar water. The bait was distributed as follows: one dark pitfall trap with fermented banana, one open pitfall trap with fermented banana, one dark pitfall trap with sugar water, and one open pitfall trap with sugar water.

Wasp Trap

The wasp traps in this experiment were also made from plastic bottles of approximately the same size and shape (Figure 5). The bottles were cut in half, and the top part of each bottle was turned upside down and placed inside the lower half. Holes were poked in both halves to attach a rope, allowing the trap to hang from a branch. Half of the traps contained fermented banana bait, while the other half contained sugar water.

Butterfly Trap

The butterfly trap was modeled after tropical butterfly traps. This trap was constructed using a plastic bottle, rope, and a Styrofoam container (Figure 6). The lower part of the bottle was removed, and four holes were poked around the circumference of the bottle for attachment. The Styrofoam served as a platform, with four attachment holes. Using four ropes, the platform was connected to the bottle, and a rope attached to the bottle neck allowed the trap to be suspended from a branch. All butterfly traps were loaded with fermented banana.

Each plot contained the following traps: 4 pitfall traps (2 covered and 2 open), 2 wasp traps, and 1 butterfly trap. There were three types of trap locations in each plot: (1) Traps with sugar water as bait, consisting of an open pitfall trap, a closed pitfall trap and a wasp trap; (2) Traps with fermented banana as bait, consisting of an open pitfall trap, a closed pitfall trap and a wasp trap and (3) Butterfly traps with fermented banana as bait. These three different types of trap locations were randomly distributed across each plot using the GIS program QGIS. Due to GPS issues during setup, two trap locations—traps with fermented banana in Plot B and traps with fermented banana in Plot D—were positioned slightly outside their boundaries (Figure 2). All traps were checked and emptied daily between 7:00 and 13:00, and bait was refreshed during these daily check-ups.

Figure 3: Open pitfall trap.
This figure shows an open pitfall trap used to collect arthropods.

Figure 4: covered pitfall trap.
This figure shows a covered pitfall trap used to collect arthropods.

Figure 5: Wasp trap.
This figure shows a wasp trap used to collect arthropods.

Figure 6: Butterfly trap.
This figure shows a butterfly trap used to collect arthropods.

Analyzing captured specimens

The number of specimens and the family to which each captured individual belonged were recorded for each trap during each collection round. This data was then entered into WPS Spreadsheet for further analysis. The captured specimens were identified either in the field or back at the field station. Photos of the captured specimens were taken and posted on iNaturalist. The integrated AI, as well as other iNaturalist users, assisted in identifying the specimens. Most specimens were generally identifiable to the family level. Consequently, all analyses were conducted using the family level of the arthropod specimens.

Analyses

To better understand the effect of the road on the study site, analyses were performed on the collected data, focusing on abundance, number of families, and a diversity index calculation.

<u>Abundance</u>

The total abundance for each plot over the ten days was calculated, along with the average abundance of specimens found per plot for each collection round. An analysis of Variance (ANOVA) or F-test was conducted to determine whether the average abundance of specimens differed between the plots.

<u>Families</u>

The total number of families over the entire collection period was calculated, for the entire research area as well as for each specific plot. The average number of different families found per plot each day was also determined. An ANOVA or F-test was conducted to assess whether the average number of different families differed between plots. A post hoc test, Tukey's Honest Significant Difference (HSD), was then performed to identify which specific plots were significantly different from one another. The most prevalent family overall and within each plot were also examined. For this analysis, the total number of specimens for the entire research area, as well as per plot were calculated. The *Formicidae* family was the most prevalent across all plots. The average number of *Formicidae* specimens per plot per day was therefor also calculated. An ANOVA or F-test was conducted to determine whether the average number of *Formicidae* differed between plots, followed by a Tukey's HSD test to identify any significant differences between specific plots.

<u>Diversity Index</u>

An analysis that includes a biodiversity index provides deeper insight into biodiversity and the effect of the road on biodiversity within the study site. The biodiversity index used in this study was the Shannon Diversity Index (SDI). The SDI accounts for both the abundance and evenness of the species, and in this study families, present in an area. The value of the SDI is calculated using the following formula:

$$\text{Shannon Index } (H) = -\sum_{i=1}^{s} p_i \ln p_i$$

P = the proportion of families in an area

The SDI value for each plot over the entire collection period was calculated using this formula. Additionally, the SDI value for each plot was calculated for each day, allowing for the determination of an average SDI value per plot per day. An ANOVA or F-test was conducted to assess whether the average SDI value differed between plots, followed by a Tukey's HSD test to identify any significant differences between specific plots.

Software

The software used in this study included WPS Spreadsheet, QGIS Desktop (version 3.34.8), iNaturalist, and R (version 4.4.0). WPS Spreadsheet was utilized to organize all the collected data into a table so that it could be used in further analysis in R. QGIS was used to randomly assign the locations of the traps within their designated plots and to create the visual map presented in this study. iNaturalist was employed to identify the families of the captured specimens. R was used for analyses, calculations, statistical analyses, and visualizations in the form of figures present in this study.

Results

Abundance

The total number of individuals found during the collection period was 1,614. Plot A had the highest total number, with 448 individuals, followed by plot B with 389, plot C with 385, and plot D with 392 (Figure 7). There was no significant difference in the average daily abundance of individuals across different plots (F-test, *P-value* = 0.640, *F-value* = 0.568; Figure 8).

Figure 7: Total number of captured specimens for the different plots.

This bargraph illustrates the total number of captured specimens in each plot. Different colors represent various arthropod families, providing a visual breakdown of family distribution across the plots.

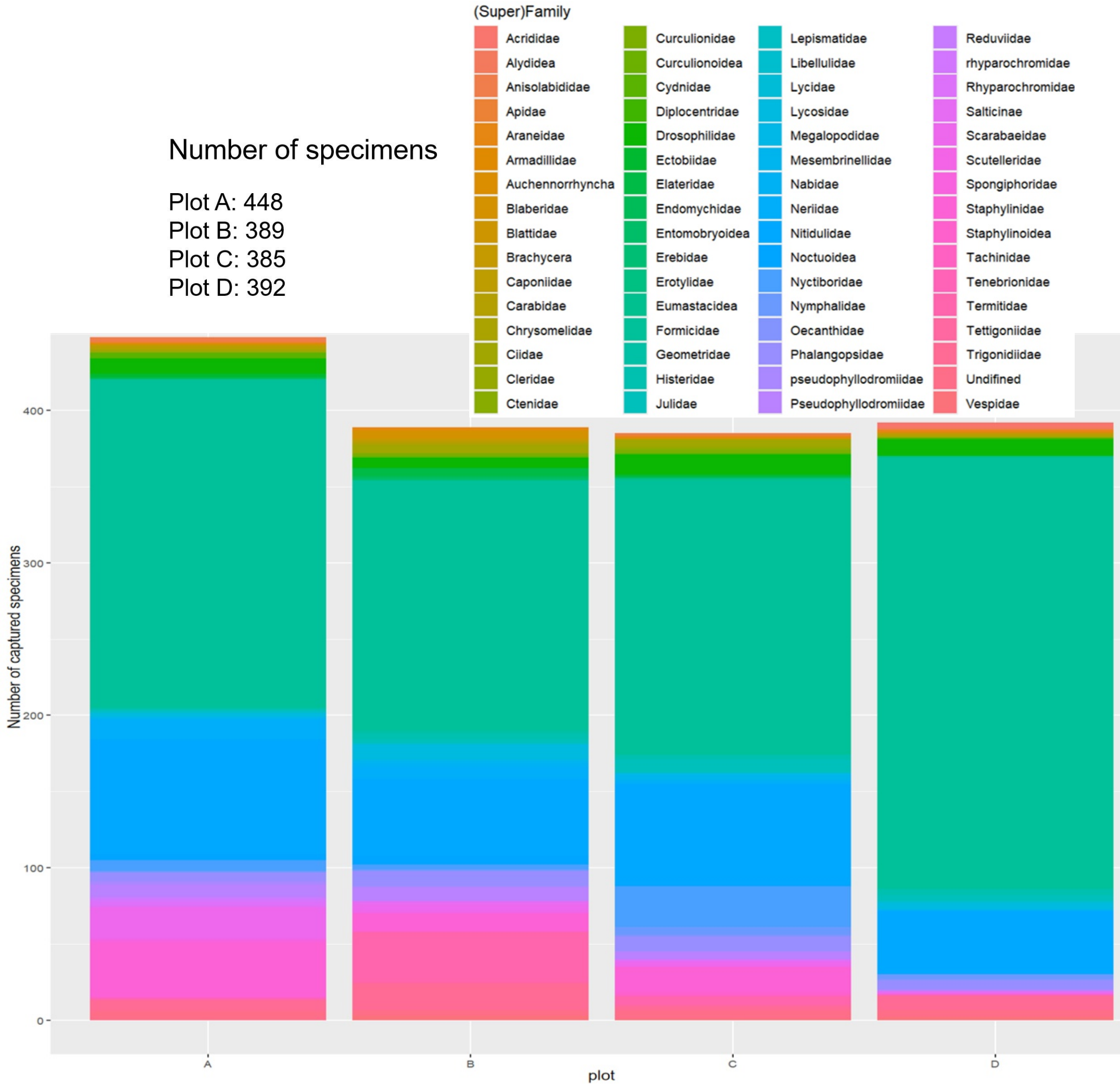
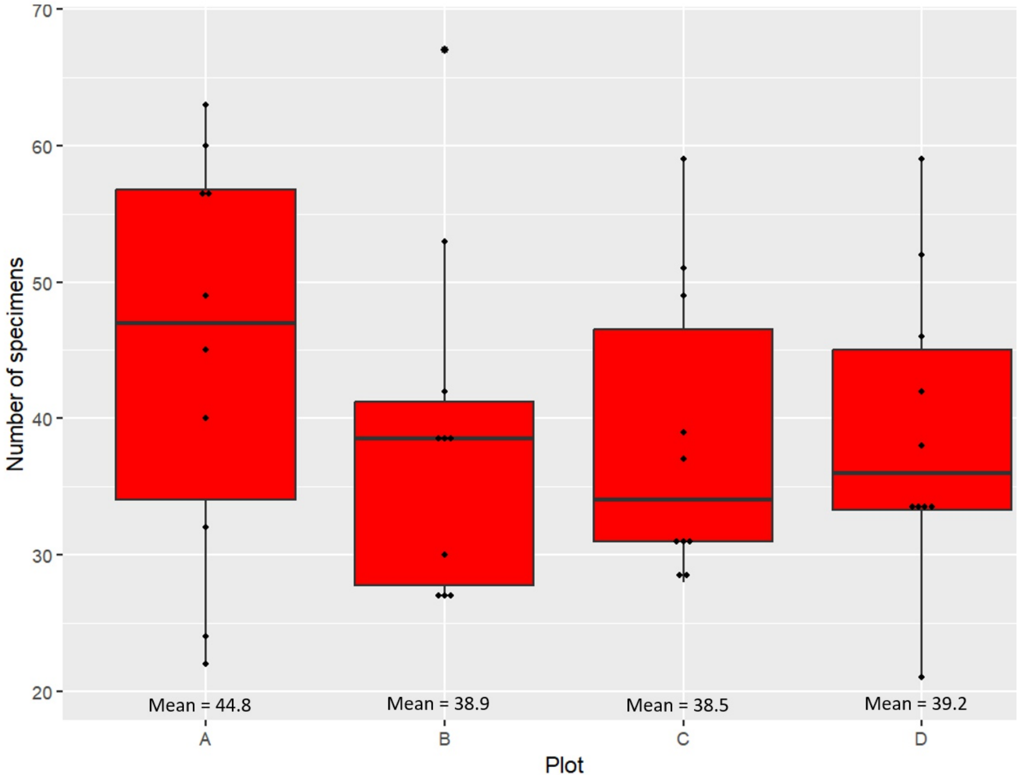


Figure 8: Average number of specimens found in each plot.

This boxplot illustrates the average number of specimens captured per day across the different plots. Black dots represent the number of specimens recorded on individual days, while the black horizontal line within each boxplot indicates the median.



Families

Formicidae was the family with the highest number of individuals, totaling 812. The family with the second-highest number was *Nitidulidae*, with 220 individuals (Figure 9). *Formicidae* was also the most prevalent family across all plots, with 215 individuals at plot A, 164 at plot B, 180 at plot C, and 283 at plot D (Figure 10). The average daily number of individuals in the *Formicidae* family was 21.5 for plot A, 16.4 for plot B, 18 for plot C, and 28.3 for location D. The average daily number of *Formicidae* individuals was significantly higher in plot D compared to plot B (Tukey's HSD, *P-value* < 0.001) and plot C (Tukey's HSD, *P-value* = 0.001; Figure 11). The total number of families found during the collection period was 64 . The number of families at each location were 38 at plot A, 40 at plot B, 38 at plot C, and 28 at plot D (Figure 12). The average number of families per day at plot D, with an average of 12.2, was significantly lower when compared to plot B with an average of 7.2 (Tukey's HDS, *P-value* = 0.012). The rest of the sites did however not differ significantly from one another (Figure 13).

Shannon Diversity Index

Location B had the highest Shannon Diversity Index value of 2.38, while plot D had the lowest value of 1.28. Plots A and C had Shannon Diversity Index values of 2.04 and 2.10, respectively (Figure 14). The average daily Shannon Diversity Index followed a similar trend, being highest at location B with 1.82 and lowest at location D with 0.973. Plots A and C had average values of 1.65 and 1.56, respectively (Figure 15). The average Shannon Diversity Index at plot D was significantly lower compared to all other plots (Tukey's HSD, A-D *P-value* = 0.005, B-D *P-value* < 0.001, C-D *P-value* = 0.019; Figure 15).

Figure 9: Total number of individuals found for each family.

This bargraph shows the total number of individuals captured for each family.

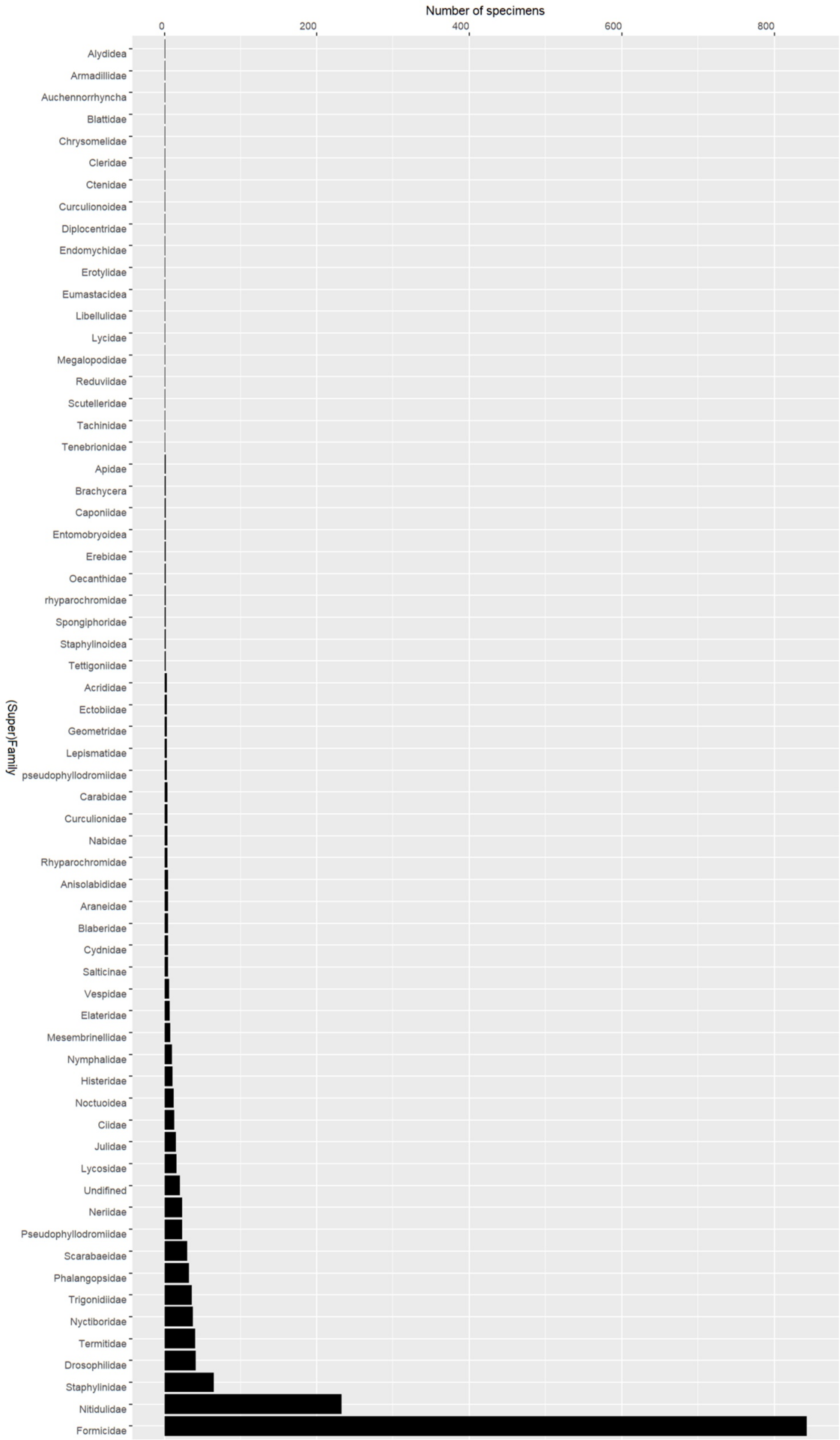


Figure 10: Total number of individuals found for each family in each plot.

This bargraph shows the total number of individuals captured for each family in the different plots.

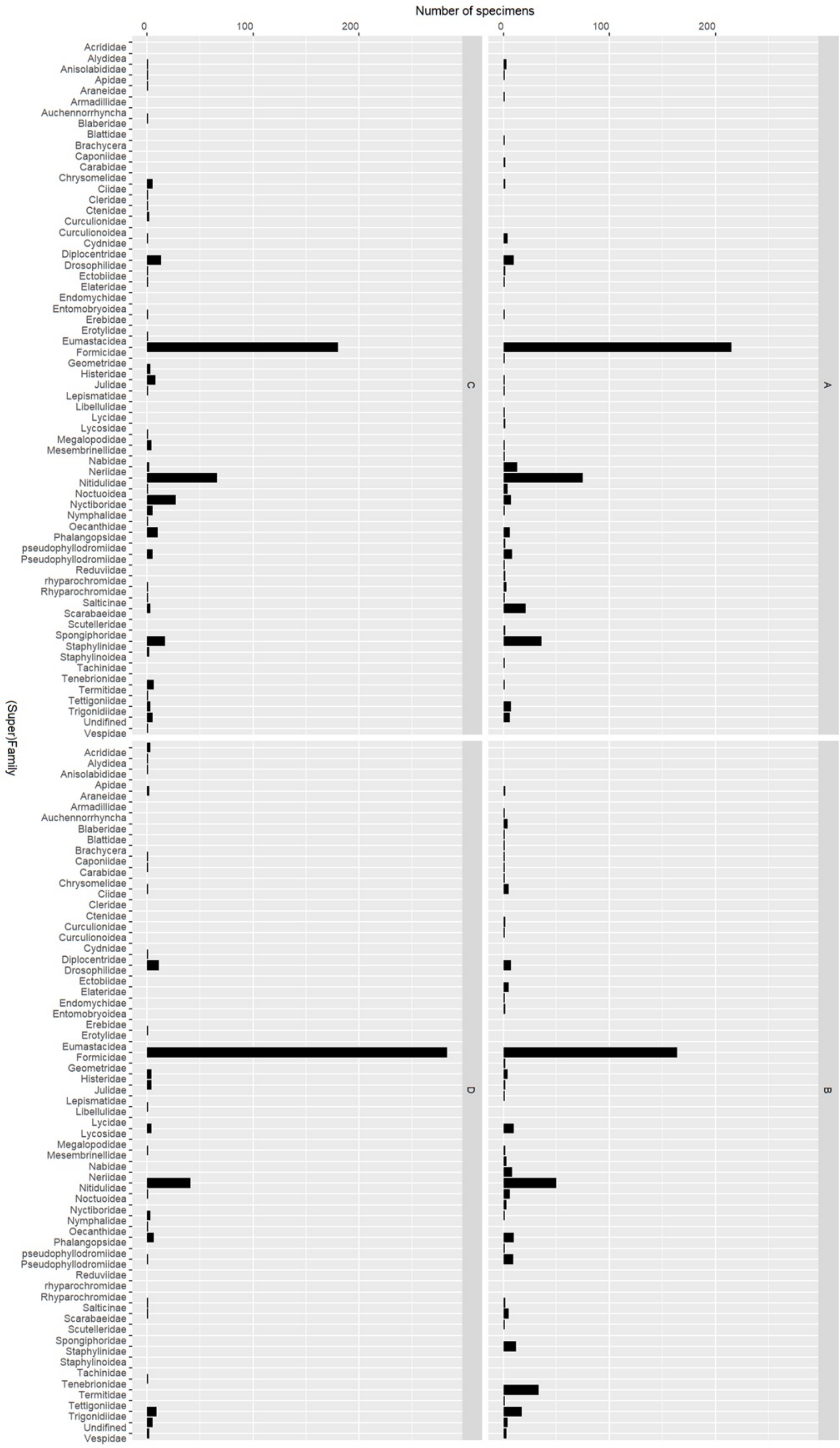


Figure 11: Average number of *Formicidae* specimens found in each plot.
This boxplot illustrates the average number *Formicidae* specimens found per day across the different plots. Black dots represent possible outliers, while the black horizontal line within each boxplot indicates the median.

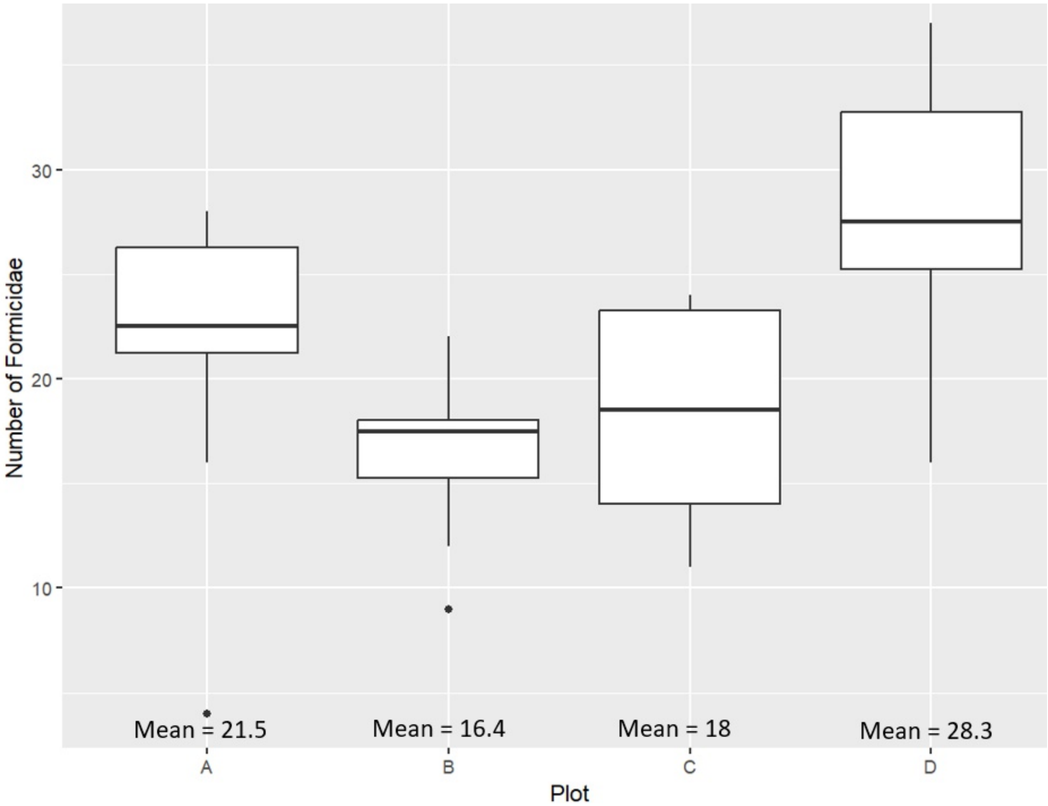


Figure 12: Total number of unique families in each plot.
This bargraph shows the total number of unique families found in each of the plots.

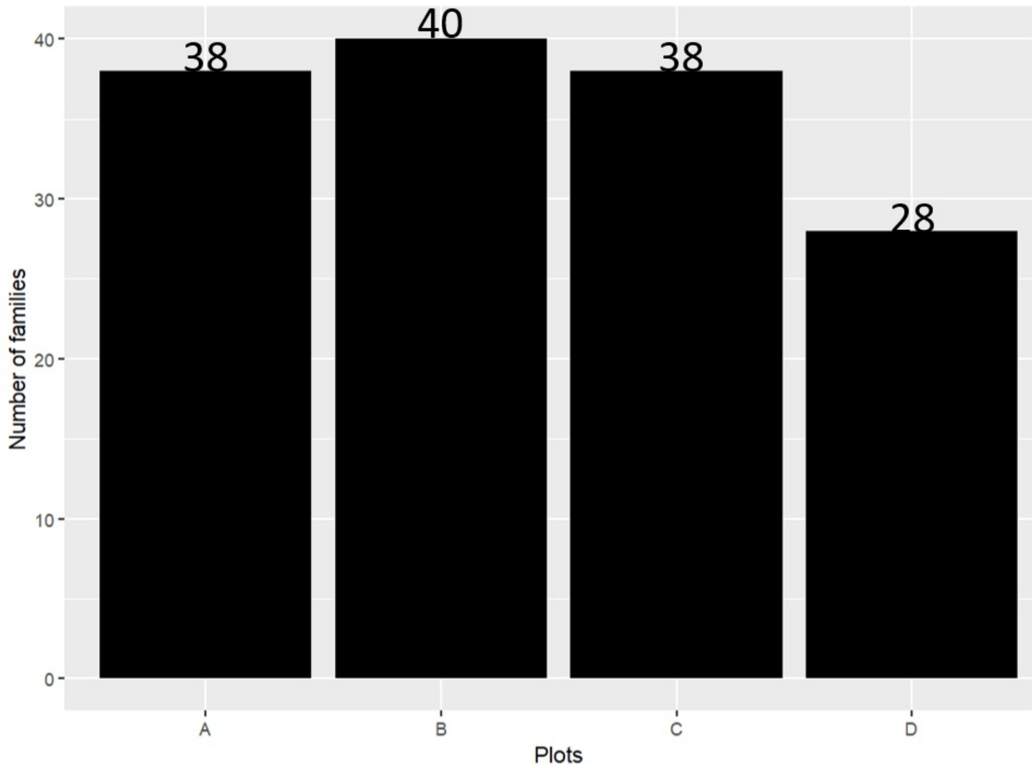


Figure 13: Average number of unique families found in each plot.

This boxplot illustrates the average number of families found per day across the different plots. Black dots represent the number of families recorded on individual days, while the black horizontal line within each boxplot indicates the median.

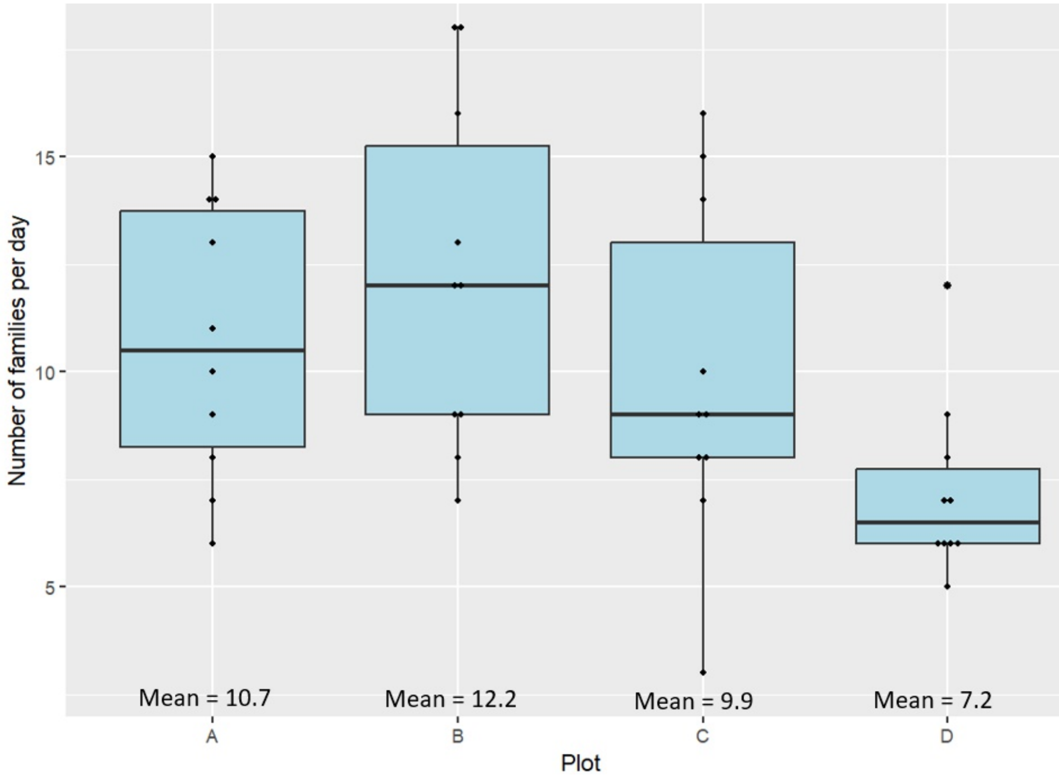


Figure 14: SDI value for each of the plots.

This bargraph shows the SDI value of each of the plots.

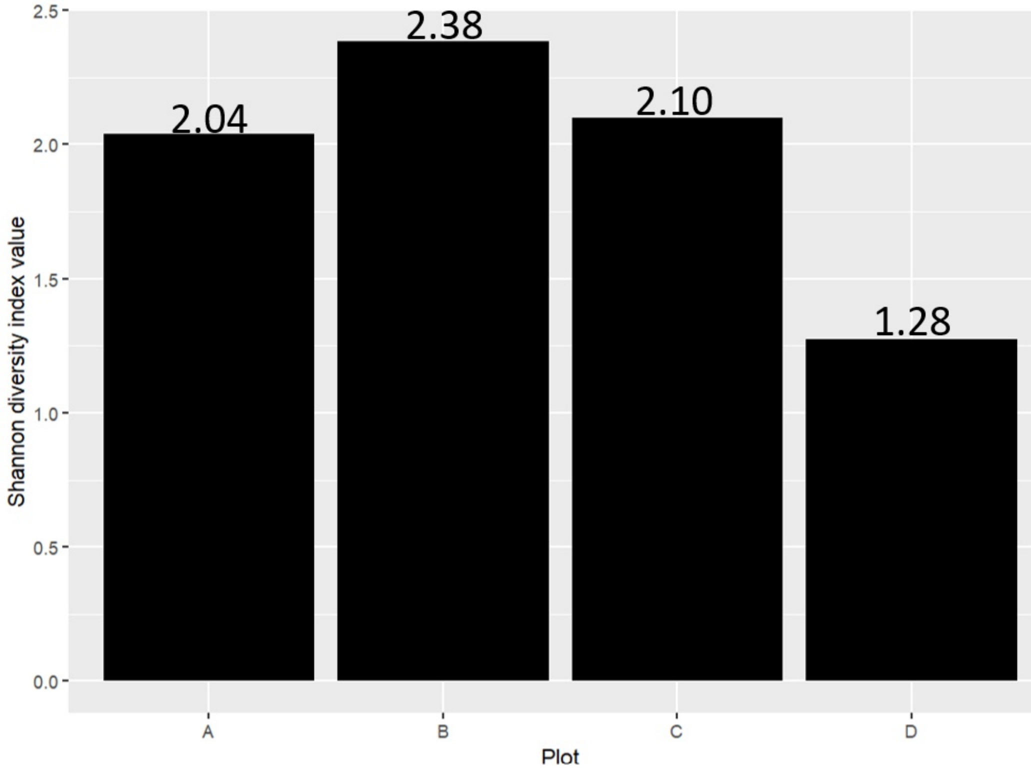
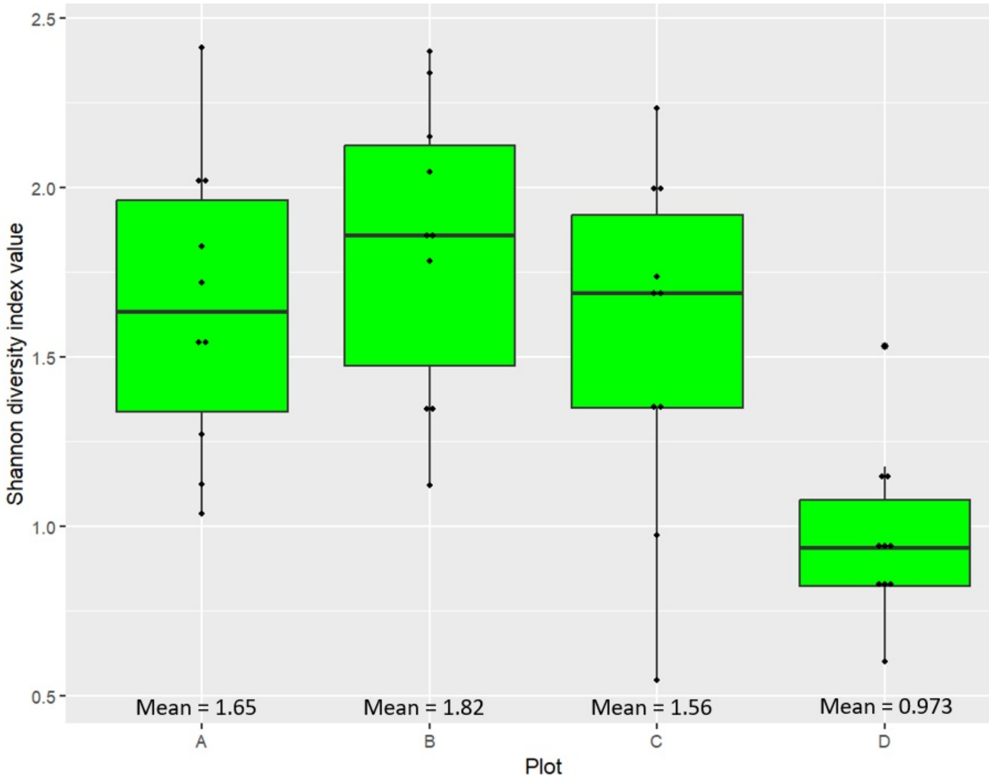


Figure 15: Average SDI value found in each plot.

This boxplot illustrates the average SDI value found per day across the different plots. Black dots represent the SDI value on each individual day, while the black horizontal line within each boxplot indicates the median.



Discussion

This study examined the effects of a dirt road on arthropod diversity within a Brazil nut ecosystem. The impact was measured using various types of traps, which were distributed across four plots at different distances from the road. Biodiversity was assessed by examining the number of individuals, the number of different families, and the SDI values across the different plots. No significant difference was observed between plots in terms of average daily abundance. However, the number of different families found in Plot D was significantly lower than in Plot B. The average SDI value was also significantly lower in Plot B compared to the other plots. Plot D, a native food forest, exhibited lower biodiversity based on two different biodiversity metrics, despite having similar abundance levels.

Abundance

The abundance of specimens did not differ significantly between the plots, which contradicted the initial expectation of lower abundance levels closer to the road. However, this finding aligns with results from other studies, which have also reported consistent abundance levels at varying distances from roads (Carpio et al., 2013; Whitworth, 2016). One possible explanation for similar abundance across plots is interspecies competition. Typically, specialist species are expected to outcompete generalists within their specific habitats, while generalist species may thrive in areas where specialists are absent. As a result, while the total abundance of specimens might remain constant, the species composition could vary substantially between plots. In more disturbed areas, for example, it's likely that generalist species fill the gaps left by specialist species typically found only in pristine forest environments.

Families

The most prevalent family across the entire study site was *Formicidae*, which was also the most common family in each individual plot. *Formicidae* are known for their biomass dominance and their ability to thrive in various forest strata (Philpott & Armbrecht, 2006; Solar et al., 2016). Thus, finding *Formicidae* as the most prevalent family across all plots was expected. It is worth noting, however, that while every plot shared the same dominant family, Plot D had a significantly higher number of *Formicidae* compared to the other plots. This is interesting because plot D may be considered the most disturbed plot in this study due to its overlap with a native food forest, which cannot be classified as primary forest. Plot A, closest to the road, likely experiences some effects due to its proximity but is largely composed of primary forest, making it less disturbed than Plot D. Some *Formicidae* species are known to take advantage of moderately disturbed areas. The native food forest in Plot D is more open, with less canopy cover, compared to the Brazil nut forest. Certain *Formicidae* species thrive in systems with less canopy cover due to increased sunlight reaching the ground, which warms the soil (Graham et al., 2009; Tiede et al., 2017). This may explain the higher number of *Formicidae* individuals collected in Plot D. However, a higher abundance of *Formicidae* does not necessarily indicate greater diversity within the family, which is large and contains many species. The species composition within *Formicidae* could differ across plots, as studies suggest that primary forests may support unique *Formicidae* species not found in more disturbed areas (Philpott & Armbrecht, 2006; Solar et al., 2016; Fontenele & Schmidt, 2021). A deeper analysis of the genera and species within *Formicidae* would be needed to determine if the biodiversity within this family varies significantly between plots. This deeper analysis could also clarify if the road besides the study site has an effect on the biodiversity within the *Formicidae* family.

Shannon Diversity Index

The average SDI value did not differ significantly between plots A, B, and C. However, plot D exhibited an SDI value significantly lower than the other plots. This finding contradicted initial expectations, which predicted plot A would have the lowest biodiversity levels. Unlike prior studies that have shown reduced biodiversity in forests adjacent to roads due to disturbance and edge effects (Muñoz et al., 2014; Maynard et al., 2016; Meza-Elizalde & Armenteras-Pascual, 2021), this study found no such decrease near the road. The difference in findings may be attributed to the type of road in this study, a low-traffic dirt road with only a few vehicles passing daily. The edge effect induced by this road may thus be limited, allowing species that typically inhabit interior forests to survive near the edge. Simultaneously, species that thrive in edge environments may also be present. This overlap of interior and edge species could explain the observed biodiversity levels. This hypothesis could also clarify why studies of larger, busier roads—where the edge and interior forest environments are more distinct—often report different trends.

Another unexpected result was the significantly lower biodiversity levels in plot D, which was partially located within a native food forest. This lower biodiversity may be explained by the food forest's reduced plant diversity compared to the surrounding Brazil nut forest, as arthropod biodiversity is closely linked to plant diversity in an area. Reduced plant diversity directly impacts arthropod diversity, which could account for the lower SDI value observed in plot D. Native food forests are often promoted as a strategy to combat biodiversity loss (Philpott & Armbrecht, 2006; Porro et al., 2012; Udawatta et al., 2021). However, the reduced biodiversity in plot D suggests that native food forests may not universally support biodiversity conservation. This does not imply that agroforestry lacks conservation value, but rather emphasizes that it should be implemented strategically. In particular, establishing food forests in pristine forest areas should be avoided, while already disturbed areas may offer more suitable locations.

Conclusion

The distance from the road did not significantly impact biodiversity, the number of individuals found, or the dominant arthropod family. However, the presence of a native food forest in one of the research plots may be associated with lower biodiversity levels in that plot compared to the others. A possible explanation for this reduced arthropod diversity could be the lower plant diversity in the native food forest. This does not suggest that native food forests should be avoided, but it underscores the need for further research into the types of food forests that best support biodiversity. Strategically placed food forests could be valuable tools in combating biodiversity loss if designed with an understanding of their impact on local ecosystems.

Additional studies comparing the diversity within different types of food forests, as well as their effects on surrounding areas, are essential. Furthermore, more research on roads and their specific impacts on local biodiversity would help clarify the conditions under which roads contribute to biodiversity loss versus when their effect is minimal. Identifying factors that lead to biodiversity decline in certain contexts could provide valuable insights for policymakers and project planners, guiding them on the types of roads and conservation measures that can effectively protect biodiversity.

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Works Cited

Alarcon-Aguirre, G., Mamani, M. M., Canahuire-Robles, R. R., Zavaleta, T. V., Valdeiglesias, J. P., Revoredo, J. D., … Garate-Quispe, J., (2023). Forest Loss Related to Brazil Nut Production in Non-Timber Forest Product Concessions in a Micro-Watershed in the Peruvian Amazon. https://doi.org/10.3390/rs15235438

Albert, J. S., Carnaval, A. C., Flantua, S. G. A., Lohmann, L. G., Ribas, C. C., Riff, D., … Nobre, C. A. (2023). Human impacts outpace natural processes in the Amazon. https://doi.org/10.1126/science.abo5003

Baarbe, C. P., Cochrane, M. A., Souza, C. M. Jr., Luarance, W. F. (2014). Roads, deforestation, and the mitigating effect of protected areas in the Amazon. https://doi.org/10.1016/j.biocon.2014.07.004

Biggs, C. R., Yeager, L. A., Bolser, D. G., Bonsell, C., Dichiera, Angelina. M., Erisman, B. E. (2020). Does functional redundancy affect ecological stability and resilience? A review and meta-analysis.

https://doi.org/10.1002/ecs2.3184

Borma, L. S., Costa, M. H., da Rocha, M. H., Arieira, J., Nascimento, N. C. C., Jaramillo-Giraldo, C., … Nobre, C. A. (2022) Beyond Carbon: The Contributions of South American Tropical Humid and Subhumid Forests to Ecosystem Services. https://doi.org/10.1029/2021RG000766

Brouwer, R. G., Zuidema, P. A., Chiriboga-Arroyo, F. Guariguata, M. R., Kettle, C. J. Ehrenberg-Azcárate, F., … Jansen, M. (2021). Establishment success of Brazil nut trees in smallholder Amazon forest restoration depends on site conditions and management. https://doi.org/10.1016/j.foreco.2021.119575

Carlos, C., Donoso, D. A., Ramón, G,. Bungelt, O. (2013). Short term response of dung beetle communities to disturbance by road construction in the Ecuadorian Amazon. https://doi.org/10.1080/00379271.2009.10697629

De Bello, F., Lavorel, S., Hallett, L., Valencia, E., Garnier, E., Roscher, … Lepš, J. (2021). Functional trait effects on ecosystem stability: assembling the jigsaw puzzle. *Trends in Ecology & Evolution*, 36(9), 822–836. https://doi.org/10.1016/j.tree.2021.05.001

Fontenele, L. K., & Schmidt, F. A. (2021). Forest-pasture shifting alters the assemblages of seed-removing ants in southwestern Brazilian Amazon. https://doi.org/10.1007/s10841-021-00295-x

Gallice, G., Larrea-Gallegos, G., Vázquez-Rowe, I. (2017). The threat of road expansion in the Peruvian Amazon. https://doi.org/10.1017/S0030605317000412

Graham, J. H., Krzysik, A. J., Kovacic, D. A., Duda, J. J., Freeman, D. C., Emlen J. M., … Balbach, H. E. (2009).Species richness, equitability, and abundance of ants in disturbed landscapes. https://doi.org/10.1016/j.ecolind.2008.10.003

Heraldo, L., & Bruna, E. M. (2016). Arthropod responses to the experimental isolation of Amazonian forest fragments. https://doi.org/10.1590/S1984-46702012000600003

Jansen, M., Guariguata, M. R., Chiriboga-Arroyo, F., Quaedvlieg, J., Vargas Quispe, F. M., Arroyo Quispe, E., Kettle, C. J. (2021). Forest Degradation and Inter-annual Tree Level Brazil Nut Production in the Peruvian Amazon. https://doi.org/10.3389/ffgc.2020.525533

Laurance, W. F., Vasconcelos, H. L., Lovejoy, T. E. (2000). Forest loss and fragmentation in the Amazon: implications for wildlife conservation. https://doi.org/10.1046/j.1365-3008.2000.00094.x

Londe, V. (2021). The Importance of Ecological Redundancy for Ecosystems Restoration. https://doi.org/10.30564/re.v3i2.2957

Maynard, R. J., Aall, N. C., Saenz, D., Hamilton, P. S., Kwiatkowski, M. A. (2016). Road-Edge Effects on Herpetofauna in a Lowland Amazonian Rainforest. https://doi.org/10.1177/194008291600900114

Meza-Elizalde, M. C., & Armenteras-Pascual, D, A., (2021) Edge influence on the microclimate and vegetation of fragments of a north Amazonian forest. https://doi.org/10.1016/j.foreco.2021.119546

Moll-Rocek, J., Gilbert, M. E., Broadbent, E. N. (2014). Brazil Nut (*Bertholletia excelsa, Lecythidaceae*) Regeneration in Logging Gaps in the Peruvian Amazon. https://doi.org/10.1155/2014/420764

Muñoz, P. T., Torres, F. P., Megías, A. G. (2014). Effects of roads on insects: a review. *Biodiversity And Conservation*, 24(3), 659–682. https://doi.org/10.1007/s10531-014-0831-2

Philpott S. M., & Armbrecht, I. (2006) Biodiversity in tropical agroforests and the ecological role of ants and ant diversity in predatory function. https://doi.org/10.1111/j.1365-2311.2006.00793.x

Porro, R., Miller, R. P., Tito, M. R., Donovan, J. A., Vivan, J. L., Trancoso, R., … Gonçalves, A. L. (2012). Agroforestry in the Amazon Region: A Pathway for Balancing Conservation and Development. In *Advances in agroforestry* (pp. 391–428). https://doi.org/10.1007/978-94-007-4676-3_20

Sankarganesh, E. (2017) Insect Biodiversity: The Teeming Millions- A review. *Bull. Env. Pharmacol. Life Sci.*, Vol 6 Special issue [3]: 101-105

Solar, R. R. C., Barlow, J., Andersen, A. N., Schoereder, J. H., Berenguer, E. Ferreira, J. N., Gardner, T. A. (2016). Biodiversity consequences of land-use change and forest disturbance in the Amazon: A multi-scale assessment using ant communities. https://doi.org/10.1016/j.biocon.2016.03.005

Tiede, Y., Schlautmann, J., Donoso, D. A., Wallis, C. I. B., Bendix, J., Brandl, R., Farwig, N. (2017). Ants as indicators of environmental change and ecosystem processes. https://doi.org/10.1016/j.ecolind.2017.01.029

Tuck Haugaasen, J. M., Haugaasen, T., Peres, C. A., Gribel, R., Wegge, P. (2010). Seed dispersal of the Brazil nut tree (*Bertholletia excelsa*) by scatter-hoarding rodents in a central Amazonian forest. https://doi.org/10.1017/S0266467410000027

Udawatta, R. P., Rankoth, L. M., Jose, S. (2021). Agroforestry for Biodiversity Conservation. In *Springer eBooks* (pp. 245–274). https://doi.org/10.1007/978-3-030-80060-4_10

Vilela, T., Harb, A. M., Bruner, A., Arruda, V. L. S., Riveiro, V., Costa, A. A., Botero, R. (2020). A better Amazon road network for people and the environment. https://doi.org/10.1073/pnas.1910853117

Whitworth, A. W. (2016) Conservation value, biodiversity value and methods of assessment in regenerating and human disturbed tropical forest. Chapter 3 The response of faunal biodiversity to an unmarked road in the Western Amazon. http://theses.gla.ac.uk/7426/

Willem, H. V., Ingram, V. J., Guariguata, M. R. (2019). Brazil nut forest concessions in the Peruvian Amazon: success or failure? https://doi.org/10.1505/146554819826606540