

Baseline study on biodiversity in family-owned forests of the Mushullakta community, Napo, Ecuador



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Colophon

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Cover picture by Yorrick Grobben - *José Narváez in his Finca / the project area*

Abstract

This report presents 1) a biodiversity baseline study conducted in the restored areas of the Mushullakta community, Napo, Ecuador, and 2) a community-based monitoring protocol for ongoing biodiversity monitoring. Monitoring is a vital part of conservation and restoration, as it provides practitioners with insight into the process and shows where cost-effective adjustments need to be made to maximize the socio-environmental success of their work. Furthermore, the community receives donations for the restoration work that they perform, so the results from monitoring are crucial for reporting back to the investors that financially enable this project.

The main research question addressed in this study was the assessment of biodiversity variations among different forest/landscape types within the family-owned lands of the Mushullakta community. To answer the main research question, several sub-questions were formulated and investigated. The study focused on four key aspects: 1) tree species diversity, 2) vegetation structure and composition, 3) soil macro-fauna diversity, and 4) vertebrate diversity. Vegetation sample plots of 25x25 were used for tree species sampling, and a drone was employed to create an orthomosaic of the project area. Fauna sampling was conducted using camera traps and AudioMoths, and soil samples were collected to identify and record macrofauna families.

The diversity of tree species varied notably among the different forest types, with the highest species richness observed in secondary forests and the lowest in the *Ilex guayusa* plantation. Basal area, reflecting tree density and size distribution, also exhibited variations, particularly in the *Ilex guayusa* plantation where a high tree density was observed due to intentional close spacing during planting. Regarding soil macro-fauna family diversity, slight differences were observed among the forest types, primarily influenced by leaf litter and canopy cover variations. Higher canopy cover corresponded to greater soil fauna presence. Drone imagery indicated a predominantly high canopy cover across the study area, with only a few less dense areas. The study furthermore quantified the already relatively high vertebrate diversity in the project area, with 33 species identified. Although some remained unidentified due to low image quality or inappropriate methodology. AudioMoth recordings showed higher acoustic evenness and a slightly greater presence of insect activity or geophonic sounds in the primary forest, while the project area had lower evenness and temporal entropy, suggesting a higher presence of birds. The AudioMoth data also indicated a predominantly natural soundscape with minimal human interference, which holds promise for the forest's development.

These findings provide baseline information for future biodiversity monitoring. To establish trendlines, it is recommended to replicate this research in other project areas within the community and conduct regular monitoring. The proposed monitoring protocol is valuable as it requires minimal resources and encourages the active participation of the local community. By involving community members in monitoring and witnessing the changes firsthand, it is expected to increase the vitality of the restoration project. With a shared commitment to preserving their forests for future generations, the Mushullakta community can leverage the outcomes of this project and potentially provide an opportunity to improve the forest-management practices within the community to support their mission of forest conservation.

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Preface

This technical report was commissioned by Van Hall Larenstein University of Applied Sciences and Humans for Abundance to document the process of designing a community-based biodiversity monitoring protocol. The project was carried out in the Mushullakta community by Yorrick Grobben from February to June 2023, during the final year of the BSc Tropical Forestry.

The objective of this project was to provide the local community with an easily applicable monitoring protocol that does not require expert knowledge to understand and implement correctly. This protocol will enable them to inform investors about conservation progress and observe changes in their family-owned lands.

I would like to express my gratitude to Fidel Chiriboga and Anko Stilma for their continuous support throughout the project. I am also thankful to Chochi Iturralde for facilitating my connection with the Mushullakta community and for the assistance and hospitality she provided. I am deeply indebted to the Mushullakta community for welcoming me into their community and families for these three months. I would like to extend special thanks to José & Bryan Narváez, Mayra Shiguango, Juan and Inés Narváez, Andrés and María Avilés, Ángel and Angelina Pauchi, Nila Narváez, and all the other children of the community who helped me identify trees, assisted me with my fieldwork, and were always committed to learning.

Finally, I would like to express my appreciation to the organizations that supported me throughout this research: Restor, Stichting het Kronendak, and Stichting het Scholten-Cordes fonds.

1. Introduction

Forests worldwide are facing significant endangerment and damage, resulting in a severe threat to the biodiversity they host. The Neo-tropics serve as a prominent example, highlighting the crucial role of indigenous communities in the planning, execution, and monitoring of conservation efforts for long-term effectiveness in promoting biodiversity. Indigenous people possess invaluable ecological knowledge passed down through generations and rely on forests for their livelihoods. Unfortunately, unsustainable agricultural practices, as well as threats from mining activities, oil drilling, and wood harvesting, are causing a decline in biodiversity in their inhabited areas.

Humans for Abundance is an Ecuadorian organization that collaborates with landowners from local indigenous communities in the Amazon. Their mission is to conserve biodiversity through enrichment planting while simultaneously fostering sustainable livelihoods via regenerative agricultural practices such as agroforestry and permaculture. The Mushullakta community is part of the Indigenous Kichwa community of Ecuador and is situated south of the Sumaco Napo-Galeras National Park. The community receives financial support for restoration initiatives through donations to Humans for Abundance and the organization Terraformation. Consequently, the results obtained from this study will contribute to restoration efforts while providing investors with insights into the outcomes of their investments.

The objective of this project was twofold: firstly, to conduct a baseline assessment of the restored areas' biodiversity by evaluating the existing levels of biodiversity within those regions. Secondly, to develop a participatory monitoring protocol for biodiversity that the community can utilize in the future. This protocol will empower the community to gather data on the progress of the restored areas. This report combines information obtained from preliminary desk-based research with data collected in the field to describe the biodiversity values present in the study area.

1.1 Description of the project area

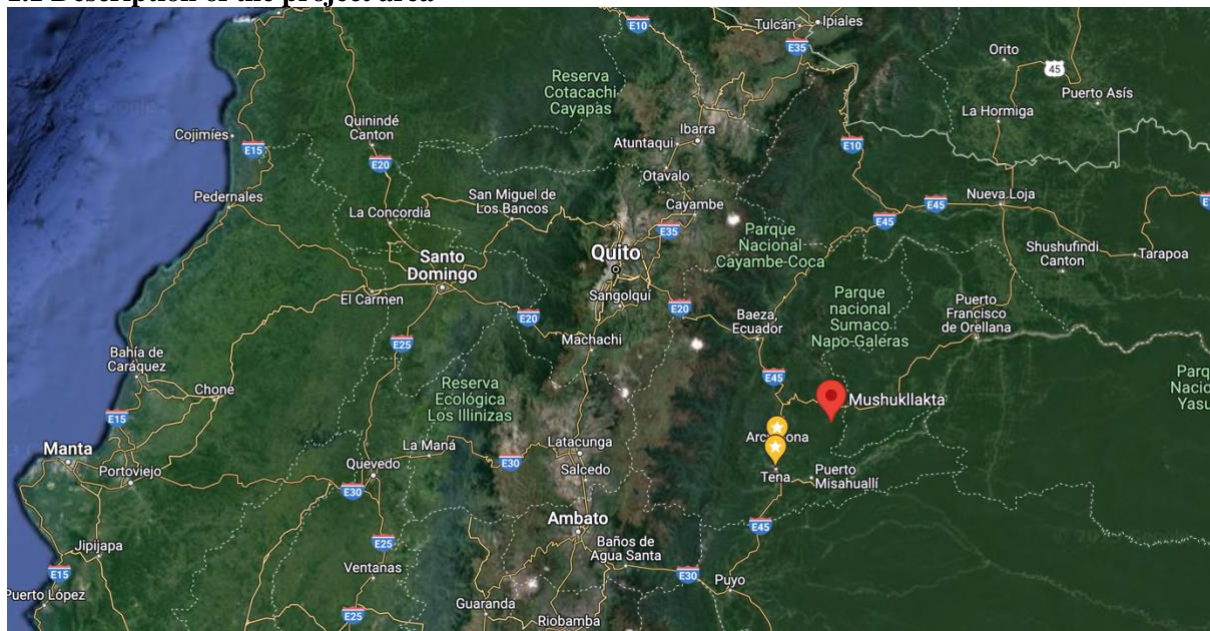


Figure 1 - Location of Mushullakta (Google Maps)

The Mushullakta community borders the Sumaco Napo-Galeras National Park (Figure 1) at an elevation of approximately 1000 meters above sea level. The region experiences a humid tropical climate, with an average annual temperature of 25.33 °C (World Bank Climate Change Knowledge Portal, n.d.). The area is predominantly covered by tropical rainforests, and each local family possesses a privately-owned plot of land known as a "Finca." Within these fincas, families have the freedom to utilize the land the way they see fit, primarily for a combination of subsistence farming (*Chakra*), coffee plantations, tree plantations, and minimally used secondary or primary forests for sustainable wood harvesting.

Collaborating with the non-governmental organization Humans for Abundance (H4A), the Mushullakta community is embarking on initiatives to diversify their sources of income, reduce their reliance on the land, and enhance income generation security while valuing biodiversity. The key strategies employed include enrichment planting and eco-tourism, where the community offers guided tours of neighboring forests and coffee plantations. The mission of H4A aligns with these efforts, aiming “To restore and conserve the planet's ecosystems and biodiversity by empowering humans who can take real, concrete actions that have large-scale positive environmental and social impact.” (*Humans for Abundance*, n.d.) This project aligns with their mission by focusing on educating the community about conducting high-quality monitoring and eventually transferring the governance of this initiative to the community itself.

The primary objective of the enrichment planting carried out by H4A in this project is the conservation of biodiversity, specifically focusing on endangered tree species. Through the planting of native tree species, the aim is to ensure the survival of these species and expand their habitats beyond the confines of the national park. This expansion would benefit various wildlife, including the Jaguar (*Panthera onca*), which serves as the community's namesake, “*Puma Wasi*” in Kichwa, meaning House of the Jaguar.

To effectively document the progress and success of the conservation and biodiversity recovery efforts, it is essential to monitor the area. Monitoring plays a crucial role in quantifying the development of biodiversity values within the region. Positive developments can be utilized to provide feedback to the investing parties, demonstrating the effective use of their resources. Conversely, monitoring may also reveal negative trends, such as low survival rates and forest loss, allowing for proactive management interventions to mitigate these adverse developments.

It is important to recognize that nature conservation begins by improving the livelihoods of the people who inhabit these areas. By providing communities with incentives to protect their environment and fostering a clear understanding of the conservation reasons, the likelihood of exploitation by external entities decreases significantly. When the local population has no reason to harm the environment and fully comprehends the importance of protecting it, they are less susceptible to being taken advantage of by invasive companies or external forces.

1.2 Problem Description and Analysis

Tropical wood has always been and still is a highly valuable product, which is why species used for wood harvesting are most often endangered with extinction. Often, trees that are being harvested are not replanted and since there are so many species, it is not that obvious when a species disappears from a forest. Indigenous people have suffered from discrimination since the time of colonization. They lack sufficient education and are often taken advantage of. The wood from ancestral trees generally has a high economic value, which leads to the logging of forests in unsustainable ways. Apart from the losses in forest cover and biodiversity of this process, cultural heritage is also threatened and there are few natural resources left for local communities or their children to generate income from. They then often turn to monoculture plantations, in this area mainly *Naranjilla* (*Solanum quitoense*), an orange fruit with a taste of citrus used for consumption. These plantations are often sprayed with pesticides, create no or not sufficient revenue, and cause degradation of the soils.

This is what also took place in the forests of Mushullakta, and they are now trying to reverse this. The project area for this research was a primary forest before, but when the big trees were logged, the current secondary forest and other land use types were left over. The project's main landscape type consists of relatively young forests where *Cecropia spp.*, a fast-growing pioneer species, is the most dominant species. The enrichment planting in these landscapes is performed by members of the community through the collection and germination of specific tree seeds from the old-growth forest that borders the community. The choice of trees is made in collaboration with a local botanist and restoration expert Omar Tello, an Ecuadorian landowner and former accountant, who dedicated 40 years to restoring a corner of the Amazon from cleared farmland back to pristine rainforest. The germinated seedlings are planted

within all parts of the family-owned lands and protected from dominant herbal vegetation taking over. Apart from planting and weeding around the planted trees, no further silvicultural treatments are done in the area. Examples of trees that are being planted are the endangered Mahogany/Caoba (*Swietenia macrophylla*) and Capirona (*Capirona decorticans*), trees that have high-value timber. High-value timber species possess exceptional wood quality and often have limited availability due to factors like rarity or restricted distribution. They play a significant role in supporting local economies, but because of this are nowadays often endangered with extinction. E.g., *Swietenia macrophylla* has a notable influence on the ecosystem due to its ecological characteristics and interactions with other organisms. As a large canopy tree, it provides important habitat and food resources for a diverse range of species, including birds, insects, and mammals. Furthermore, the species has been known to enhance soil fertility through nutrient cycling, contributing to the overall health and productivity of the ecosystem (Dinesha et al., 2020).

By restoring the forests and implementing sustainable agricultural practices, the project seeks to reverse degradation by reintroducing and protecting high-value timber species, like *Swietenia macrophylla*, and create a thriving ecosystem that supports diverse species while providing sustainable livelihoods for the local community. Yet, the success of the restoration efforts is not quantified.

1.3 Main Objectives

This study aims to fill this knowledge gap within this running restoration project by conducting a baseline study on biodiversity for the monitoring of development and improvement of biodiversity values in the area, ensuring that the purpose of increased biodiversity is effectively achieved. Secondly, using this study a community-based monitoring protocol for biodiversity was designed which the community can use for conducting this study in the other project areas and for the continued monitoring of the project areas in the years to come. This monitoring protocol was taught to the community while they were helping with the fieldwork, and the results and protocol will be communicated back to the community when completed. This protocol can be found in Appendix 7 – *Community-based monitoring protocol*.

The main objectives were to create more visibility of results from the restoration project for the community by which they can 1) get more investors onboard to increase financial investments flow into the community, 2) identify best working practices to improve their future forest management and improves sustainability and 3) give the community a way to actively participate in the restoration of their ancestral lands.

Sustainability means “*the ability to be maintained at a certain rate or level*”. The contribution of this project to sustainability is in two ways. The focus is to generate quantified results of the biodiversity levels, which can be used to protect the endangered ecosystem better and improve land use by optimizing organic food production and natural values. Secondly and perhaps most importantly; to develop the community’s capacity and training on how research takes place and thereby provide more tools to support their project governance and empowerment, improve their connection to the land and knowledge of how to protect it by learning how to systematically measure it.

The main research question was: How does biodiversity differ between forest/landscape types within the family-owned lands of the Mushullakta community? To help answer this question, the following sub-questions were formulated:

1. What is the difference in diversity in tree species in the different forest types within the project area?
2. What is the difference in vegetation structure, composition, and canopy cover between the forest types?
3. What is the diversity of soil macro-fauna families in the project area?
4. What is the diversity of vertebrates in the project area compared to that of the primary forest?

2. Theoretical Framework

In recent years conservation of biodiversity has been becoming of growing interest. Interest increased in the Western world especially when the Amazonian rainforest was threatened by fires and human influences and natural disasters became more frequent. The International Institute of sustainable development stated, “*Indigenous lands make up around 20% of the Earth’s territory, containing 80% of the world’s remaining biodiversity—a sign Indigenous Peoples are the most effective stewards of the environment.*” (Recio & Hestad, n.d.) Yet Indigenous people are still discriminated against or looked over.

Biodiversity values are next to their intrinsic value, important for sustaining balance within ecosystems and preserving ecosystem services that humans are dependent on. Services like clean water, clean air, and erosion prevention are just some examples of these services. Diminishing levels of biodiversity can threaten these services by cascade effects, where species that disappear can influence the rest of the food chain and consequently the abiotic characteristics of an ecosystem (Zhang et al., 2022).

Monitoring of biodiversity is often done by third-party organizations, but Danielsen et al. (2022) put forward a few arguments for letting local communities actively participate in the monitoring, such as low costs, a higher chance of continuity in monitoring time and enhancing local perceptions of engaging with the environment. In the same research, they point to shortcomings, such as the possibility of persecution of community members, probable lack of rigor, and large effort needed for development. They advocate for the development of community monitoring because the positive arguments outweigh the negative ones.

In a study by Sampaio Dos Reis and Benchimol (2023) on the effectiveness of community-based monitoring projects, a finding was that management actions were hampered by the lack of local participation, but that community-based monitoring projects would be more efficient and effective when local participants are involved in all stages of the restoration and monitoring.

The monitoring of vegetation is a very regular field of study, but most of the time the main objective is wood production. In the monitoring protocol by Viani et al. (2017) vegetation is used to measure canopy structure, tree and shrub species composition, and vegetation structure. There are many variables measured, such as basal area and species richness. Most of these variables are also answered in this project, except for most variables concerning soil e.g., chemical, and physical analysis of soil properties and soil compaction. These were not measured, because measuring these variables requires expert knowledge and a high monetary investment that is not available.

Soil macrofauna is an essential facet of the ecosystem. They are a food source for other fauna but also have been described as ‘facilitators’ and ‘regulators’ of interactions between other groups of organisms (Goss & Oliver, 2023). Goss & Oliver (2023) also state how they play important and sometimes critical roles in ecosystem nutrient cycles by decomposing plant material with the help of fungi and distributing this throughout the soil. The presence of certain species like worms and isopods, can be an indicator of soil health which in turn creates a healthy ecosystem. Soils help to regulate nutrients, water availability, stability, and decomposition (FAO, n.d.).

Drone imagery can be used to assess the canopy cover of the restored area and compare it with the canopy cover of a non-restored area. Holl et al. (2018) did research in Costa Rica to provide general rules of thumb on when it is necessary to invest resources in active restoration. Their result was that areas with a higher canopy cover recovered faster than those with a higher grass cover, which informs the decision-making process of which are the most cost-efficient forest-restoration practices to be applied at each specific intervention site.

When the correct trees are present and flowering and/or fruiting, this will in turn draw animals back to the area which will then complete the cycle of seed dispersal and decomposition. Vertebrates play their role within the ecosystem, one of the most important being seed dispersal (Severtsov, 2013). Each type of vertebrate has its preferable diet, and a high diversity of animals results in a high variety of seeds

being dispersed on different scales (Severtsov, 2013, p. 576). Birds eat fruits and then, through their excrements, drop 'seed bombs' sometimes kilometers from the mother tree. Other types of species like bats are necessary because they are the only possible pollinators for certain types of species (Tremlett et al., 2019) such as *Parkia multijuga*, a pioneer species cut for wood and now being planted by the community.

The monitoring of fauna is difficult because the research often needs a focus species or group of species. Camera trap monitoring is a widely used method for collecting data on terrestrial mammals, but depending on the placement of the cameras remains a method with a high error rate. Yet, a study done by Wearn and Glover-Kapfer (2019) states that camera traps are significantly more effective at detecting a large number of species (31% more). This shows that it is the most appropriate method for this study. Yet, birds, bats, and monkeys are of great importance for an ecosystem serving e.g., seed dispersal and pollination. These species, yet possible to find on camera traps, require a different methodology to be monitored adequately. Birds are often done by bird counts, which requires a high level of knowledge of bird species and time investment. Monkeys can be surveyed by using transect lines and personal observation (Rovero et al., 2015). Finally, bats can best be researched using acoustic recording the high frequencies of the sonar, that show the type of species and habitat use (Frick, 2013).

The enrichment planting done by Humans for Abundance is a more common method for improving both the number of trees and the number of tree species in an area. It can be described as the introduction of endangered species to forests without impeding the growth of the trees already present (Forest Restoration Research Unit, 2008). Saplings are planted within the existing forest to increase species richness. Next to that, regenerative agriculture is gaining momentum in a lot of countries, for the higher value in terms of sustainability, both financially and for natural values. There are different forms of regenerative agriculture, such as permaculture, agroforestry, and the relatively new concept of food forests. Seeing that the Amazon always used to be a food forest for the indigenous communities, this is something not so new for the neo-tropics. The biggest problem is how most of these techniques have been lost to time. Regenerative Agriculture can improve soil health, sequester carbon, and increase biodiversity (Newton et al., 2020).

3. Methodology

This chapter describes the steps that have been taken to answer the research questions. It starts with a general overview of how time was spent, after which each methodology for answering the sub-questions is briefly discussed and explained. What was outside the scope of this study are the planting techniques, carbon storage, wood production, and scientific botanical research.

3.1 Sequence of Steps

Figure 2 shows an overview of the study timeline. General desk-study background research was done in January and February, on which the project plan was based. When this was finished the fieldwork took place during the months of March and April. The final analysis was done during the month of May and based on the outcomes of this study conclusions, recommendations, and a protocol were made.

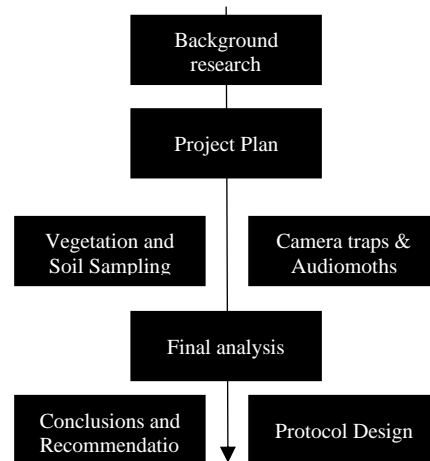


Figure 2 - Project Timeline

3.2 Vegetation plots

To answer the sub-question on vegetation, it was needed to know a) information on the number of species of trees and b) information on vegetation structure. The variables that were measured for this were 1) the number of species, Diameter at Breast Height (DBH), and tree height. The types of vegetation that were studied are the ones present on the family-owned lands. The project area was divided into strata based on the type of forest type/land use. These strata were decided upon by walking through the area and checking whether the earlier made planting zones in ArcGIS Field Maps by Terraformation, the assisting organization within the tree planting project, were accurate. The diversity indices used in data analysis are the Shannon Wiener Index (H') and the Simpson's Diversity Index (D). Furthermore, the trees were assessed using the *Importance Value Index*. See paragraph 5.5 for the description of the indices and metrics used.

Tree species diversity was measured by the use of plots in the project area. The size of the area and the structural evenness influence the number of plots necessary, but generally the more plots the better. The aim is to measure about 10 percent of the area for a reliable result (Bullen & Bullen, 2022), but when the area is very homogenous, fewer plots can suffice. The plots that were used are 25x25m (Figure 3), thus cover an area of 625 square meters. For this project, the starting point was one plot for every area under one hectare, if an area was more than one hectare a plot was added, and a plot for every hectare. This means for an area of 7 hectares, 7 plots were measured. When the structural evenness of an area appeared different in the field, more plots were added to get a representable view of the area.

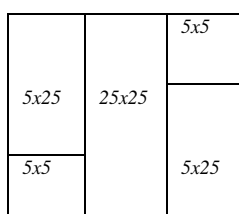


Figure 3 - Plot Design

Plot Design

Using plots of 25x25m in each forest type, data on species present has been collected in three groups: regenerating woody vegetation with a *Diameter at Breast Height* (DBH) of <10cm (when saplings/trees were >2m in height), trees DBH >10cm and trees DBH >30cm. Within the plots, shrubs, and trees with a diameter at breast height (DBH) of <10 cm have been recorded in two plots of 5x5, giving a plot size of 25 m² two times. This was only one when a tree or sapling was higher than 2 meters and DBH >2cm. Trees with DBH >10 cm have been measured in two plots of 5x25m, giving two plots with a size of 125 m² for trees in this size range. Trees with DBH > 30 cm have been measured in

a plot 25x25m giving a plot size of 625 m² for larger trees. All individuals within the plot were measured. The map in Appendix 1 shows the location of the plots within the project area. The plots

were placed randomly throughout the areas, permanently to ensure that monitoring will occur in the exact locations each time. The plots have been marked with nylon cords and GPS locations have been saved using ArcGIS Field maps.

The selection of this plot type was based on the dense nature of the project area, its simplicity in teaching the community, and its low margin of error. This method ensures reliable results as the number of plots is determined in the field based on the observed variation in the data. E.g., in the case of the secondary forests where half of the species found were previously unobserved, seven plots were used to assess tree species diversity, covering 6% of the total area and a standard error of 1.29. This is considering the mean species number of 22 acceptable.

Plot location was decided by using the map with forest types for the project area and, according to the size of each forest type, plots were divided to cover the entire area as representable as possible. The location of the plots depended also on differences in landform or limiting vegetation.

3.3 Drone

Next to the plots, a DJI Mini SE drone was used for acquiring images through programmed, controlled flight missions. The images were later converted into orthomosaics for the assessment of canopy cover and tree count in the project area. This data gives insight into most importantly canopy cover, but can furthermore give insight into tree density, tree-size distribution, and structural diversity. Yearly drone flight would be optimal for monitoring the changes in these variables. Yet, this is still in development and cannot yet be applied to this project. If the orthomosaics are saved, they could be used as baseline material and data that could contribute to developing the drone-based analytical approach at later stages.

For the drone the steps that were taken are 1) designing a mission in Litchi, 2) flying the mission and 3) creating the orthomosaic. The drone is part of the monitoring kit from Restor and the guide is inspired by the guide draft made by the team that developed the ecological-monitoring pilot project within the organization.

The first step was done using a polygon of the project area and with help of an expert designing the mission in Litchi. After the missions were complete, they were run, and the pictures collected were converted into an orthomosaic. This project followed a draft guide made by the team that developed the ecological-monitoring pilot project within Restor.

Materials used:	DBH measuring tape, flagging tape, measuring tape for setting out plots, field forms, phone with GPS and compass, binoculars, computer with Excel and a DJI Mini SE drone.
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3.4 Soil

Soil, an important indicator for biodiversity and the health of an ecosystem, will be sampled through macrofauna. Generally, soil macrofauna research is a topic that requires expert knowledge, laboratory equipment and a large timeframe for results to return. All of these are not preferable for the objective of this study, and because of this, a new and so far, untested methodology was designed in collaboration with a soil and macro-fauna expert. The focus was on biodiversity in the soil, but since the protocol needs to be simple enough to be applied by the community, the method remained small and simple. It did not result in a thorough analysis of the soil, but it created an image of the soil health in terms of the most important families. To answer the sub question on soil, data that was needed was a) information on the number of indicator families present and b) information meaning of these families for the state of the soil.

Sample Design

2 soil samples of ca. 20x20x20 cm were extracted from the two sub plots (5x5) in each plot and examined in the field by placing the sample on a sheet of white plastic. The sample was examined, and all insects found in the soil sample were identified towards families of macrofauna (Table 1). Taxonomic family identification was done using pictures from the JRC Global Soil Biology atlas (Centre, 2016). An overview of the mentioned families can be found in Appendix 3. *Soil Macro-Fauna Families.*

FAMILIES

Formicidae

Termites

Myriapoda

Earthworms

Coleoptera

Isopoda

Soil insect larvae

Table 1 - Macro Fauna Families

This was a heuristic model for the assessment of soil health because it is reliant on 1) the ability to apply by the community members, 2) the chance of what would be found in the small number of samples and 3) how the results can inform about soil quality. Data collected from soil research was in the form of “yes” or “no” for the presence of a certain family and stored in databases in Excel, which were then used to create a soil score between 0-8 (average of number of “yes”) and comparing this score between the strata. The higher the number, the higher the family richness in the soil and thus the healthier the soil. This method is easy to apply and gives insight into soil biodiversity, soil characteristics, and an idea on use of pesticides if otherwise expected groups of macro-fauna are missing.

Importance of mentioned families for ecosystems according to the JRC Global Soil Biology atlas (Centre, 2016):

Formicidae (Ants):

Ants belonging to the family Formicidae play a crucial role in the ecosystem. They are known for their highly organized social structures and impressive collective behavior. Ants contribute to soil aeration and nutrient cycling through their burrowing activities. They help in dispersing seeds, thus facilitating plant regeneration and biodiversity. Some ant species act as effective predators, regulating populations of other insects. Their foraging behavior also aids in the decomposition of organic matter, further enhancing nutrient availability in the soil.

Termites:

Termites, often considered ecosystem engineers, play a vital role in various ecosystems, particularly those with high wood decomposition rates. Termites are efficient decomposers of plant material, including dead wood and plant litter. Their digestive capabilities allow them to break down complex carbohydrates, releasing essential nutrients back into the ecosystem. Termites also contribute to soil formation and fertility by creating extensive underground tunnel networks, promoting soil aeration and water infiltration. Furthermore, termite mounds serve as microhabitats for other organisms and enhance local biodiversity.

Myriapoda (Millipedes and Centipedes):

Myriapods have important ecological roles in terrestrial ecosystems. Millipedes primarily feed on decaying organic matter, including leaf litter, contributing to the decomposition process and nutrient cycling. Their feeding activities enhance soil fertility by breaking down complex organic compounds. Additionally, millipedes act as prey for various vertebrates and invertebrates, thus forming an essential link in the food web. Centipedes are predatory arthropods, preying on insects, spiders, and other small invertebrates. They help regulate the populations of these organisms, contributing to pest control and maintaining ecological balance.

Earthworms:

Earthworms are recognized as key soil organisms with significant influences on ecosystem functioning. They play a fundamental role in soil structure formation through their burrowing activities, which improve soil aeration, water infiltration, and nutrient distribution. Earthworms facilitate organic matter decomposition by consuming and breaking down plant material, enhancing nutrient availability in the soil. Their casts, excreted as waste, are rich in nutrients and promote soil fertility. Moreover, earthworms increase microbial activity in the soil and aid in the formation of stable aggregates, which reduces erosion and enhances soil stability.

Coleoptera (Beetles):

Beetles, the largest order of insects, play various roles in ecosystems depending on their diet and habitat preferences. Many beetle species are important pollinators, aiding in the reproduction of flowering plants. Some beetles act as decomposers, consuming dead organic matter and contributing to nutrient recycling. Others are predatory, regulating populations of other insects. Beetles also serve as a valuable food source for many vertebrates, playing a crucial role in energy transfer through the food chain.

Isopoda:

Isopods are small terrestrial crustaceans that inhabit diverse ecosystems. Isopods primarily feed on decaying organic matter, playing a vital role in the decomposition process. They help break down dead plant material and accelerate nutrient cycling in the soil. They furthermore contribute to soil structure formation by fragmenting and mixing organic matter, promoting soil aeration and moisture retention. Paoletti and Hassall (1999) state that Isopods tend to be more abundant in semi-natural grasslands than woodlands, but woodlands are higher than cultivated areas. Isopods are also thought to be some of the first to disappear when pesticides, but also herbicides are used, as they reduce the availability of high-quality food from leaf litter of dicotyledonous plants, which constitute the majority of weeds.

Soil Insect Larvae

The vast majority of insects, up to 95 % in fact, are linked to the soil during their life cycle. Some lay eggs in the soil or use it as a substrate for overwintering. Due to very specific features of the soil as a habitat, insect larvae have made numerous adaptations to live in this environment. When these features are changed due to changes in the ecosystem like the use of pesticides or herbicides, it could potentially intervene with the ability of these insects to reproduce.

Materials used:	Shovel, sheet of white plastic for examination of soil sample and JRC Global Soil Biology atlas
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3.5 Fauna

To answer the sub-question on fauna, it was needed to know a) information on number of species and individuals of vertebrates and b) information on their influence on the ecosystem. Fauna data collection was performed by using nine camera traps and three AudioMoths (*AudioMoth*, n.d.). Camera traps are cameras that respond to movement and start recording when motion is detected. AudioMoths are microphones that are placed in the forest and record the soundscape of the area.

AudioMoth:

- Records in standard UTC time and 48 kHz sample rate, for 60 seconds and sleeps for 240 seconds throughout a 24-hours recording period.
- Placed at a height that is above 1.5 meters and ensured that it is not cluttered by vegetation, which would reduce the sound the recorder can capture.

The cameras and AudioMoths were placed in the project area and in a neighboring finca where there is a primary forest present to compare fauna between primary and disturbed forest. Both were family-owned land, included in the restoration project, and at a similar distance from the community, yet the road was nearer to the patch of primary forest. The cameras were set up randomly at locations where there were known faunal passes in areas that were the most representative of the entire research area. They were placed 50 cm above the ground on animal trails or areas where they were expected to be seen and GPS locations of the plots were collected right after placing the cameras. The cameras were set up to record videos when animals passed by and remained installed in the field for 21 days. The collected data was received every week. The three AudioMoths were rotated between the nine cameras, yet due to a technical error with one of the AudioMoths placed in the project area, the SD card was unreadable and as such unusable.

After the data collection, the camera trap footage was analyzed manually since the AI products like Agouti by Wageningen UR and others are not yet up to date with Neo-Tropical species. AudioMoth data was analyzed using a predesigned code (Ronga, 2022) run in the coding language Python which delivers several biodiversity indices from the collected audio files. The indices that were generated are Acoustic Complexity Index, Acoustic Diversity Index, Bioacoustic Index, Acoustic Evenness Index, Temporal Entropy, and Normalized Difference Soundscape Index. The next paragraph describes all indices used.

Materials used:	Camera traps & AudioMoths
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3.6 Description of indices and metrics used

Indices and metrics used for vegetation and camera trap analysis:

- **The Shannon Wiener (H') index** considers both the number of species and their distribution within the area but puts more importance on species richness and less on abundant species. Because of this, it is very sensitive to small changes in diversity. The value has a minimum of 0, which would mean that there is just one species present, and no maximum. However, in practice, there are rarely values above 4. H'_{max} is the value when all species would be equally present (*Shannon Diversity Index*, n.d.).
- **Simpson's Diversity Index (D)** takes into account the number of species present and the relative abundance of each species (Simpson's Diversity Index, n.d.). Compared to the Shannon Wiener index, Simpson's Diversity Index puts more focus on dominant species and is as such not as affected by less abundant species. The value ranges from 0 to 1, with 0 meaning no diversity and 1 meaning infinite diversity (*Simpson's Diversity Index*, n.d.).

- **Species richness** is the number of unique species per forest type.
- **The Importance Value Index (IVI)** represents the importance and relative abundance of each plant species within the sampled vegetation. A higher IVI value indicates that the species has a greater overall contribution to the ecosystem in terms of frequency, density, and dominance. The IVI can aid in identifying endangered species, assessing ecological interactions, and monitoring changes in vegetation over time. (Curtis and McIntosh, 1950)

Indices from AudioMoths (Ronga, 2022):

- **Acoustic Complexity Index (ACI)**
Based on the difference in intensity (I and I_{next}) for each frequency bin, relative to the total amplitude/intensity within that band. It assumes the differences in intensity that occur in biogenic sound and anthropogenic sound to have constant intensity. Looks only at the biophony, ignoring the anthrophony. This is because it assumes that differences in intensity (within the same frequency bin) occur in the biophony, whereas anthropogenic sound remains constant in intensity.
From my experimentation: the ACI does a good job at detecting the biophony vs geophony or anthropological sounds. 429 was the highest ACI, looking at birds chirping. 290-300 had more geophony and anthrophony.
- **Acoustic Diversity Index (ADI)**
Checks the proportion of frequency bands (representing a specific species) that exists, and then calculates the Shannon index. Close to 3.00, there is constant insect noise with not much aviatory sound. In the 2.00 or high 1.00, more birds can be heard.
- **Bioacoustic Index (BI)**
The Bioacoustic Index (BI) selects the frequency range used by most birds and computes the total signal energy in this range. The BI was used to estimate bird abundance and compare it with the vegetation structure. The BI is calculated by applying the fast-Fourier transform (FFT) to the audio signal. Then, the area of the FFT between 2-8 kHz is obtained as the value of BI.
The range is 130 (bird chirping) and 22 (no birds heard).
- **Acoustic Evenness Index (AEI)**
Higher values indicate greater unevenness among frequency bands when there is a greater sound intensity in a restricted range of frequencies. Values go from 1 \rightarrow 0. Acoustically rich habitats may produce low values because there is little variation in intensity among frequency bands in saturated soundscapes.
- **Temporal Entropy (TE)**
The entropy of an audio signal is a measure of energy dispersion. In the temporal domain, values below 0.7 indicate a brief concentration of energy (few milliseconds), while values close to 1 indicate a low concentration of energy, no peaks, and smooth and constant background noise. This is a good measure of insect activity. The higher the value, the more even the signal, which is a good indicator of insects or geophony. The lower the value, the greater change in frequencies over time, therefore birds chirping. Values go from 0.99 to 0.77.
- **Normalized Difference Soundscape Index (NDSI)**
Relies on a theoretical frequency split between anthrophony (1–2 kHz) and biophony (2–11 kHz). The ratio of the two components gives values of -1 to $+1$, with $+1$ indicating no anthrophony in the soundscape.

4. Results

This chapter describes the results of the different parts of the field methodology described in the previous chapter, starting with the stratification of forest types within the project area and the data on vegetation, forest cover, and forest structure, followed by the results of the soil samples and finally the results of the fauna methodology.

4.1 Stratification of land use types in the project area

Table 2 describes the stratification of the different forest types within the project area.

	Type	Description	Area (m ²)	Nº Plots
1	Actively restored* Monoculture	Used to be a monoculture of Chuncho (<i>Cedrelinga cateniformis</i>) for wood production. The area was restored into permaculture with Chicken and Platanos, Guineo, Laurel.	9.879	2
2	Polyculture	Polyculture with Coffee, Chuncho, Guineo, Guadua, Citrus. Everything in the area is meant for food or wood production.	28.693	4
3	Ilex guayusa plantation	Monoculture plantation of <i>Ilex guayusa</i> . Some places have other species planted or trees left, but this is minimal. Barely undergrowth.	6.096	1
4	Secondary forest	25-30 years old secondary forest that has been planted in in the last 2-5 years. This area used to be primary forest before big trees were cut for wood.	75.877	7
6	Young regrowth actively restored*	Small part that has been actively reforested from bare ground by tree planting and is now about 4-5 years old.	8.568	1
Total Area =			129.113	14

Table 2 - Stratification of Forest Types

*Being actively restored means enrichment planting and/or regenerative agricultural practices are taking place.

4.2 Vegetation

An overview of the data collected from the vegetation plots can be seen in Table 2. The total number of species recorded is 120 and the average in the plots is 17.29, with a standard deviation of 6.39 and a standard error of 1.71.

The highest species diversity (Figure 5) and size of trees was found within the secondary forests, followed by the polyculture fields. The average number of species per plot per forest type can be seen in Figure 4. The complete species list can be found in Appendix 2 – *List of tree species*. Finally, figures 5 & 6 show Shannon Wiener and Simpson's diversity indices for the different forest types.

	TYPE	PLOT Nº	% OF LAND COVER BY SAMPLES	SPECIES RICHNESS	H'	H'max	D	AVERAGE DBH (CM)	AVERAGE HEIGHT (M)
1	Actively restored* monoculture	6.14	13%	20	2.43	3.00	0.87	16.49	7.47
2	Polyculture	4.7,10.11	9%	42	3.23	3.74	0.95	7.67	3.70
3	Ilex guayusa plantation	5	10%	10	0.64	2.30	0.24	10.74	6.72
4	Secondary forest	1.2,3.9,12.13	6%	111	3.93	4.71	0.97	21.26	11.84
5	Young regrowth actively restored*	8	7%	17	2.63	2.83	0.94	12.00	6.14
	Total Area		7%	12	4.14	4.80	0.97	13.63	7.17

Table 3 - Results Vegetation plots

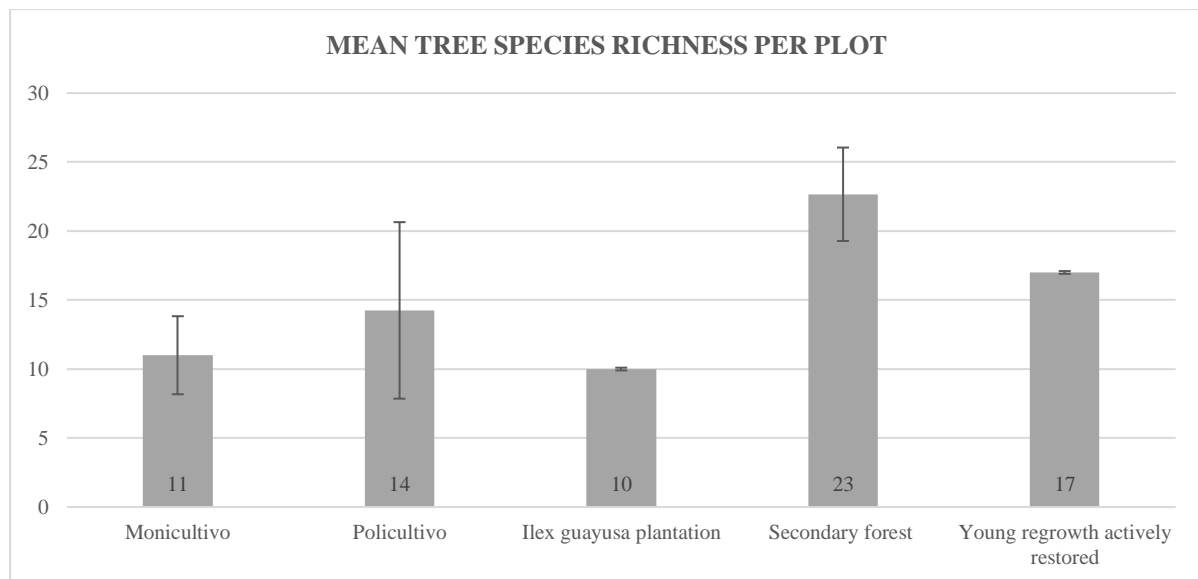


Figure 4 - Mean species richness per plot

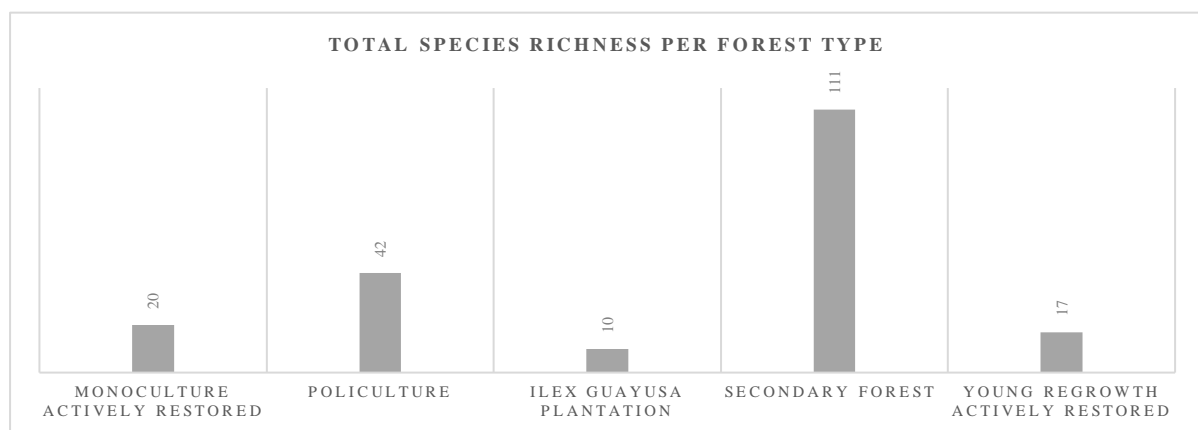


Figure 5 - Total species richness per forest type

Comparing the value when all species found would be equally present (H'_{max}) with the actual value (H') next to it in Figure 6, H'_{max} for the secondary forest is very high with 4.71, but the actual H' shows to be below 4. All types seem to be in the direction of H'_{max} , except for the *Ilex guayusa* plantation. Simpson's diversity index shows something similar. With all values being close to one, there is generally a high richness and evenness.

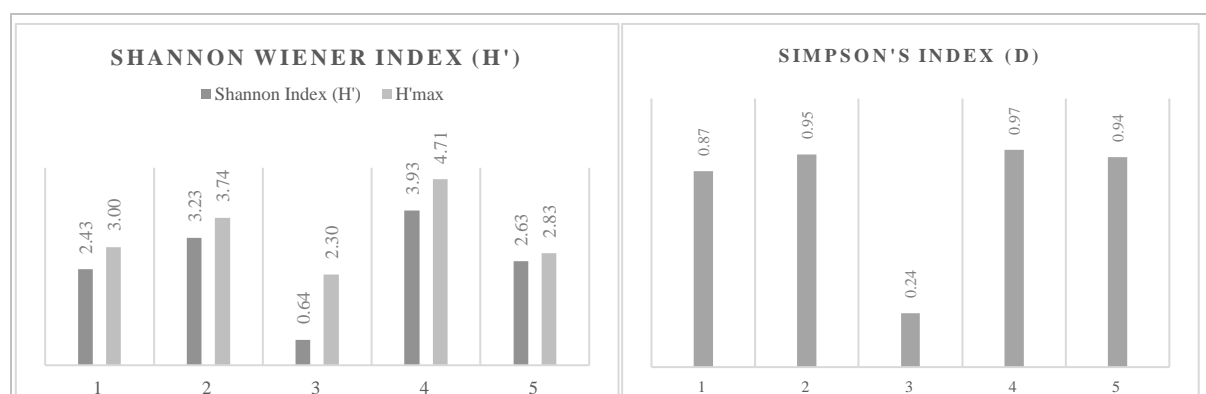


Figure 5 - Shannon Wiener Diversity Index Vegetation

Figure 6 - Simpson's Diversity Index Vegetation

1. Monoculture, 2. Policulture, 3. Ilex Guayusa Plantation, 4. Secondary Forest, 5. Young Regrowth

For the state of the project area, the diversity indices for tree species were to be expected, with the secondary forest having the highest species richness and polyculture following due to the high variance in species of bigger trees when compared to the young regrowth. With one plot in the young regrowth area, it has a surprisingly high diversity index of $H'=2.63/D=0,9$.

Importance Value Index

Table 4 shows that *Cecropia* sp. has the highest IVI value of 22.09 and is with that the most abundant species in the project area. *Ilex guayusa* follows with an IVI value of 8.88 and is not as dominant as *Cecropia* sp..

	COMMON NAME	SCIENTIFIC NAME	FAMILY	IVI
13	Buwa, Huarumo	<i>Cecropia</i> sp.	URTICACEAE	22.09
57	Guayusa	<i>Ilex guayusa</i>	AQUIFOLIACEAE	8.88
54	Huarumo	<i>Cecropia peltata</i>	URTICACEAE	4.86
95	Pukapanga Paitzi	<i>Miconia calvescens</i>	MELASTOMATACEAE	4.81
37	Chuncho	<i>Cedrelinga cateniformis</i>	FABACEAE	4.02
55	Guave / Pacay	<i>Inga feuillei</i>	FABACEAE	3.21
14	Cachik, Kachij	<i>Inga</i> sp.	FABACEAE	3.16
86	Paitzi	<i>Miconia</i> sp.	MELASTOMATACEAE	2.84
23	Carahuasca	<i>Guatteria hyposericea</i>	ANNONACEAE	2.77
69	Linchik	<i>Vernonia baccharoides</i>	ASTERACEAE	2.76

Table 4 - Importance Value Index

On the other hand, species with lower IVI values, such as *Vernonia baccharoides* (2.76) and *Guatteria hyposericea* (2.77), have comparatively lesser ecological importance and abundance within the sampled vegetation. These are the ten highest values; values for other trees can be found in the tree list in Appendix 5 - *List of Tree species*.

The difference in forest composition between the forest types is mainly in the use of the tree, having mostly wood-producing species in the secondary forests, the young regrowth area, and the *Ilex guayusa* plantation and a combination of trees for wood and food production in the mono- and polyculture areas.

4.3 Soil

None of the areas had all species present and isopods have not been found in any soil sample in the project area except for one sample within secondary forest. Figure 7 shows the average number of families found in each forest type and the corresponding standard deviation.

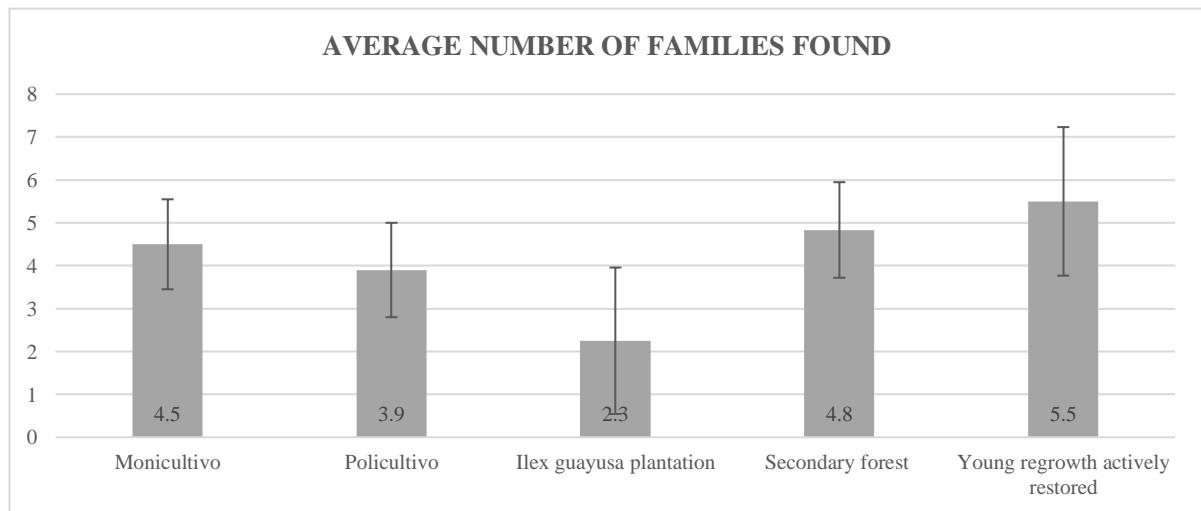


Figure 7 - Average number of Soil Macro-Fauna families

4.4 Forest Cover and Structure

Forest cover and structure was assessed with data on DBH and drone imagery. First the basal area is described, after which the results of the drone imagery is described.

4.4.1 Basal Area

Basal area, the total area occupied by tree stems per hectare, was calculated for all forest types (Figure 8). The numbers were derived from the collected DBH for all forest types, respective to the area covered and the number of sample plots used. The Ilex guayusa plantation shows to have by far the highest basal area, which can be explained by the high number of trees around 10 cm DBH. It is followed by the Secondary Forest, where there are predominantly bigger trees, as well as dense undergrowth vegetation lowering the average DBH. The young regrowth and restored Chuncho (*Cedrelinga cateniformis*) plantation as a coffee agroforestry system had similar DBH values, whereas the Polyculture had the lowest basal area, which is due to the high number of small trees for food production (e.g., *Citrus spp.*, *Coffea arabica*).

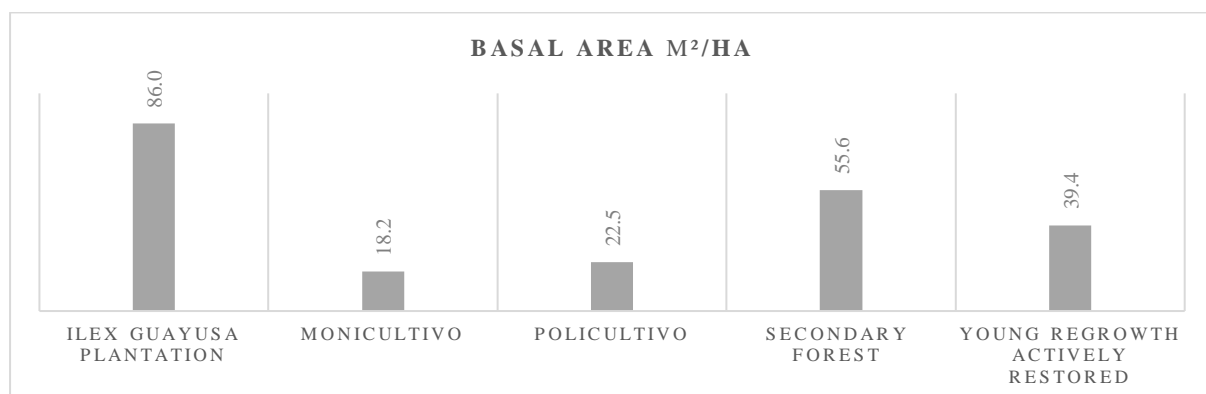


Figure 8 - Basal area of woody vegetation with DBH > 2 per forest type

6.4.2 Drone Imagery

Figure 9 shows the orthomosaic that has been generated from drone imagery of the project area.



Figure 9 - Orthomosaic Project Area

Factors that already can be seen in the orthomosaic in Figure 9 are the distance from the village (southeast), the abundance of *Cecropia ssp.* trees, the *Ilex guayusa* plantation in the southwest, and a bigger canopy gap in the northwest. Comparing this picture with the forest types in Appendix 3 - *Orthomosaic and Forest types*, it becomes visible that the route taken by the drone is missing a part of the area. Yet, it does provide a general idea of the forest cover of the project area. The area that is missing is a part of the polyculture area and a part of the *Ilex guayusa* plantation.

Furthermore, the orthomosaic can be used to assess canopy cover. The image in Figure 10 shows the canopy cover of the project area.

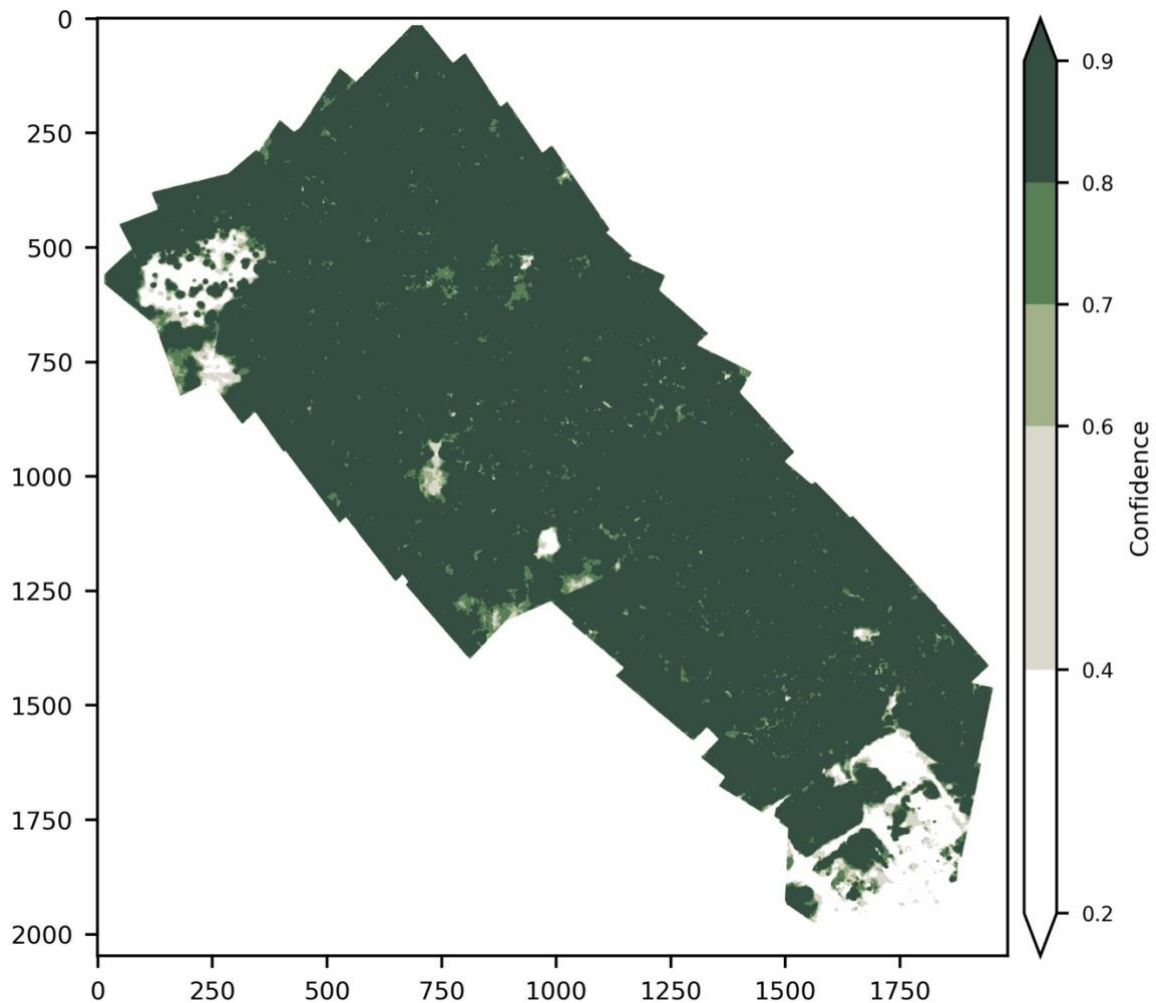


Figure 10 - Canopy Mask

In the future, this orthomosaic can be used to assess whether canopy cover is maintained or even increases. The goal for the future is to assess multiple facets of biodiversity monitoring done manually in this study using AI technology, however it is important to acknowledge that technology has not yet reached that stage. For the time of this project report, it was not possible to quantify canopy cover using the intended tree-detection model developed by Restor, which will likely be possible to be achieved when the model becomes available for public use in the future.

4.5 Fauna

From the six camera traps in the main research area, 33 different species of vertebrates were found (Table 6). Of these species, 2 are left unidentified due to poor video quality, 2 individual bats, 8 birds and 4 individuals of *Muridae* (a family within rodents) which could be different species.

The camera traps were placed on a rough line through the entire project area and can thus not be compared between the forest types. Most were placed within the secondary forest since this is the largest area and had the clearest signs of animal trails and passes. Table 5 shows the general information on the placement of the camera traps and AudioMoths. A map showing the location of the camera traps is placed in Appendix 4 - *Locations of Camera Traps*.

Nº	Type of vegetation	Location	Age	AudioMoth h	Camera	Start date Camera	Start date Audiomoth h	Location	End date
1	Secondary forest	25 y/o forest, naturally regenerated/ non-restored	25-30	c10	CM-35	09/03/2023	09/03/2023	-0.794255, -77.589248	30/03/2023
2	Young regrowth actively restored*	natural regeneration (25-30 years) with planted 4 y/o	25-30	c4	CM-30	09/03/2023	09/03/2023	-0.791526, -77.590436	30/03/2023
3	Secondary forest	Naturally regenerated 25-30 years, Planted 4 years	25-30	c10	CM-32	09/03/2023	17/03/2023	-0.792764, -77.588922	30/03/2023
4	Actively restored* monoculture	former chakra / cacao blanco mother tree (25-30 years)	25-30	c4	CM-34	09/03/2023	17/03/2023	-0.793726, -77.587806	30/03/2023
5	Secondary forest	bosque secundario, sapote viejo 25-30 years	25-30	No	CM-28	09/03/2023		-0.793749, -77.588271	30/03/2023
6	Actively restored* monoculture	Chunchu acerca 10 años sembrada	10	No	CM-21	09/03/2023		-0.794392, -77.587345	30/03/2023
7	Primary forest	100 m from river	old	c20	CM-33	09/03/2023	09/03/2023	-0.803675, -77.572588	30/03/2023
8	Primary forest	Cuero de sapo y Chichi morán	old	c20	CM-31	09/03/2023	16/03/2023	-0.802681, -77.573318	30/03/2023
9	Primary forest	Close to main trail	old	no	CM-36	09/03/2023		-0.801764, -77.574323	30/03/2023

Table 5 - General information on placement of camera traps and AudioMoth

Results from camera traps in the project area

	Kichwa / English name	Scientific name	Family	Class	Nº
1	Unknown bird species	-	-	Aves	24
2	Wanta	Cuniculus paca	Dasyproctidae	Mammalia	4
3	Guatusa	Dasyprocta punctata	Dasyproctidae	Mammalia	24
4	Armadillo	Dasypus pastasae	Dasyproctidae	Mammalia	7
5	Chanchu, Sachino	Dicotyles tajacu	Tayassuidae	Mammalia	1
6	Bat species	-	Chiroptera spp.	Mammalia	2
7	Tayra, Cabeza de Mate	Eira barbara	Mustelidae	Mammalia	1
8	Chichichu	Leontocebus nigricollis	Callitrichidae	Mammalia	1
9	Ocelot, Tigrillo	Leopardus pardalis	Felidae	Mammalia	1
10	White-bellied Slender Opossum, Ratón	Marmosops noctivagus	Didelphidae	Mammalia	4

11	Venado	Mazama americana	Cervidae	Mammalia	3
12	Rodent species	-	Muridae	Mammalia	5
13	Black-faced Antbird	Myrmoborus myotherinus	Thamnophilidae	Aves	6
14	Cuchuchu	Nasua sp.	Procyonidae	Mammalia	6
15	Raposa	Philander andersoni	Didelphidae	Mammalia	6
16	Churupoema	Procyon cancrivorus	Procyonidae	Mammalia	6
17	Southern Tamandua / Collared Anteater	Tamandua tetradactyla	Myrmecophagidae	Mammalia	1
18	Irunsa	Marmosops bishopi	Didelphidae	Mammalia	1
19	Hummingbirds	-	Trochilidae	Aves	3
Total number of individuals					106

Table 6 - Results camera traps in the project area

The highest number of recorded individuals were *Guatusa* or Central American Agouti (*Dasyprocta punctata*). This is not surprising, as it is a very common animal but a very important seed disperser. Lesser common animals are the Ocelot (*Leopardus pardalis*), Southern Tamandua or Collared Anteater (*Tamandua tetradactyla*), Cabeza de Mate or Tayra (*Eira Barbara*), *Chichichu* or Black-mantled Tamarin (*Leontocebus nigricollis*) and *Chanchu* or White-collared peccary (*Dicotyles tajacu*). The impact of these species of the interest on the ecosystem is shortly described below.

Ocelot (*Leopardus pardalis*)

Conservation status: Least Concern - Decreasing
Ocelots require a dense vegetative cover and have a high impact on their environment as hunters. They are opportunistic hunters and prey upon many types of animals, whereof mostly terrestrial vertebrates (ADW: *Leopardus pardalis*, n.d.).

Black-mantled Tamarin or Chichichu (*Leontocebus nigricollis*)

Conservation status: Least Concern - Decreasing
Tamarins are omnivores and so their roles in an ecosystem are as predators of insects and other invertebrates, as prey animals for other predators and seed dispersers for the trees of which they eat the fruits (ADW: *Saguinus nigricollis*, n.d.).

Cabeza de Mate / Tayra (*Eira Barbara*)

Conservation status: Least Concern - Decreasing
The Tayra is both a terrestrial and arboreal omnivore, influencing the ecosystem greatly by hunting mammals, invertebrates, and reptiles. They also consume fruit, with which they assist in seed dispersal (ADW: *Eira Barbara*, n.d.).

Chanchu / White-collared peccary (*Dicotyles tajacu*)

Conservation status: Least Concern
Peccaries are primarily frugivorous, consume fruits from over 128 species and seeds from 79 species and thus act as seed dispersers for native plants. They also play an important role as food source for predators and create and maintain water and mud wallows, which benefit other species (ADW: *Pecari tajacu*, n.d.).

Southern Tamandua / Collared Anteater (*Tamandua tetradactyla*)

Conservation status: Least Concern - unknown
They are listed as CITES Appendix II, and their population trend is unknown to the IUCN Red List. While widely spread, uncommon to encounter. They are hunted for the thick tendons in their tails which are used to make rope and by hunters claiming they kill dogs. Habitat differs from wet to dry forests but seem to be most common in habitats near streams and rivers (ADW: *Tamandua tetradactyla*, n.d.).

Tamanduas are signal species in terms that their presence indicates the presence of a high diversity of insects. They also influence soil quality positively by surfacing clay minerals to build their nests (Burley et al., 2004).

Then there were three camera traps placed in a different area close to the project area, of which the data is shown in Table 7. The reason for placing cameras here was to collect data on vertebrates present in primary forests in the area since these animals could be expected in the project area in a later stage of forest succession. The camera traps captured data revealing a predominant presence of birds and small mammals in the area, with the exception of a few deer. Furthermore, the high value recorded for Armadillo is believed to be indicative of a potential nesting site near the camera trap.

	Kichwa / English name	Scientific name	Family	Class	Nº
1	Ardilla de cola roja	Syntheosciurus granatensis	Sciuridae	Mammalia	3
2	Armadillo	Dasypus pastasae	Dasyproctidae	Mammalia	14
3	Cucarachero pechiblanco	Henicorhina leucosticta	Troglodytidae	Aves	2
4	Pajaro	-	-	Aves	10
5	Raposa	Metachirus myosuros	Didelphidae	Mammalia	4
6	Raposa	Philander andersoni	Didelphidae	Mammalia	4
7	Raposa	Philander sp.	Didelphidae	Mammalia	1
8	Ratón	-	Muridae	Mammalia	15
9	Tordo	Dives sp.	Icteridae	Aves	2
10	Undulated Antshrike	Frederickena unduliger	Thamnophilidae	Aves	1
11	Venado	Mazama americana	Cervidae	Mammalia	5
12	Wanta	Cuniculus paca	Dasyproctidae	Mammalia	7
13	Guatusa	Dasyprocta punctata	Dasyproctidae	Mammalia	13
14	White-bellied Slender Opossum	Marmosops noctivagus	Didelphidae	Aves	1
Total number of individuals					82

Table 7 - Results camera traps Primary Forest

Table 8 shows the Shannon Wiener Biodiversity Index (H') and Simpson's Diversity Index (D) for both areas. The main study area had an overall high diversity of animals with a Shannon Index result of 1.99, but Tirira et al. (2020) found a value of $H'=3.73$ in the same region. Simpson's diversity index has a value of $D=0.88$, whereas Tirira et al. have a value of $D=0.96$ in the same region. Primary forest has an equal Simpson's Index as the study area, but a lower H' , which suggests species richness is lower in the primary forest. The values for Aves were included to use data that was available but note that these data are not accurate, and focus lies on mammals.

	MAIN STUDY AREA	PRIMARY FOREST
MAMMALIA	$H'= 1.99$ $D= 0.88$	$H'= 1.72$ $D= 0.88$
AVES	$H'= 0.82$ $D= 0.81$	$H'= 0.35$ $D= 0.65$

Table 8 - Diversity indices fauna

6.3.2 AudioMoths

The results from the AudioMoths were scarce since there were multiple technical errors, rendering one of the SD cards unreadable. However, it did provide data that allowed for a comparison between the project area and the primary forest. The code in Python was run and resulted in the indices shown in Table 9. The values for ACI, ADI and BI are a lot larger than expected and thus cannot be interpreted. The values for AEI, TE and NDSI are described below. Figure 11 shows the same values in a graph.

	ACI	ADI	BI	AEI	TE	NDSI
PROJECT AREA	1.39E+16	1.71E+16	1.38E+16	0.21	0.93	0.91
PRIMARY FOREST	1.40E+16	1.74E+16	1.68E+16	0.09	0.97	0.74

Table 9 - Acoustic Biodiversity Indices

- Acoustic Evenness Index (AEI)**

The AEI shows that the primary forest is an acoustically more even and richer habitat than the project area. 0.21 for the project area indicates moderate unevenness and 0.09 for the primary forest indicates high evenness.

- Temporal Entropy (TE)**

The higher the TE value, the more evenly distributed the energy in the signal, suggesting a greater presence of insects or geophonic sounds. Lower TE values indicate more changes in frequencies over time, indicating bird chirping or other similar phenomena. The values for the two forest types are rather similar with 0.93 for the project area and 0.97 for the primary forest, which proves the primary forest to have a slightly higher insect activity or geophonic sounds (possibly the river).

- Normalized Difference Soundscape Index (NDSI)**

The value of 0.91 for the project area suggests a high ratio of biophonic sounds compared to anthropophonic sounds, indicating a mostly natural soundscape with minimal human interference. The value of 0.74 for the primary forest suggests a lower ratio of biophonic sounds compared to anthropophonic sounds, indicating that there is a higher presence of human-made sounds. This could be explained by the higher distance of the project area from the road compared to where the primary forest was sampled.

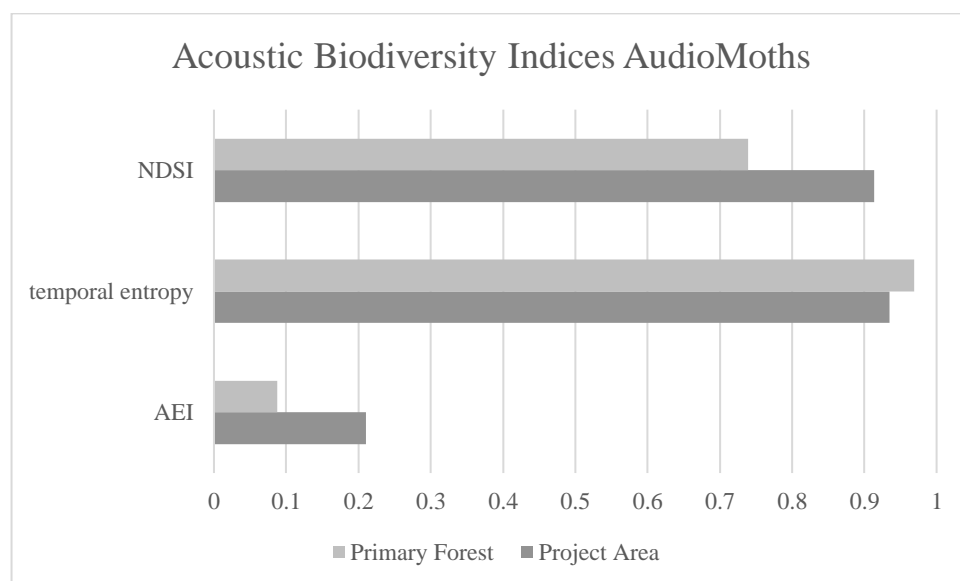


Figure 11 - Acoustic Biodiversity Indices AudioMoths

5. Discussion

Within this project, several factors caused problems. First, the used language within the community is Kichwa. Spanish is their second language, but this is limited and mixed with Kichwa. Because of this language barrier, communication did not always go as planned. Yet, with patience and understanding from both sides, we managed to work together. It was furthermore expected before starting the project that as good as all people in the village had knowledge of the plants and trees, but it turned out only a few did know all tree species, and even less to none knew other vascular or herbaceous plant species. Because of this, there were just a handful of people able to join in fieldwork, which was the reason fieldwork could not be done every day of the week.

Another problem was the usability of the technology. There were nine camera traps and ten AudioMoths available. However, because of the high cost of batteries and memory cards, the choice was made to use only three AudioMoths and rotate these among the nine camera traps. After deployment, there occurred errors on the memory cards of the AudioMoths, and one of the three turned unreadable. This resulted in scarce data on acoustics. After analysis, another error in the analysis process caused unexpected and at this stage inexplicable high values for ACI, ADI and BI.

Looking at the results from this study, the type of degraded forest would suggest low diversity and richness in tree species, but it might be more an issue of not how many, but what tree species are present. Currently, there is, next to the other more humanly influenced forest types, a natural secondary forest where *Cecropia spp.* is dominant. This shows that it is a young forest, and changes in species composition will happen soon since *Cecropia* species are pioneer species and do not live long. If everything goes well, the climax species being planted now will take the canopy space that *Cecropia* and other pioneer species are taking up now.

The methodology for soil sampling turned out to be harder than expected. The project started with one sample plot, which turned out to be too little information, after which four samples were tested. This gave more information and accuracy, but it turned out harder to keep up with the high amount of fieldwork. It was then decided to keep only two samples in each vegetation plot, but for future implementation, it might be best to adjust the number of samples to the size of the area, just as the vegetation plots, and keep vegetation and soil sampling separate. This was not done for this project to keep the fieldwork logistically easy, since it is easier to remember to do two soil samples in each vegetation plot. What turned out to be most important was to have at least 4 samples in each forest type. For these data, it did not make sense to calculate indices, since these indices are very much dependent on the number of samples. For the types with fewer samples, a minimum of four samples have been taken.

The most interesting finding from the soil samples was that Isopods were found in only one sample, in the secondary forest. Paoletti and Hassall (1999) point out that *Isopoda* are thought to be some of the first to disappear when pesticides, but also herbicides are used, as they reduce the availability of high-quality food from leaf litter of dicotyledonous plants, which constitute the majority of weeds. The general results show that the soil in the project area is healthy, judging from the presence of soil macrofauna. Yet, it also shows that there have been influences of herbicides or pesticides in the past, that probably almost removed all species of *Isopoda* from the area and might have had a negative influence on other parts of the ecosystem as well. What these other negative influences are cannot be answered with these results.

Furthermore, since the methodology for fauna is focused on terrestrial mammals, data collected on birds, but also bats and monkeys (*Leontocebus nigricollis*) is not useful or trustworthy to use. The birds and bats are barely or not at all recognizable in the videos from the camera traps. The monkeys have been seen by observation high up in a Camatoa tree (*Gyranthera amphibirolepis*) while on a survey in the field. Additionally, the diversity indices show that there is still a lot of ground to cover when it comes to the improvement of mammal species diversity. Now compared to the study done by Tirira et al., this is a small study and barely comparable. Furthermore, the fact that three cameras in the primary forest do not relate sufficiently to the six in the project area, and that correct placement and then still

the probability of animals passing by the cameras is of significant importance for the data make it hard to compare the two areas. To improve this, it would be better to have more cameras in each forest type for a longer time.

Finally, drone imagery was converted into an orthomosaic and assessed using ArcGIS Pro. However, the available data in this report is limited to the current capabilities of the technology. Hopefully, future advancements in technology will enable more comprehensive data collection, e.g., tree species identification, number of trees, and tree density assessment. These advancements would aid the possibility to partly automate the data collection done in this study and in that way make it more efficient to map larger areas more quickly.

6. Conclusion

This thesis aimed to investigate the differences in biodiversity among forest/landscape types within the family-owned lands of the Mushullakta community, guided by the main research question: "How does biodiversity differ between forest/landscape types within the family-owned lands of the Mushullakta community?" To address this question, four sub-questions were formulated to explore differences in tree species diversity, vegetation structure and composition, soil macro-fauna diversity, and vertebrate diversity within the project area.

There is a high difference in tree species between the forest types of the project area, whereby far most species were found in the secondary forest and the lowest number of species in the *Ilex guayusa* plantation. The difference in forest composition between the forest types is mainly in the use of the tree, having mostly wood-producing species in the secondary forests, the young regrowth area, and the *Ilex guayusa* plantation and a combination of trees for wood and food production in the mono- and polyculture areas. Vegetation structure varies in basal area between the forest types with the *Ilex guayusa* plantation having the highest basal area, likely due to its high tree density and limited tree size diversity. This is followed by secondary forest and the patch of young regrowth. The poli- and monoculture areas have the lowest basal area.

Drone imagery showed that the majority of the study area contains a high overall canopy cover, with only a small number of areas identified as less dense based on drone imagery. There is a slight difference in the presence of families of macro-fauna between the forest types, with leaf litter and canopy cover influencing their distribution. When leaf litter and/or canopy cover was low, the presence of soil fauna was generally also low. The diversity of vertebrates in the project area is high with a total of 33 species, some of which are left unidentified due to the fact that they were either not the correct type of species (e.g., birds, bats) or the image quality was too low.

The AudioMoth results revealed that the sampled primary forest had higher acoustic evenness and a slightly higher presence of insect activity or geophonic sounds. However, realizing that the project area scored lower on acoustic evenness, the project area scored lower on Temporal Entropy, advocating for a higher presence of birds chirping. The diversity indices of the camera traps confirm this. This variance could be explained by the higher presence of fruit trees within the project area. The AudioMoths furthermore showed to have a predominantly natural soundscape with minimal human interference, something which is hopeful for the development of the forest.

In conclusion, this study identified important differences in biodiversity among the land use types of the project area, while also revealing existing opportunities for biodiversity enhancement through restoration and conservation efforts.

7. Recommendations

The first recommendation for the restoration project is to prioritize increasing canopy cover to enhance the availability of micro-habitats, thereby promoting the occurrence of a wider range of flora and fauna. What can furthermore be interesting is to investigate schemes for biodiversity credits, and whether these can be taken into the protocol as an extra income source for the communities. This was not done for this project because all schemes included criteria for which experts and professional equipment would be necessary, e.g., air- and water quality. To establish trendlines, it is recommended to replicate this research in other project areas within the community and conduct regular monitoring.

Recommendations for going beyond canopy cover with drone imagery are to implement comprehensive biodiversity surveys, incorporate species-specific monitoring, and track changes in ecosystem functions to recognize when trends are increasing or decreasing. These approaches can provide a more holistic understanding of the forest's biodiversity and help guide sustainable forest management practices in the future.

There are platforms and software applications that focus on the analysis of orthomosaics for forest inventory purposes. Some popular platforms in this domain include Pix4D, DroneDeploy, Agisoft Metashape, and Trimble eCognition. These platforms aim to render the process of forest inventory and monitoring more efficient by providing automated and user-friendly tools for analyzing orthomosaic data captured by drones or other aerial imaging platforms.

Additionally, it is recommended to improve the AudioMoths' methodology by developing a similar user-friendly software that simplifies the analysis process, without relying on researchers to possess coding language experience. This improvement would increase the usability and accessibility of the technology, allowing for more efficient and widespread utilization in biodiversity research. There are platforms and software tools available for the analysis of AudioMoth data in the context of forest inventory such as RAVEN, which could be explored for the continuation of the project.

To get the most representable data from the project areas of Mushullakta, more cameras should be placed for longer periods of time to account for the different seasons and to increase the probability of animals being caught on camera. The values for the primary forest and the birds are the least representative due to the low number of cameras and an unfit methodology for birds. It would be interesting to see an improved methodology for measuring soil macro-fauna presence/diversity that is still easy and straightforward enough to be implemented by local communities.

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[size/#:~:text=A%20good%20maximum%20sample%20size%20is%20usually%20around%2010%25%20of,the%20maximum%20would%20be%201000.](https://tools4dev.org/resources/how-to-choose-a-sample-size/#:~:text=A%20good%20maximum%20sample%20size%20is%20usually%20around%2010%25%20of,the%20maximum%20would%20be%201000.)

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Appendix

1. Locations of plots
2. Plot numbers
3. Orthomosaic and Forest types
4. Locations of Camera traps
5. List of Tree species
6. Soil Macro Fauna Families
7. Community-Based Monitoring Protocol

1. Location of the plots



Legend

Export_Output

Type

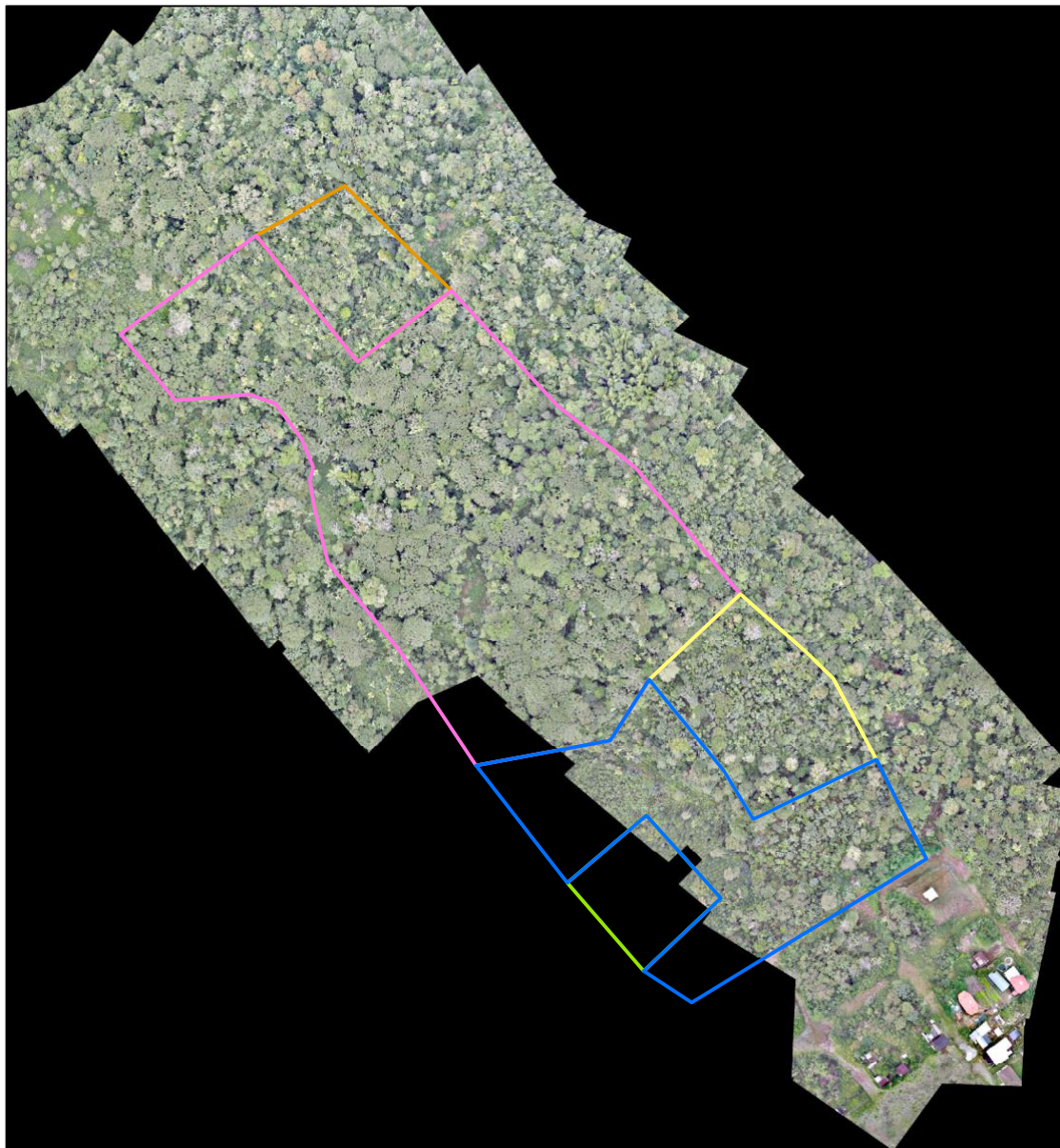
- Ilex guayusa plantation
- Monoculture - Actively Restored
- Policulture
- Secondary Forest
- Young Regrowth Actively Restored



2. Plot Numbers








3. Orthomosaic and Forest types



Legend

Export_Output

Type






-  Young Regrowth Actively Restored
-  Secondary Forest
-  Policulture
-  Monoculture - Actively Restored
-  Ilex guayusa plantation

4. Location of Camera Traps



Legend

Type

-  Ilex guayusa plantation
-  Monoculture - Actively Restored
-  Policulture
-  Secondary Forest
-  Young Regrowth Actively Restored



5. List of Tree species

	COMMON NAME	SCIENTIFIC NAME	FAMILIA	IVI
1	-	<i>Gordonia fruticosa</i>	THEACEAE	0.0969
2	-	<i>Huberodendron</i> sp.	MALVACEAE	0.0958
3	-	<i>Protium</i> sp.	BURSERACEAE	0.0958
4	-	<i>Psychotria nervosa</i>	RUBIACEAE	0.0961
5	-	<i>Solanum aphyodendron</i>	SOLANACEAE	0.0958
6	Aguacate	<i>Persea americana</i>	LAURACEAE	0.0052
7	Aguacatillo	<i>Persea</i> sp.	LAURACEAE	0.2861
8	Ananyu ruya	<i>Piper</i> sp.	PIPERACEAE	0.0958
9	Armanguyu	<i>Aegiphila integrifolia</i>	LAMIACEAE	0.5223
10	Balsa, Boya	<i>Ochroma pyramidale</i>	MALVACEAE	0.2942
11	Bálsamo	<i>Myroxylon balsamum</i>	FABACEAE	0.2147
12	Batea, Bateacapi	<i>Cabralea canjerana</i>	MELIACEAE	1.0472
13	Buwa, Huarumo	<i>Cecropia</i> sp.	URTICACEAE	22.089
14	Cachik, Kachij	<i>Inga</i> sp.	FABACEAE	3.1561
15	Café Arabica	<i>Coffea arabica</i>	RUBIACEAE	1.8378
16	Calmito caspi	<i>Chrysophyllum</i> sp.	SAPOTACEAE	0.1505
17	Camatoa / Cuero de Sapo	<i>Gyranthera amphibiolepis</i>	MALVACEAE	0.0958
18	Cambi / Cacao de monte	<i>Theobroma subincanum</i>	MALVACEAE	0.0958
19	Canelo amarillo	<i>Ocotea javitensis</i>	LAURACEAE	0.3818
20	Canelo café	<i>Nectandra reticulata</i>	LAURACEAE	0.0961
21	Canelo negro	<i>Octotea floribunda</i>	LAURACEAE	0.1232
22	Capianso	<i>Rinorea</i> sp.	VIOLACEAE	1.7306
23	Carahuasca	<i>Guatteria hyposericea</i>	ANNONACEAE	2.7724
24	Caucho	<i>Hevea guianensis</i>	EUPHORBIACEAE	0.2564
25	Cedrillo	<i>Huetea glandulosa</i>	STAPHYLEACEAE	0.0958
26	Cedrillo blanco	<i>Tapirira guianensis</i>	ANACARDIACEAE	0.121
27	Cedro	<i>Cedrela odorata</i>	MELIACEAE	0.3875
28	Chancha avio	<i>Pouteria reticulata</i>	SAPOTACEAE	0.3855
29	Chinchi, Moral bobo	<i>Clarisia racemosa</i>	MORACEAE	0.7122
30	Chingu	<i>Socratea exorrhiza</i>	ARECACEAE	0.5446
31	Chini ortiga, Hortiga	<i>Urera laciniata</i>	URTICACEAE	0.923
32	Chirimoya de monte	<i>Annona emarginata</i>	ANNONACEAE	0.319
33	Chispu	<i>Maclura tinctoria</i>	MORACEAE	0.2372
34	Chonta	<i>Bactris gasipaes</i>	ARECACEAE	0.2723
35	Chuku muyu	<i>Erythrina amazonica</i>	FABOIDEAE	0.1998
36	Chuncha tucuta	<i>Guarea purusana</i>	MELIACEAE	0.2024
37	Chuncho	<i>Cedrelinga cateniformis</i>	FABACEAE	4.0184
38	Cimbio	<i>Witheringia solanacea</i>	SOLANACEAE	0.6705
39	Cipi, sipi	<i>Sapium marmieri</i>	EUPHORBIACEAE	0.1709

40	Coco, fam Sangre de Gallina	Virola spp.	MYRISTICACEAE	0.3539
41	Copal	Trattinnickia burserifolia	BURSERACEAE	1.805
42	Cresta de Gallo	Erythrina crista-galli	FABACEAE	0.0958
43	Damagua	Poulsenia armata	MORACEAE	1.4581
44	Doncel	Virola spp.	MYRISTICACEAE	0.1545
45	Familia Shikra Caspi	Euplassa sp.	PROTEACEAE	0.0958
46	Familia Mindal	Simira cordifolia	RUBIACEAE	0.1586
47	Familia Rayu cachik	Browneopsis ucayalina	FABACEAE	0.126
48	Frutipán de monte	Quararibea cordata	MALVACEAE	0.197
49	Guaba, Guava	Inga sp.	FABACEAE	0.8829
50	Guabilla	Inga ingoides	FABACEAE	0.5063
51	Guabillo de monte	Inga sp.	FABACEAE	0.4816
52	Guambula	Minquartia guianensis	COULACEAE	0.1952
53	Guaranga	Caesalpinia spinosa	FABACEAE	0.8463
54	Guarumo	Cecropia peltata	URTICACEAE	4.8606
55	Guave / Pacay	Inga feuillei	FABACEAE	3.2082
56	Guayacan pechinche	Vitex cymosa	LAMIACEAE	0.1916
57	Guayusa	Ilex guayusa	AQUIFOLIACEAE	8.8801
58	Hortiga	Urera sp.	URTICACEAE	0.4917
59	Huachanse	Caryodendron orinocense	EUPHORBIACEAE	0.0958
60	Ikiyura, ikuyura	Sapium glandulosum	EUPHORBIACEAE	0.3159
61	Ila	Clusia mamillata	MORACEAE	0.0958
62	Jacarandá	Jacaranda copaia	BIGNONIACEAE	0.1998
63	Kachio	Inga sp.	FABACEAE	0.5058
64	Kilig	Wettinia maynensis	ARECACEAE	0.871
65	Kuilichik	Acalypha diversifolia	EUPHORBIACEAE	0.5756
66	Laurel negro	Cordia gerascanthus	CORDIACEAE	0.8614
67	Leche de Sandi	Brosimum utile	MORACEAE	0.2064
68	Limón	Citrus × limon	RUTACEAE	0.4694
69	Linchik	Vernonia baccharoides	ASTERACEAE	2.7569
70	Lisan	Carludovica palmata	CYCLANTHACEAE	0.1916
71	Llanchas ruya, Zapote bobo	Pachira aquatica	BOMBACACEAE	0.1936
72	Machakuy ruya	Renealmia thyrsoides	ZINGIBERACEAE	0.0958
73	Machitón	Inga spectabilis	FABACEAE	0.1296
74	Malayri panga	Saurauia sp.	ACTINIDIACEAE	0.4315
75	Mandarina	Citrus reticulata	RUTACEAE	0.4372
76	Maria panga	Piper peltatum	PIPERACEAE	0.1938
77	Mascarey	Hyeronima alchorneoides	PHYLLANTHACEAE	0.7691
78	Mata pala	Ficus sp.	MORACEAE	0.4055
79	Matico	Piper aduncum	PIPERACEAE	0.0969
80	Matico	Piper sp.	PIPERACEAE	0.098
81	Matico minta	Piper sp.	PIPERACEAE	0.2874
82	Matipana / Matiruya	Clavija procera	PRIMULACEAE	0.0958

83	Mindal	<i>Simira rubescens</i>	RUBIACEAE	0.2075
84	Mintapanga	<i>Mentha piperita</i>	LAMIACEAE	0.0964
85	Paitzi	<i>Clidemia dimorphica</i>	MELASTOMATAACEAE	0.1916
86	Paitzi	<i>Miconia</i> sp.	MELASTOMATAACEAE	2.8445
87	Pechichi	<i>Vitex</i> sp.	LAMIACEAE	0.4822
88	Pibi, Piwi	<i>Pictocoma discolor</i>	ASTERACEAE	0.1927
89	Pinkullu cachik	<i>Inga marginata</i>	FABACEAE	0.1737
90	Pishku muyu	<i>Trema micrantha</i>	CANNABACEAE	0.5221
91	Pitón	<i>Grias neuberthii</i>	LECYTHIDACEAE	0.0969
92	Platáno / Palando	<i>Musa</i> sp.	MUSACEAE	0.6511
93	Puchan paparu, Frutipan del Bosque	<i>Perebea tessmannii</i>	MORACEAE	0.7565
94	Puchiwa, pambil	<i>Iriartea deltoidea</i>	ARECACEAE	0.6571
95	Pukapanga Paitzi	<i>Miconia calvescens</i>	MELASTOMATAACEAE	4.8125
96	Pumamaqui	<i>Oreopanax ecuadorense</i>	ARALIACEAE	0.2656
97	Punsi muyu	<i>Alchornea glandulosa</i>	ACALYPHOIDEAE	0.0958
98	Puscalan	<i>Sterculia colombiana</i>	MALVACEAE	0.2009
99	Rujak Paitzi	<i>Clidemia</i> sp.	MELASTOMATAACEAE	0.0958
100	Sacha punsi	<i>Alchornea glandulosa</i>	ACALYPHOIDEAE	0.0958
101	Sacha ruya, Avio de Monte	<i>Duroia hirsuta</i>	RUBIACEAE	0.0975
102	sacha waysa muyu	<i>Hedyosmum racemosum</i>	CHLORANTHACEAE	0.0969
103	Sangre de drago	<i>Croton lechleri</i>	EUPHORBIACEAE	0.0961
104	Sapotillo	<i>Matisia cordata</i>	MALVACEAE	1.5408
105	Shikra caspi	<i>Euplassa occidentalis</i>	PROTEACEAE	0.8864
106	Sikcha Paitzi	<i>Clidemia</i> sp.	MELASTOMATAACEAE	1.7975
107	Siku ruya	<i>Eschweilera rimbachii</i>	LECYTHIDACEAE	0.0958
108	Tabaco de Monte	<i>Drymonia</i> sp.	GESNERIACEAE	0.0969
109	Tamburo	<i>Vochysia leguiana</i>	VOCHYSIACEAE	0.1916
110	Tocota	<i>Guarea kunthiana</i>	MELIACEAE	0.1296
111	Uksha	<i>Geonoma macrostachys</i>	ARECACEAE	0.2009
112	Urku caspi	<i>Colocophyllum megisticaulum</i>	CLUSIACEAE	0.0958
113	Urku punsi	<i>Alchornea tripleneria</i>	EUPHORBIACEAE	0.0958
114	Urku ruya	<i>Tapura peruviana</i>	DICHAPETALACEAE	0.0981
115	Urku shani	<i>Picramnia latifolia</i>	PICRAMNIACEAE	0.3884
116	Vejuco / Tasahuasca	<i>Ficus</i> sp.	MORACEAE	0.0958
117	Verde Paitzi	<i>Clidemia</i> sp.	MELASTOMATAACEAE	0.2876
118	Wairuru	<i>Ormosia coccinea</i>	FABACEAE	0.1916
119	Yucca	<i>Manihot esculenta</i>	EUPHORBIACEAE	0.0958
120	Zapoté de monte	<i>Pouteria hypoglauca</i>	SAPOTACEAE	0.6219

6. Soil Macro Fauna Families

a. Formicidae



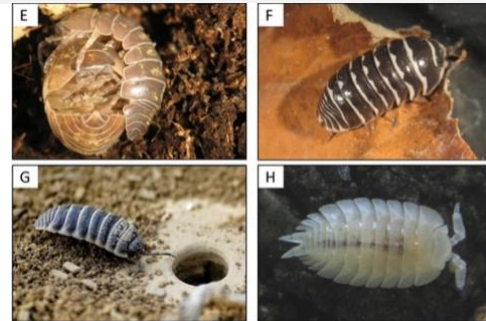
e. Coleoptera



b. Termites



f. Isopods



c. Myriapoda



g. Soil insect larvae



d. Earthworms



h. Other

7. Community-based Monitoring Protocol

Community-Based biodiversity monitoring protocol



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BSc Tropical Forestry Thesis
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Colophon

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Mushullakta, Napo, Ecuador,
April 30, 2023

Cover photo by Yorrick Grobben - *Community members processing camera trap footage*

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1. Introduction

This protocol is designed to act as a guide for communities working on restoration to get an insight into the conservation or uplift of biodiversity in the project areas. The protocol focuses on three main parts: faunal diversity, tree species diversity, and the presence of the main macrofauna families in the soil.

Faunal diversity is important for the role that animals play within the ecosystem, such as seed dispersal and habitat creation. Fauna can be assessed by human observations or whenever available, with the use of camera traps and bioacoustic devices. Camera traps are cameras placed in the field and start documenting images or videos after an animal passes. Audio moths as bioacoustics devices work by recording audio at predetermined moments and can then be analyzed on species diversity in the given area, for this all that is needed is the placement of the equipment, correct storage, and data analysis.

Tree species diversity is what forest ecological monitoring most frequently focuses on, whether it is for the reintroduction of lost species, protection of endangered species, or carbon storage, it is important that the development of diversity is monitored to provide insights about the success of each intervention, know when to improve the forest management and to identify trends.

Macro-fauna is an often-overlooked aspect of forestry that has an enormous impact on the health of a forest. The absence of certain families like worms and isopods can show that pesticides have been used or that the soil has been damaged in another way that would suggest soil analysis in a lab. A healthy soil is necessary for the entire forest to thrive, as they are the base layer of the food system in a forest.

This protocol has been designed in collaboration with Humans for Abundance and Restor, using a restoration site of the Mushullakta community in Napo, Ecuador from February until April 2023. The entire protocol has been tested on applicability by the members of the community.

2. Vegetation

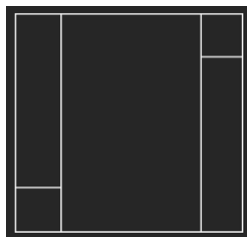
Tree species diversity will be measured using plots in the project area. The size of the area and the structural evenness influence the number of plots necessary, but generally the more plots the better. The aim is to measure about 10 percent of the area for a reliable result, but when the area is very homogenous, less can work. The plots that are used are 25x25m, thus covering an area of 625 square meters. For this protocol the starting point is one plot for every area under one hectare, if you cross one hectare add a plot, and add a plot for every hectare more. This means for an area of seven hectares, at least seven plots. Might the area look variable go for eight or nine plots, to get a representable view of the area.

Next to the plots, a drone will be used for acquiring images through programmed, controlled flight missions. The images are later converted into orthomosaics that will be used for the assessment of canopy cover and tree count in the three forest types. This data will give insight into the following forest characteristics: canopy cover, tree density, tree-size distribution, and structural diversity.

2.1 Vegetation sampling plots

2.1.1 Plot Design

Data on species present will be collected in three groups: regenerating woody vegetation DBH <10cm (so trees and shrubs), trees DBH >10cm, and trees DBH >30cm. The plots need to be placed randomly throughout the areas, permanently to ensure that monitoring will occur in the exact locations each time.



Within the plots, shrubs, and trees with a diameter at breast height (DBH) of <10 cm are recorded in two plots of 5x5, giving a plot size of 25 m² two times. Trees with DBH >10 cm are measured in two plots of 5x25m, giving two plots with a size of 125 m² for trees in this size range. Trees with DBH > 30 cm are measured in a plot 25x25m giving a plot size of 625 m² for larger trees. Datasheets used in the field can be drawn up on any paper, using the example in paragraph 2.1.4.

Figure 1 - Plot Design

2.1.2 Choosing the location of the plots

Choosing a location to do a plot depends on whether there are already permanent sample plots in place or not. If so, use these plots. If these are not in place, look at the map for the project area and divide the area up into strata for different forest types. Then, according to the size of each forest type, divide plots to cover the entire area as non-biased and representable as possible using a map of the area. Consider that some of the plots in practice might need to be adjusted due to landforms or limiting vegetation.

An example of different forest/land use types and the distribution of the plots of a finca in Ecuador:

	Forest/Land-use type	Area (m ²)	Nº Plots
1	Monocultivo	9.879	1
2	Policultivo	28.693	4
3	Ilex guayusa plantation	6.096	1
4	Secondary forest	72.414	7
5	Primary forest	3.463	1
6	Young regrowth actively restored	8.568	1

Table 1 - Stratification of land use types

2.1.3 Placing the plots

Placing the plots happens by going to the field with the following materials:

DBH measuring tape, flagging tape, metal bars for marking the permanent plots, measuring tape for setting out plots (30m), field forms, phone with GPS, and compass.

- You start at the corner point and set out the plots going 25m North using a compass, then 25m east, etc. Do not forget to place markers on the five-meter points from the corners to create the plot design (fig. 1).
- Place a metal or plastic bar on each corner of the plot, so that the plot can be found back in the years to come, we are setting out permanent sample plots.
- Mark the corners and the subplots with the flagging tape to avoid losing your way and ensure you measure all the correct trees.

2.1.3 Measuring the plots

For measuring the trees in the plots, you need a DBH measuring tape and a field form. You work your way through the plot, starting at one of the 5x5 plots measuring everything below 10cm DBH. Make sure that you write down all individuals, so if there are five seedlings of one species, write them all down. After that you move on to the 5x25 plot measuring all trees with a DBH of 10-30 cm, then the 25x25 plot with every tree above 30 cm DBH, and then the other two subplots. Use a notepad to record the following variables for your field forms:

Plot	Name	DBH (cm)	Height (m)	Flowering	Fruiting	Planted
1.11	Chuncho	11,5	15		0	0

Table 2 – Field Form

Plot:	the number you have given to the subplot
Name:	local name of the tree species
DBH:	the diameter of the tree at 1,5m from the forest floor
Height:	the approximate altitude of the tree
Flowering:	yes/no
Fruiting:	yes/no
Planted:	yes/no

Table 3 - Field Form data



Figure 2 - Stratification and sample plot distribution

2.1.6 Adding the Data in the Database

Then when you get back home, the field forms can be entered into the database in Excel. Use the list of tree species to find the correct scientific name for each tree, if the specific tree is not in this list, just enter the local name.

VEGETATION										
No	Plot	Common name	Scientific name	Family	DBH (cm)	Height (m)	Flowering	Fruiting	Planted	Notes
1	1.11	Caucho	<i>Hevea guianensis</i>	EUPHORBIACEAE	11,5	15	0	0	0	
2	1.1	Frutipán de monte	<i>Quararibea cordata</i>	MALVACEAE	2,7	2	0	0	0	
3	1.1	Paítzi	<i>Clidemia dimorphica</i>	MELASTOMATACEAE	<1		0	0	0	fruit is eaten by birds

Table 4 - Data sheet vegetation

2.2 Drone

For the drone the steps that need to be taken are 1) designing a mission in Litchi, 2) flying the mission and 3) creating the Orthomosaic. The drone is part of the monitoring kit from Restor, and the following guide is inspired by the guide draft made by the team that developed the ecological-monitoring pilot project within the organization.

2.2.1 Mission planning

The first step is to [design a mission in Litchi](#) if this has not been done yet for your project area. For this, it is best to ask for assistance from the providing company, as every detail is of utmost importance for the safety of the drone and data. You can draw the mission in Litchi's mission hub if there is enough resolution for the site that you will monitor with the drone. If there is not enough resolution in the Litchi map for you to design the flight, you can use a polygon of the area. If you do not have a polygon of the area, you can draw and save one using the [Geojson tool](#). Once you upload the polygon to the Litchi mission hub, you can design a flight mission around it. For more details on how to design a mission, you can follow the instructions provided by the [Community Drone Kit manual](#), a project under development by the Speclab at Florida University. If you need support to create and validate your mission, reach out to Fidel Chiriboga (see Colophon).

2.2.2 Flying the drone

Once the mission is ready, the next step to be taken is to watch the following video, to familiarize yourself with the drone and how to fly it: [Basic DJI Mini SE flying instructions](#)

Take some time to test fly the drone and get familiar with how to fly the drone, and how the "Return to Home" function works. Bear in mind that this function will only work after the drone has a distance of a minimum of twenty meters from the controller and a distance of max. 500m. must be maintained to avoid losing connection to the drone. Vegetation and mountains can impede connection and make the reach even lower.

Once familiar with the drone, you can go to the start point of the mission that you can see on the map and simply press play for the mission. Before leaving follow the following steps:

- Ensure the climate conditions are fine for the flight: No strong winds, No rain, No heavy clouds.
- Make sure that all batteries are fully charged.
**Note that a 10-minute mission will consume almost the whole battery on the drone.*
- Make sure that the drone has an SD card.
- Open the Litchi App with the mobile phone that you will control the drone and the mission with → for this you need an internet connection to upload the mission to the phone before going to the field. The mission can be conducted with the phone afterward, even without an internet connection.
- Open the mission in the Litchi App by clicking on the folder icon → look for the mission → click Load.

After all, this is done, you can leave for the start point of the mission. Once there make sure that you have at least 10 meters radius for safe take-off and landing. You do not have to do anything more than just turn on and connect the drone, controller, and cellphone as you learned in the video, and make sure the controller and drone are aligned and the connection to the drone does not get lost. Then just wait until the mission is complete and the drone returns to you.

Might you lose connection, make sure the controller is pointing towards the drone and the antennas are parallel to the drone. Now you just must wait, the drone will return home if the connection is lost. Follow the route of the drone on the phone screen as much as possible. This means you would have to retry the mission.

Do not touch the controller while on the mission, might you need to abort the mission for any reason; press the “Return to Home” button on the controller.

2.2.3 Data Analysis and Orthomosaic

After the mission is complete and the drone has returned to you, you insert the SD card in your computer and open the DCIM folder to download the pictures.

3. Fauna

For fauna monitoring camera traps will be used. Camera traps are cameras that respond to movement and start recording when motion is detected. The placement is very important for the quality of the data.

3.1 Setting up the Camera Trap

Before you place the camera trap in the field, it is important to see if the SD card is working properly by putting the SD card in and when turned on, the screen will show the number of videos or photos to be taken in the lower right corner. An SD card of either 32 GB or 64 GB will be enough. Take in mind that if the cameras are left in the field for a longer period need more storage than those that are being checked every few days.

Batteries are preferably rechargeable, to avoid battery waste. Check the battery requirements of the camera trap to plan how many batteries you will need for the monitoring season. If the batteries and SD cards are working properly, the next step is to check the settings of each camera trap.

- Make sure the date (mm/dd/year) and time is correct.
- 15 s Capture Delay
- High-size image 12 MP
- Rapid Fire 2 Shot for the Multishot option

All the other settings can be left to DEFAULT

3.2 Placing the camera traps

After you set up the camera traps, it is time for the placement in the field. Try to place the cameras on known faunal passes along a line transect to cover the most area. The idea is to sample the entire area on the areas that are the most representative for the research area.

Place the camera on a tree about 50 cm above the ground and make sure the camera is angled correctly by maybe using a stick between the camera and the tree to angle it. If this is done correctly, try to camouflage the camera a little bit with leaves, but make sure there are no leaves in front of the camera or sensor. Also clear the area in front of the camera of any leaves that might trigger the camera due to wind.

3.3 Collecting and processing data

Data can be collected by either switching the SD cards or taking a computer to the field and copying the data to the computer. Make sure you organize the data clearly.

Processing the data is done by watching the videos and writing down what can be seen. Use the provided Excel sheet:

Camera	Video	Común	Genus	Family	Qt.	Sex	blank	time	date	Note	Owner
CA-21	IMG_0001	Pajaro 21			1	-		10:46:11	09/03/2023		José
CA-21	IMG_0002						-				José
CA-21	IMG_0003	Churupoema	??	Procyonidae	1			00:15:36	12/03/2023		José

Table 5 - Data Sheet camera traps

4 Soil Macrofauna

For soil monitoring, the focus will lie on biodiversity in the soil. Using a guide, families will be identified, and these will then be noted on a form which will give insight into the diversity and characteristics of the soil and give an idea on the use of pesticides, since if there are important groups of macro-fauna missing, this can point to the use of pesticides. Families that are listed are described in Annex 1. *Soil macrofauna families.*

4.1 Creating a soil sample



Figure 3 - Community member taking a soil sample

2 soil samples of ca. 20x20x20 cm will be extracted from the two sub-plots in each plot using a spade. A soil sample is taken by creating a rectangle in the soil using the spade, and then carefully taking this out on a sheet of white plastic.

When the soil sample is on the sheet of white plastic, the sample is examined, and all insects found in the soil sample are identified as families. Using the field form below the families will be recorded in either 1 when present or 0 when not present.

MACRO-FAUNA	Plot: 1	Plot: 2	Score: 5
Group	Sample 1	Sample 2	
<i>Formicidae</i>	1	1	
<i>Termites</i>	1	1	
<i>Myriapoda</i>	1	1	
<i>Earthworms</i>	0	0	
<i>Coleoptera</i>	1	1	
<i>Isopods</i>	0	0	
<i>Soil insect larvae</i>	0	0	
<i>Other</i>	1	1	

Table 6 - Data collection from soil samples



Figure 4 - Members of the community analyzing the soil sample

4.2 Data analysis

Data collected from soil research will be either 1 (yes) or 0 (no) in terms of presence and be stored in databases in Excel, which can then be analyzed by comparing the naturalness of a stratum with families. The provided Excel sheet will create a score for the forest type in terms of species between 0 and 8. The higher the number, the higher the family richness in the soil, thus the healthier the soil.

Appendix

1. Soil macrofauna families

Soil macrofauna families

a. Formicidae



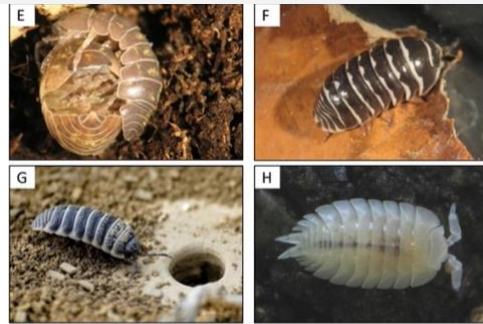
e. Coleoptera



b. Termites



f. Isopods



c. Myriapoda



g. Soil insect larvae



d. Earthworms



h. Other