

Tree plantation as solution for deforestation and recovery of biodiversity in Bolivian farms



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by

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Preface

My name is Denny Dalvan Majokko. A Surinamese student studying in the Netherlands. I am writing this report to complete the bachelor's degree of the specialization tropical forestry at VHL.

The influence for pursuing this type of work came from my mother. As a young boy growing up, I always admired her knowledge of the rainforest and the nature around us. I wanted to know more about the forest too. This was confirmed years later after a walk in the forest with a tour guide. He could explain relations of the forest as well. Since then, I am in pursue of knowledge of nature and try contributing to awareness, protection and conservation of it as much as possible.

I want to start by thanking Anko Stilma for introducing me to the project and for the opportunity to be part of the solution. I would also like to thank my mentors Gonzalo Valdivieso, Jorge Goitia, Jose Bailly and the whole team in San Carlos for the support and making it all possible. A special thanks to the technicians Carlos Janko, Jose Chuve and Benjamin Garcia Flores for always being willing and ready to assist me in the field. Haha, next time I will be well prepared for the mosquitos. I would also like to thank to the whole team for their time, resources and especially their dedication to the work. The positive work environment motivated me and encouraged me to give it my best. And not to forget, their patience and teaching of the Spanish language.

I would like to thank my family for encouraging me in my journeys. I would like to thank Edith Majokko for proofreading and a very special thanks to Japke Roest and Mahesh Sewgobind for joining and supporting me along this journey.

Abstract

This report presents a comparison of biodiversity benefits of tree plantation with areas managed traditionally outside the plantation in farmlands. The aim of the research was to provide data that can be used for evaluating and certifying biodiversity benefits of the plantations. The question used to examine this was: how do tree plantations established on farmlands in the Ichilo province of Bolivia benefit biodiversity over time in comparison to biodiversity on reference sites outside of the plantations? Reference sites are areas that represent what the plantation was before the planting of trees. It is managed traditionally and differs from the management on the plantations.

The methods used for data collection are literature review, maps, interview, line transect, flora inventory and pitfalls. It was concluded that tree plantations provide benefits since the biodiversity on the plantations was found higher than the biodiversity on the reference sites. The interview has shown that there has been an increase of 9 fauna species, from 15 pre plantation to 24 now. Signs of 10 fauna species were recorded on the transects in the plantations and sign belonging to 1 species in the reference sites. The Shannon wiener index (H) and Simpsons index (D) for the plantations and reference sites were respectively 2,29_0,82 and 0,71_0,31. This is calculated for the seedlings and trees and showed a higher diversity on the plantations. However, there were more species recorded for grasses and herbs on the reference sites than the plantations. The macro fauna differs insignificantly with $t=1,1$ $df=2$ $p=0,38$. The H and the D are respectively 0,6 and 0,34 for plantations and 0,41_0,25 for the reference sites.

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1. Introduction

Bolivia is the fifth largest country on the south America continent with an area of 109.9 million hectares. 52% of the country was covered with forest in 2010. It is also the twelfth most biodiverse country. There is a pressure on the forest of Bolivia. It has lost 10% of its tree cover in 20 years' time between 2001 and 2021. This is caused by a high demand for forest products and services. About 82% of this forest loss is caused by deforestation (Bolivia, n.d.).

One of the drivers of deforestations is poverty. This forces farmers to cut down primary forest and practice slash and burn farming technique. With this method forest is clear cut and burned. The burned layer functions as fertilizer. When the plot is depleted of nutrients, another location is chosen, and the process starts over again (Arbolivia , n.d.).

This threatens the western fringes of the amazon rainforest. It results in loss of biodiversity and forest fragmentation. Other effects on the environment are floods and erosion which influence agriculture and the price of crops (Arbolivia , n.d.). This all result in more poverty and the circle starts again with deforestation to overcome the poverty.

Arbolivia (fusion of the words árbol=tree and Bolivia) project was introduced by Sicirec in 2007 as a business opportunity for farmers. It falls under the 'clean development mechanism for forestry and reforestation through pequeña Escala (small scale). It provides ecological benefits (e.g., restoration of habitat/ ecosystems), improves the socioeconomics of farmers and prevent deforestation (Cardozo, 2012). "The project seeks to implement reforestation by linking local Bolivian smallholders with ethical timber investors, whilst also producing carbon credits for local participants" (Arbolivia , n.d.).

With the Arbolivia project, small tree plantations are established on farmlands. These plantations only cover part of the farms. The established plantations cover more than 2000 ha and consist mainly of native hardwood species. All farmers are allowed to join the project. The requirements for registering are prove of ownership of the concerned farm and identification (Franco, 2023).

To show that the project really generates the intended benefits it is necessary to measure, monitor and evaluate the growing of trees and the biodiversity on the plantations. This provides data on the status and condition of the plantations. Continues monitoring is done on growth and development of trees.

That is where the research stepped in. There was a lack of monitoring data of the plantations. The research's aim was therefore to provide this data.

Organization

Sicirec Ltda. Bolivia was established in 2006 as a socially and environmental motivated organization with the focus on forestry, agroforestry plantations and integral management of forests. There are three fundamental pillars guiding initiatives of Sicirec. These are:

- conservation of environment,
- correct use of natural resources and improvement of the living conditions of farmer partners,
- generation of fair and equitable income for all participants (Arbolivia , n.d.).

Sicirec Bolivia works according to environmental and social standards and has certified its projects for climate mitigation and adaption standards with Plan Vivo and Gold Standard. It is aiming on conservation of other ecological function like biodiversity and is willing to certify this as well.

1.1. Research question

The main question for the research was:

How do tree plantations established on farmlands in the Ichilo province of Bolivia benefit biodiversity over time in comparison to biodiversity on reference sites outside of the plantations?

Sub questions

What is the diversity of fauna found in the tree plantations and reference sites?

What is the flora diversity in the tree plantations and reference sites?

What is the macrofauna diversity on the plantations and reference sites?

1.2. Objective and sustainability

The data provided by the research is used for certification of biodiversity conservation under the plan vivo certification scheme. Furthermore, the data is used for monitoring and interpretation of the development of trees in the plantations. It can also be used to show other farmers what benefits can be obtained from this long-term sustainable collaboration. Getting to know what the benefits are may lead to more participation of farmers. This will lead to less deforestation of the amazon rain forest.

1.3. Scope and delimitation

This research focused on the bioindicators mammals, plants, birds and macrofauna. It examined the ecological benefits of established and sustainably managed tree plantation for these indicators in comparison to traditionally managed reference sites. It is not a comparison between plantations with different tree species. Biodiversity assessment was carried out to obtain data. Fauna, direct observation and signs of mammals and birds were recorded using transects. This was enriched by interview of the farmers. Flora inventory was done to determine the species richness of the research area. Macrofauna, the aim was to get the most representative sample of specific ground dwelling groups (ants, beetles and termites) on the plantation, not all invertebrates.

1.4. Overview of structure

The next chapter presents a theoretical framework for the research. It is followed by chapter 3 which gives a general description of the Arbolivia project and the research area. Then comes chapter 4 which outlines the methodology and data collection. Chapter 5 presents the results of the research and is followed by conclusion and discussion. The report ends with recommendation and appendices.

2. Theoretical framework

The amazon rainforest is under high pressure due to deforestation. This has an impact on the flora, fauna and global climate (Laurence, Vasconcelos, & Lovejoy, 2009). Reforestation projects, plantations, are seen as a solution to the growing problem of deforestation. The effects on the biodiversity however are poorly understood and has led to debate on whether they can be valuable habitat for biodiversity (Bremer & Kathleen, 2010). There is a need in better understanding of the influence on the biodiversity. Reforestation however is a long-term process and requires years of monitoring. For better understanding of the changes on reforestation projects they are compared to the initial situation, previous land use, or natural forest (Stephens & Wagner, 2007).

(Rácz, et al., 2013) used the space for time substitution method for detecting change in richness and abundance over time in restoration of grassland. The selected reforestation areas had previously been cultivated. 33 sampling sites were established on 22 field over an area of 4000 ha. Distance between sampling sites was at least 250 m. The collected data was compared to data from the restoration year ($t=0$). Data was gathered annually over a period of 5 years (2005-2009). It was found that the abundance was higher in older restoration sites.

(Fragoso, et al., 2016) used line transect to collect signs for assessing terrestrial wildlife (mammals, reptiles and birds). Interview was carried out to get information of the game species. Surveys were administered weekly to every household to collect information of killings over the time of the research. A total of 23 villages were involved in the research. There were also 4 uninhabited control sites as reference. Each village had a research area divided into 2 zones, 0-6 km and 6-12 km from the village. A total of 8 straight line transects were situated in the research area of each village and each control site which meant that 216 transects were used for data collection. A transect had a length of 4 km. Signs were collected within one meter centre width of the entire transect. The minimum distance between transects was 3 km to maximize independence of individual species or herds recorded. The length of the transect was chosen to increase the probability of crossing the home range of the farthest ranging species in their system, (the white-lipped peccaries, *Tayassu pecari*). Animal signs (predominantly tracks, but also faeces, hair, carcasses or body parts, digging, burrows, eaten fruit or seeds, and browsed plants) and direct contact were recorded on the transect for 3 years (May 2007-june 2010). Only signs deemed by indigenous trackers to be 3 days old or fresher were recorded to avoid recounting. It was concluded that this method is most efficient and effective for monitoring than distance observations. Signs of species were detected that were never recorded using distance sampling. All 32 game species were recorded on the transects. "Sign data thus performed better or equally well as encounter data for detecting hunted terrestrial rodents and birds where they occur, and outperformed encounter data for hunted ungulates, nocturnal species, and four non hunted terrestrial species" (Fragoso, et al., 2016).

(Altamirano, 2013) provided baseline study for plant structure and composition in plantations between 3-5 years old in the Arbolivia project. Existing monitoring design for monitoring biodiversity on the plantations by (Cardozo, 2012) was used. The design was adjusted in which the 1*1 quadrats meant for the measuring of herbaceous plants and grasses was eliminated. An additional 2*2 quadrat was included in its place for measuring shrub species. This moderation was done because of the early age of the plantations at that time in which the plant diversity consisted of mainly fast-growing herbaceous and shrubby species. The PPM's (permanent monitoring plots) were 27*27 m in which all trees with DBH > 10 cm were recorded. There were 2 quadrants within the ppm for measuring other classes of vegetation. Quadrats of 5*5 m were situated for measuring plants with dbh of 5 cm and quadrats of 2*2 quadrats for measuring and counting shrubs with diameter ≤ 1 cm.

A total of 19 permanent sample plots (ppm) were used for flora inventory in which 268 species were detected belonging to 76 families.

(Ayuke, et al., 2009) found a higher value for Simpson index and Shannon wiener index for the macrofauna on plantation forest than fallow/pasture. 3 methods were used for sampling macrofauna; monolith, transect and pitfalls.

- monolith: sampling took place by excavating soil monolith of 25* 25 * 30 cm. The sample was then divided into 3 layers (0-10 cm, 10-20- cm and 20- 30 cm). All animals larger than 2mm in diameter were removed. (Eli, et al., 2021) used this same method for sampling macrofauna.
- transect: these were 20*2 m and were situated 8 meters from the monolith. A section of 5*2 was randomly selected on each transect and excavated to a depth of 5 cm for termites using shovels. The following habitats were also searched for termites: accumulation of litter and humus at tree base; inside of branches and twigs; mounds, subterranean nests, carton sheeting and arboreal nests up to 2 m above ground.
- Pitfalls: these were unbated filled with 70% alcohol for 24 hours. 3 pitfalls were situated alongside each transect

According to (Bignell, et al., 2008) and (Ruiz, Lavelle, & Jiménez, 2008) the indicator groups of macrofauna in tropical environments are termites, ants and beetles. The methods described are the same as (Ayuke, et al., 2009). The pitfall design differs. The traps were filled with 1-2 cm of water with a drop of detergent. The water was to drown or immobilize animals and the detergent was to counteract the hydrophobic properties of many arthropod cuticles. As alternative salt or chloral hydrate solution could be used as preservative. A cover could be placed 2-3 cm above fall to keep rain out.

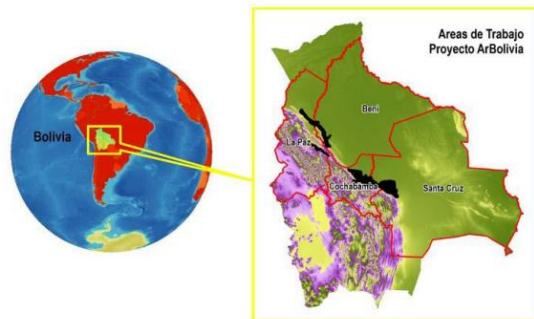
(Knapp & Růžička, 2012) have shown that pitfall design and preservative used effects the results in pitfall sampling. 36 pitfalls were set of 4 different designs. The designs changed in size and preservative used. One of the trap constructions consisted of a round conical transparent plastic pot with volume of 0,5 l, diameter of 9,4 cm and a depth of 10,2 cm. The other trap construction consisted of one litre bottle. This was cut in two thirds horizontally and inserted upside down creating a tunnel like structure. The diameter of this trap was 9,5 cm. The space between traps was 12 m. The used preservatives were formaldehyde solution (with water) and propylene glycol solution (with water). All pitfall traps had a transparent roof of 15*15 cm. This was placed 5 cm above the traps supported on 4 nails. The traps were filled with 200ml preservative.

(Stephens & Wagner, 2007) show that the most used bioindicators for biodiversity in forest plantations are invertebrates (50%), birds (36%), mammals (6%) and vascular plants (6%).

3. General description

3.1. Work area of Arbolivia project

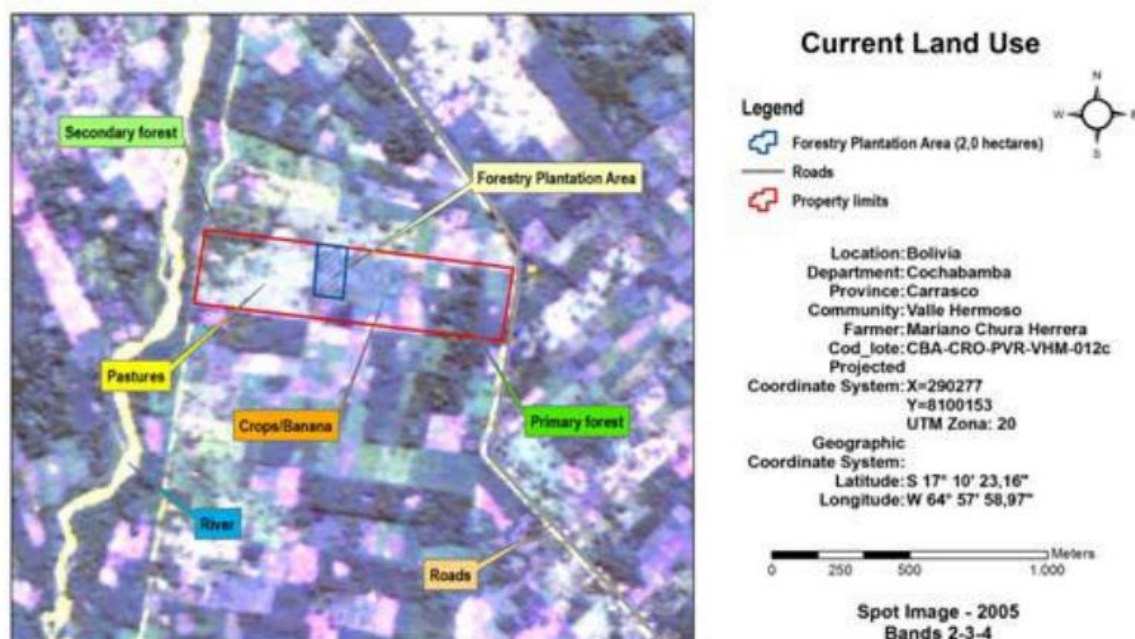
The plantations are established on farms in various provinces in Bolivia in the region at the foot of the Andes Mountain and the edge of the amazon basin in the Cochabamba tropics, the province of Ichilo in the Santa Cruz department, northern La Paz and Western Beni (Plan vivo project design document PDD, 2011), fig1.



1: working area of Arbolivia project (Plan vivo project design document PDD, 2011)

95% of the land in the project belongs to the farmers. There are differences in the size of the properties but on average a family in the Cochabamba region owns 20 hectares. This is 50 hectares for families in the other regions. A small group of farmers have properties less than 20 hectares (Plan vivo project design document PDD, 2011).

It takes years before one can start benefiting economically from the tree plantations since the trees must grow first. This is also considered by introducing agroforestry system. There are crops to foresee in nourishment and there are cash crops as coffee, cacao and citrus. This ensures that the farmers have food and income while the trees in the plantations are growing (Franco, 2023). Fig 2 is an example of the division of a farm with plantation. Besides the location of the tree plantation there are also pasture, crops, primary forest and secondary forest to be seen (Plan vivo project design document PDD, 2011).



2: division of farm, source (Plan vivo project design document PDD, 2011)

3.1.1. Benefits of the Arbolivia project

The Arbolivia project provides environmental benefits however it is not meant to replace primary forest in any way. Farmers can't cut down primary forest to join the project. This is considered as there is a measure build in to prevent it. Areas to be planted should have been deforested for at least 10 years. It is assumed that people won't cut down forest just to wait 10 years to establish a tree plantation (Plan vivo project design document PDD, 2011).

Fig 3. Show the benefits of the Arbolivia project. Nr 1. is achieved with the tree plantations. The farmers are involved in the management of the plantation and are paid accordingly. The net benefits of timber harvest are shared 50-50 with the farmers as well. The whole project is an action on combating climate change with its ecological benefits (13). It provides and restores terrestrial ecosystems and habitat for wildlife (nr 15). The execution of the project involves different parties. Farmers, Sicirec Ltda, communities, comities, governmental departments, timber markets, investors, crops markets and certifying agencies, nr17.



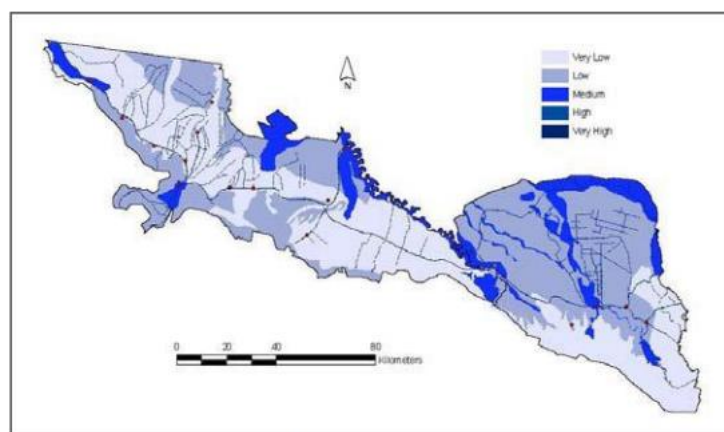
3:benefits Arbolivia project source (Arbolivia Bolivia, n.d.)

3.2. Description of research area

The research was done in the Ichilo province in Bolivia. The province counts 92721 inhabitants divided over 4 municipalities San Carlos and Buena Vista, Yapacani and San Juan de Yapacani (Municipios de boliva, n.d.). The map in appendix I shows the elevation for the research area with a minimum elevation of 331 m and a maximum of 2262 m.

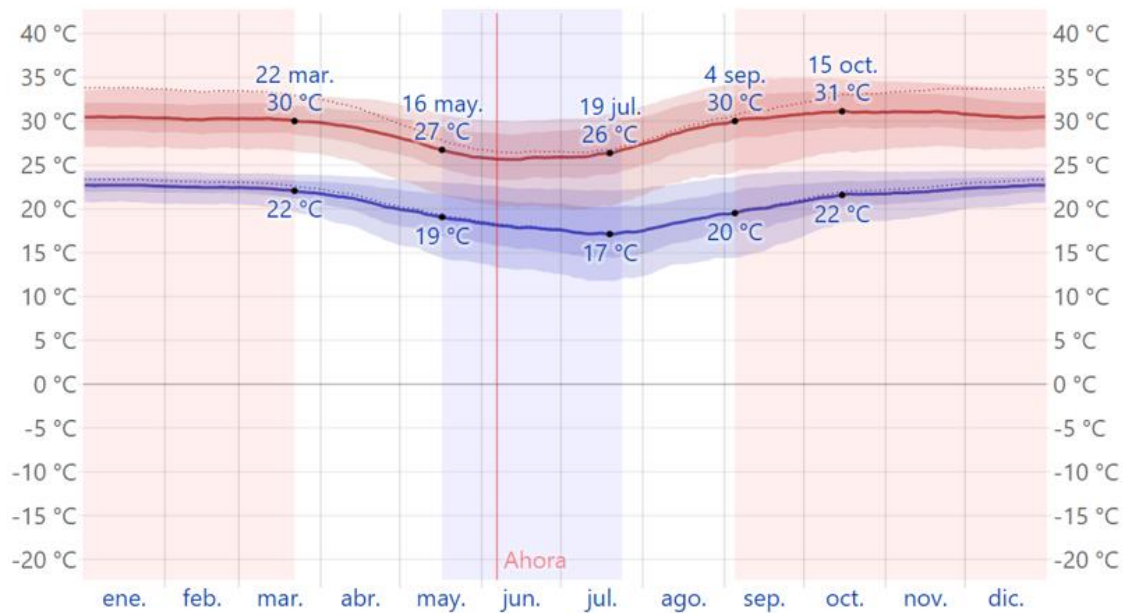
There is a network of roads in the research area consisting of primary roads, secondary roads and paths. This makes it possible to access all plantations. There are also rivers and streams running through the research area. The main rivers are río Yapacani, río Surutú, río Palacios and río Guenda. The streams are Besa, Moreno, Semayo, Mataraco, Colorado, Cheyo, Cuchi and las Delicias. There's a national park in the south of the research area, parque Amboró. This park is protected and has a buffer zone, área natural de manejo integrado. There are 4 plantations (6, 8, 3 and 4) in the buffer zone. These plantations are closer to the protected national park than the others. All the above can be seen in the map in appendix II.

The research area is divided in 3 zones: low, medium and high. This division is based on flood risks and duration. The locations with high frequency of flooding are marked as high zones. These are locations near river, creek or water bodies with soil that are not well drained. Low zones are the locations where the risk of flooding is low fig 4. These zones are lies farther away from water bodies and are located in the parts with higher elevation (Plan vivo project design document PDD, 2011).



4: flood risks of project areas, source (Plan vivo project design document PDD, 2011)

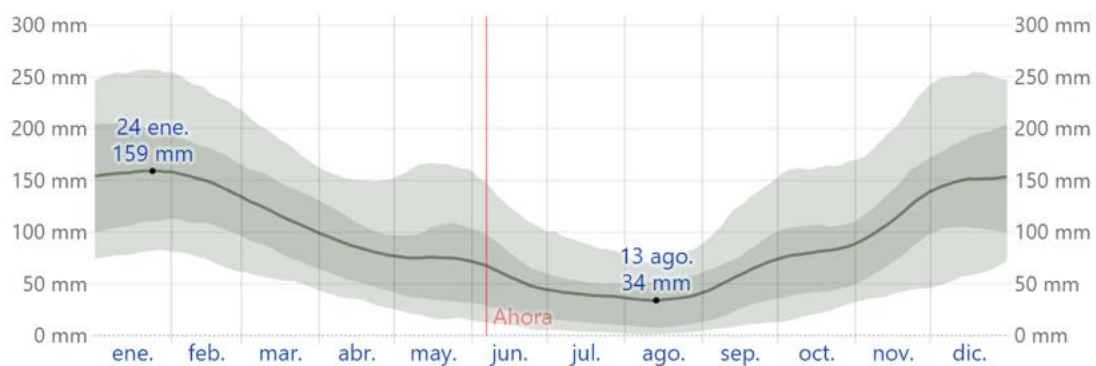
Fig 5 and fig 6 show information of the weather. The highest temperature is 31° C and the lowest 21° C. The hot season lasts 6,5 months and is from September to march. It is followed by a decline in temperature in April and the cool season starts in May to July for 2,2 months fig 5. It rains throughout the year. The month with lowest rainfall is august with 34,7 mm and the rainiest month is January with 157,9 mm fig6 (The average climate and weather throughout the year in Villa Yapacaní Bolivia, n.d.).



The maximum temperature (red line) and the minimum temperature (blue line) average daily with the percentile bands 25° to 75°, and 10° to 90°. The thin dotted lines are the corresponding average perceived temperatures.

Average	jan.	feb.	sea.	apr.	may.	jun.	jul.	aug.	sep.	oct.	nov.	dec.
maximum	30°C	30°C	30°C	29°C	27°C	26°C	26°C	29°C	30°C	31°C	31°C	31°C
Temp.	26°C	26°C	26°C	24°C	22°C	21°C	21°C	23°C	25°C	26°C	26°C	26°C
minimum	23°C	22°C	22°C	21°C	19°C	18°C	17°C	19°C	20°C	22°C	22°C	23°C

5: temperature, source (The average climate and weather throughout the year in Villa Yapacaní Bolivia, n.d.)



The average rainfall (solid line) accumulated over a 31-day period on a sliding scale, centered on the day in question, with the 25th to 75th and 10th to 90th percentile bands. The thin dashed line is the corresponding average snowfall.

	jan.	feb.	sea.	apr.	may.	jun.	jul.	aug.	sep.	oct.	nov.	dec.
Rain	157.9mm	149.9mm	115.8mm	85.9mm	75.8mm	57.4mm	39.6mm	34.7mm	58.2mm	80.9mm	110.5mm	151.5mm

6: average rainfall source (The average climate and weather throughout the year in Villa Yapacaní Bolivia, n.d.)

3.2.1. Tree plantations and monitoring

There are 4 types of plantations, according to (Mapa Sicirec, n.d.) these are:

- agroforestry plantations, AGR, (679,54 ha): to provide food security and income in short term.
- forestry plantations for sustainable wood production, FP, (2265,24 ha): the aim with this type of plantation is to improve income and to achieve environmental benefits.
- sylvopastoral systems, SILV, (1,80 ha). To improve the productivity of grazing land and cattle production. The aim is also to avoid deforestation and to improve income.
- protection units (43,57 ha): these are forestry plantation without commercial aims. They serve as buffer zone to waterbodies and protection of ecosystem.

The plantations in this research fall in the group of the FP.

Every plantation has a unique code, the batch code. Below is an example and explanation for this code. Beside that there is a sector code. For example, S1-P1 in which the first part is for the sector and the second part the plantation.

Batch code: SCZ-ICH-BVT-ACL-4

SCZ: the department, in this case Santa Cruz

ICH: the province, here it's Ichilo

BVT: municipality, in this case Buena Vista

ACL: community, here it's Agua calientes

4: lot number 4

The sizes of the plantations vary between 0,4 ha and 7,8 ha. The planting distance for trees are 3m*3m or 3m*4m.

3.2.1.1. *Management of farm and plantations*

Traditional management of the land consist of slash and burn. After that, annual crop is planted (mainly rice). When this is harvested the land is used for a few months more for planting maize. Then the land become fallow land for several years due to loss of fertility and is used as pastures (Plan vivo project design document PDD, 2011).

The vegetation in pasture consists mainly of grasses. Beside that there are herbaceous plants. The land is used for feeding of livestock (horses and cows). Other land use is cultivation area. These areas consist of grasses, herbaceous plants, crop (maize) or plants (Plan vivo project design document PDD, 2011).

The growth and management of the trees in the plantations is monitored by Sicirec Ltda. The activities on the plantation are site preparation, planting, tending, weed control, thinning, pruning and harvesting. Other activities involve pest control, animal control and fire control. The farmers are also involved in the plantations. The weeding in the plantation is done by the farmers. The farmers get compensated economical for carried out activities (Plan vivo project design document PDD, 2011).

3.2.2. Tree species

Tree species planted in the chosen plantations are: Tejeyeque *Centrolobium tomentosum*, Teak *Tectona grandis*, Palomaria *Calophyllum Brasilense*.

Tejeyeque *Centrolobium tomentosum* Guillem. ex Benth

This is a commercial tree species that is primary used in furniture and constructions among others. It can grow up to 22 m high and reach a diameter of 60 cm. It is grown as pioneer species in reforestation practices and is planted along streets and parks because of being ornamented when it blooms (Useful tropical plants, 2023). It is native to eastern Brazil (Tropicos.org, 2023).

As seed it should be sown in shaded area but in later stage grows best with sunlight available and can tolerate drought. It does not tolerate flooding and compact soils. Loamy soils with a good drainage are favourable. It is categorised as fast growing with a growth rate of 4 to 5 m in 2 years from seed. It belongs to the plant family Fabaceae and can undergo symbiotic relation with bacteria which form nodule on its roots that can fix atmospheric nitrogen (N). Some of the N is used for growing but nearby plants can also use/ benefit from this (Fern, *Centrolobium tomentosum*, 2022).

Teak *Tectona grandis*

Commercially used and grows up to 45 meters high and reach up to 100 cm in diameter. It can be used in shipbuilding, bridge and furniture among other uses. The tree is exotic to Bolivia. It belongs to the plant family lamiaceae and is native to east Asia; Indian subcontinent, Myanmar, Thailand, Laos, Cambodia and Vietnam (Useful tropical plants, 2023). It is used a lot in reforestation activities for its many uses. It is classified as pioneer species and requires high light intensity and space for growth. Young teak grows fast. It can reach 3 meters in the first 2 years and 5 meters after 5 years of planting (teak, 2022).

Teak can be found at sites with elevation up to 1300 m and can grow in various soil types but prefers well drained and well-ventilated soils with neutral pH and high oxygen content. Its root system is shallow which make it sensitive to oxygen deprivation. Ideal soil type would be soil with sandy loams. It doesn't tolerate compacted soils and flooding.

The leaves of teak are large, about 20-35 cm long. It produces small white flowers between June-August. Its seeds are covered with a thick layer making it hard. The wood contains natural oil which makes it resistant to insect and termites (teak, 2022). It can grow in a climate condition with annual temperature between 14 and 36 C and annual rainfall between 600 and 4000 mm (Sousa, Cardoso, Quilho, & Pereira, 2012).

Palomaria *Calophyllum Brasilense cambess*

This is a commercial native tree species that can be used for shingles, shipbuilding and construction among many other uses. It can grow up to 20 m but there are recorded cases of 45 meters tall species. It belongs to the plant family calophyllaceae and is native to the countries Bolivia, Brazil, Costa Rica, Cuba, Guyana, Jamaica, Mexico, Nicaragua, Peru and Puerto Rico (Useful tropical plants, 2023). The trunk can be unbranched up to two third of its high and reach a diameter of 60 cm. It can be found in the wild but is also used for reforestation purposes and as ornamental tree. Furthermore, it is used to provide shade for crops in plantations.

It can be found in elevation up to 1500 m and occurs in almost all soil types. It is known to stabilize soil and relieve the compaction of degraded pastures. It tolerates floodings and soil with poor drainage. Its preference for mean annual rainfall is between 1500- 6000 mm (Useful tropical plants, 2023). It doesn't tolerate sunlight when it's young and it's a slow growing species (Fern, *Calophyllum*

brasiliense, 2022). It flowers in the period of August-November and bears fruits in January-March. Water or animals disperse the seeds. Without treatment the seed takes up to 6 months to germinate (Arbolivia , n.d.).

4. Methodology

This part describes the methods used for data collection. The bioindicators fauna (mammals and birds), flora and macrofauna (termites, ants and beetles) were used to examine the ecological benefits of tree plantations. The space for time substitution method by (Rácz, et al., 2013) was used to detect change in diversity over time for the bioindicators. In this method the reference sites represent year (0) of reforestation. That is the situation before the establishment of the plantations.

The methods used for data collection are:

- line transects (for fauna) with the length of the plantations. 1,5 m was observed for signs on each side of the transect. Direct encounters were also recorded.
- Flora: ppm's as provided by (Cardozo, 2012) for monitoring the plantations. The design wasn't altered as done by (Altamirano, 2013) because the plantations are in an older stage of development (≥ 10 years)
- Macrofauna: Pitfalls, but these were situated in the ppm.

4.1. Plantation selection

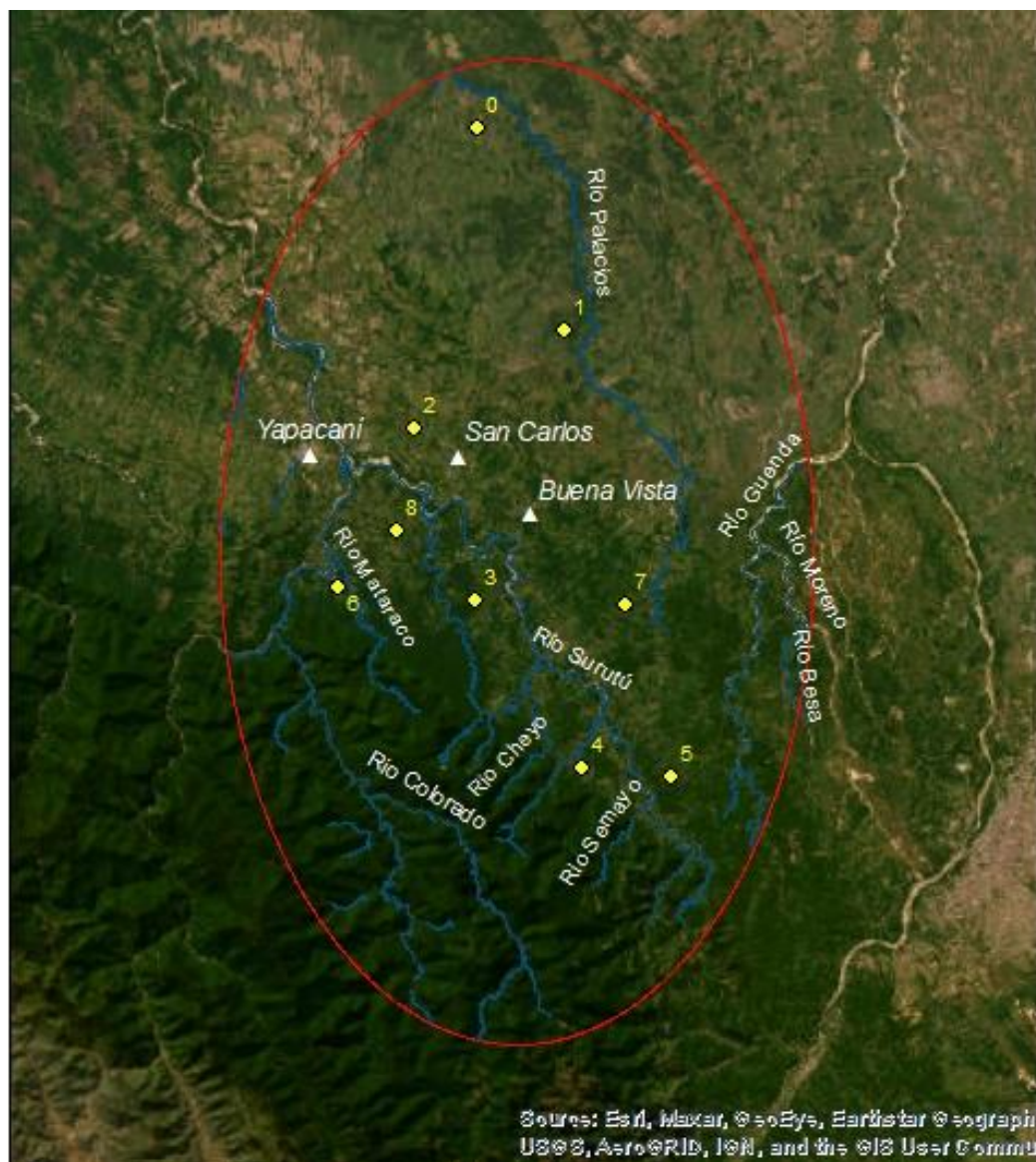
The chosen plantations represent plantations of the 3 tree species in the 3 zones. This information was obtained from Sicirec Ltda. In each zone each tree species was represented by 1 plantation. The criteria for selecting plantations were:

- location: Ichilo, the plantations in this province were reachable from the field station. This field station was in San Carlos (there are other field stations).
- tree species: the species were chosen in consultation with the organisation. These are species that are used the most.
- size: the chosen plantations had a size of ± 1 ha. This is the most common size of plantations. This size was chosen based on the planning for field work.
- age: older than 10 years. Since the research was about biodiversity benefits; the focus was on the older plantations. Plantations where the trees have more influence on the environment. (Wang, Zhang, Li, & Wu, 2022) stated that biodiversity increases with age in reforestation.

A total of 51 plantations were left after selection using the criteria above. 9 plantations were chosen randomly (table 1). Fig 7 shows the research site and locations of the plantations. A reference site was chosen for each plantation. The reference sites were selected based on the previous land use of the plantations. These sites were at least 50 m away from the plantations to avoid influences as seed dispersion from the plantations. Table 1 give information about the community (location), the land use, the tree species planted, the age and zone of the plantations. The plantation nr corresponds with the numbers used for the plantations in fig 7 and the maps in appendices I and II. There was one permanent monitoring plot (ppm) in each plantation and one sampling plot in each reference site.

Table 1: chosen plantations.

Plantation nr	Batch code	Community	land use	Species	Age	Zone
0	SCZ-ICH-SCS-NOT-27	Nuevo Oriente	pasture	Teca	14,2	Low
1	SCZ-ICH-SCS-SCP-43	Propiedad Privada	pasture	Palo maría	11,9	Low
2	SCZ-ICH-SCS-LLD-85	La Lidia	cultivated area	Tejeyeque	14,3	Low
3	SCZ-ICH-BVT-ECM-54	El Carmen	pasture	Tejeyeque	13,0	medium
4	SCZ-ICH-BVT-IZ2-20	Izama 2	pasture	Teca	14,0	high
5	SCZ-ICH-BVT-SFE-98	Santa Fe de Amboró Eduardo Abaroa	pasture	Tejeyeque	11,0	high
6	SCZ-ICH-SCS-MAT-32	Mataracú	Cultivated area	Palo maría	12,8	high
7	SCZ-ICH-BVT-ACL-4	Aguas Calientes	pasture	Teca	12,8	medium
8	SCZ-ICH-SCS-ABT-32	Agua Bonita	pasture	Palo maría	12,9	medium



7: research area with plantations

4.2. Fauna

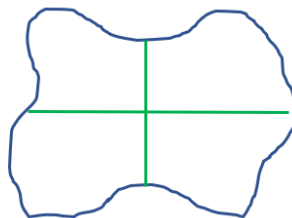
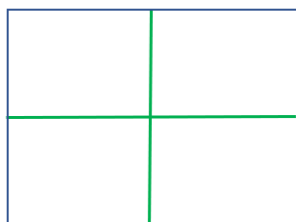
This part is about the fauna and aim at answering the sub question: What is the diversity of fauna found in the tree plantations and reference sites? The focus was on mammals and birds. What is the presence of these 2 groups in the research area. The aim was to discover what species of mammal and birds occur on the plantations and what species on the reference sites.

Data collection took place in for 2 months period, March-April. Line transects were used for collecting data on the fauna (Buckland, 1985). Fauna that only occur in particular time of the year or seasonal could be missed. Interviewing farmers provided information about the fauna occurrence in the area (Islas, Seixas, & Verdade, 2022).

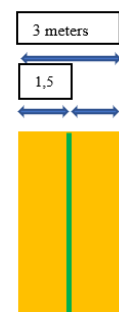
4.2.1. How was the information obtained?

4.2.1.1. Line transects.

Line transects were used to look for signs and prints of the fauna (Buckland, 1985). The transects were situated transecting each other on 90° (fig 8). A distance of 1,5-meter (fig 9) was observed on both sides for animal signs.



8: position of line transects in plantation with regular and irregular form



9: width of observation

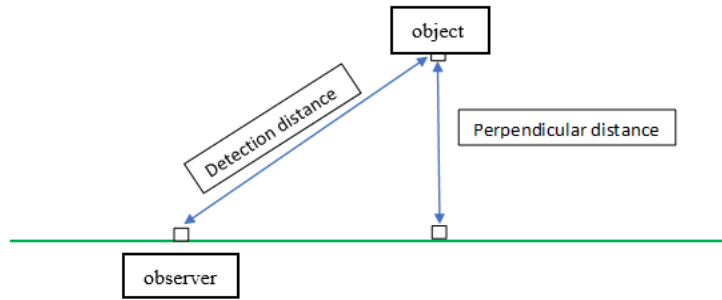
Data collection

All of the transect observations were done in the morning between 8.00 and 10.00 am for practical reasons. The form in appendix III was used for the observations. The recording was as follow:

- observations were done by walking the circumference of the area.
- 10 minutes was waited (preparation time) before starting the second transect observation. This was the transect north- south.
- when finished, 10 minutes was waited before commencing the last transect observation, transect east-west.

Upon encountering a track or sign it was recorded as follow:

- perpendicular distance fig 10, was measured. The detection distance was estimated for direct observations
- it was recorded if it falls within the 1,5m of the transect.
- a ruler was put beside it for reference and a photo was taken



10: distance measured, source (Buckland, 1985)

4.2.1.2. Interview

This was a small interview about fauna species encountered in the farms. The interview served as mean for collecting information of fauna species. Appendix IV (Animalia, 2023) was shown to the farmer and ask to point out animal encountered on the farm. One should keep in mind that the figures in appendix IV are not in proportion to the animal sizes in reality. It was meant to give an indication of animal's prints.

How was it done?

- there was an introduction of the researcher.
- there was a brief description of the purpose of the research and what data would be collected.

The questions used for collecting information about the mammals and bird's occurrence were:

- what animals have you encountered on the farm?
- what animals have you encountered in the plantation?
- have you notice change in animal occurrence with the establishment of the plantation?

4.2.2. How was the information measured

The variables recorded were tracks, diggings, borrows, markings, partly eaten fruits or seed and direct encounters. The data recorded were analysed using sorensen similarity index and content analysis. The data obtained on the plantations was structured and compared to the data collected on the reference sites.

4.3. Floristic diversity

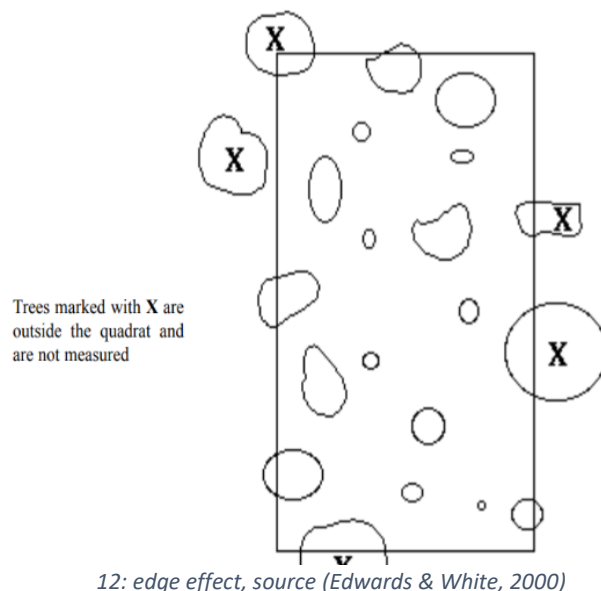
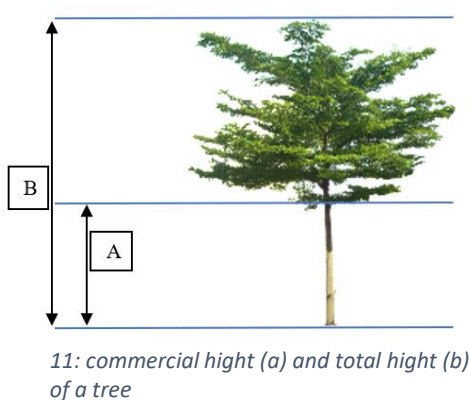
The floristic diversity is described in this part. Existing monitoring practice was followed for the assessment. The aim was to discover what the species richness is on the plantations and on the reference sites. The sub question for this part was:

What is the floristic diversity in the plantations and the reference sites?

Appendix V is used for recording variables. Variables of plantation structure and composition are also recorded beside variables for flora diversity. Sicirec Ltda will use this data for certification and in future monitoring of the plantations. The variables recorded were dbh (if applicable), name, commercial high and total high (A and B in fig 11). Explanation for the following variables can be found in appendices VI and VII: crown form, crown position, competition, stem and health. Additional information were date, remarks, plot and number of the farm.

4.3.1. How was the inventory done for the floristic diversity?

Permanent sample plots (ppm) were used for the inventory of the floristic diversity on the research areas. The shape of the plots was rectangle. This made detecting the plots easy and edge effects as shown in (fig 12) was reduced (Edwards & White, 2000). (Fig 13) shows the design for permanent sample plots (PPM) required for diversity sampling in the Arbolivia project. The 4 groups of plants were measured in 4 types of plots (fig 14). The size of the subplots differed for each group. The sizes were: D (27*27m), for trees with dbh ≥ 10 cm. C (5*5m), for all trees with a dbh between 5 and 10 cm. B (2*2m), for seedlings less than 1 m height and A (1*1m) for herbs and grasses (Cardozo, 2012). The species of grasses and herbs were recorded as number of species per plot.



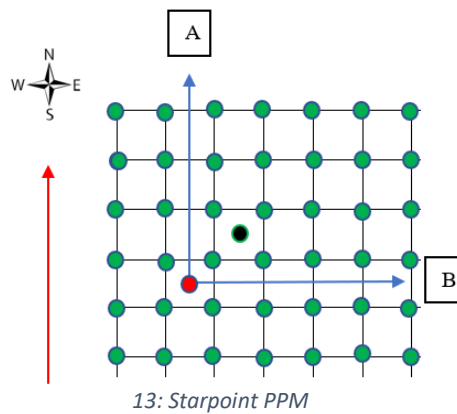
Data collection

Preparations:

- gathering sticks for plots
- labelling the top of the sticks with flagging tape to make them easily detectable.
- taking out /gathering needed tools
- creating a "statief" (somewhat thicker stick to put compass on top of)

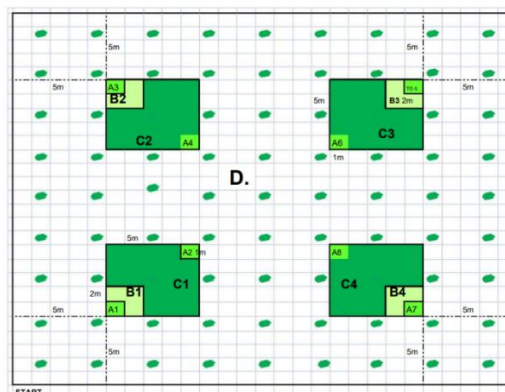
When done with preparations the PPM was marked out as following:

- the southwest corner of the area was determined.
- from there the starting point of the ppm was determined as the red dot shown in (fig. 13). The rows of trees were counted to find this point. The green dots represent planted trees. Two rows of tree were counted from the south and 2 rows of trees from the west. The starting point is between row 2 and 3 from the south and between row 2 and 3 from the west. This was decided together with the organization for practical reasons.
- this is the south-west corner of the ppm.
- from there the ppm is situated to the north and to the east.
- The next thing was marking out the south- north border, line A. The trees are the guideline. From the starting point (red dot fig 13) the line is between tree row 2 and 3 from the west. The degrees of this line were recorded.



Before marking out the rest of the PPM, line B was checked with the compass. This line is 90° from line A. If it went out of the plantation, the starting position was moved to the position of the black dot. All the plots and subplots from now on refer to (fig 14). Marking out the whole ppm with subplots, A, B, C and D, required a lot of sticks. The ppm (D) subplots C1, B1 and A2 were marked out first. C1, B1 and A1 were recorded and when finished C2, B2 and A2 were marked out and recorded.

After finishing the recording of subplots, the plots of the reference site were marked out. If there were trees in the reference site, the main plot was 27m*27m, D, if there are no trees (grassland), the plot was 17m*17m. This was the measurement for the border of subplots C1- C4. Subplot C was 5m*5m, the distance between C- subplots was 7m. This made the border of the C-subplots 5+5+7.



14: Permanent monitoring plot design for Arbolivia plantations source (Cardozo, 2012)

4.3.2. How was the data analysed?

The data collected for seedlings (plot B) and trees (pot C and D) are analysed using the Shannon wiener index (H) (equation 1), the Simpson index (D) (equation 2) and species richness (the number of species to be found on the plantation and reference site). H and D were used to estimate the species diversity in the research areas. The 'pi' in equation 1 was the number per species divided by the total of all species. Indicator species were identified. The data collected for the A plots were analysed using content analyses by comparing data from the plantations with data from the reference sites.

Equation 2: Shannon wiener index

$$H' = - \sum_{i=1}^S p_i \ln p_i$$

Equation 1: Simpson index

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

4.4. Macrofauna

The sub question examined in this part was:

What is the macrofauna diversity on the plantations and reference sites?

The aim was to discover the diversity in the research area. The focus of this part was obtaining data on the indicator group:

- Beetles: They are indicators for a good food pyramid and also for high biodiversity (Manhoudt, 2021). feed on organic material and plant roots among others therefore effecting plants directly. The activities of beetles effect the structure and nutrients in the soil (Bignell, et al., 2008).
- termites: food material consist of plant parts (roots, seeds, decaying material) above or below the soil surface. They influence the soil through making of tunnels, ingestion and transport. Nutrient cycle is also influenced through shredding, transport and digesting of organic material. This all effect the vegetation in that area (Bignell, et al., 2008).
- ants: They are sensitive to environmental changes and react rapidly. Ants are also a key group in food web making them suitable as indicators (Donoso, et al., 2017). Their activities can increase the amounts of organic material, phosphor (P), potassium (K) and Nitrogen (N). This influences the vegetation in the area. Ants sometimes have mutualistic relations with plants and sometimes parasitic (e.g., mutual relation with *Triplaris americana* L.(palo diablo) and the parasitic relation of leafcutter ants (Bignell, et al., 2008).

4.4.1. How was the data recorded?

Pitfall traps were used with inter-trap space of 12 meters to collect data of the macrofauna (Yen, New, & Ward, 2001). Organism that needed to be kept longer for identification were kept in 70% ethyl alcohol (Eli, et al., 2021). The pitfalls of both plantation and reference site were situated the first day. This made it possible to collect them the next day since they were only left on the field for 24 hours. The pitfalls fig 15 was situated on in the middle of subplot C fig 14. This gave a total of 4 pitfalls in each ppm. The containers were filled with water and salt (for the preservation). The containers used:

- had a height of 15 cm.
- had a diameter of 10 cm.
- they were filled with salt water to a hight of 2-3 cm.
- had a cover with a hight of cm

Rice bag fig 16 was used to separate the organisms from the salt water. The content of the container was poured out bit by bit on the rice bag. If the content contained soil and was muddy, more water was added to get it clear to make separation of organisms easier. The organisms were determinated to the taxonomy rank of order. Some could be identified to genus or name. This was done by taking pictures with the cell phone using google lens. If the (local)name of an organism was known, this was recorded.



16: pitfall source: (Bignell, et al., 2008)



15: item to use for Determination

4.4.2. How was the data analysed?

The species found for the macro fauna were described and compared between the plantation and reference site. Statistical analyses were used to analyse the data. The F- test (equation 4) two sample for variances was calculated to determine what T test (equation 3) to use. The analysis was done using the excel programme. The formulas are shown for reference only. These analyses are further complemented by the Shannon wiener index and the Simpson index (equation 1 and 2).

Equation 4: t-test

$$t_{df} = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}}$$

$$df = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2 - 1}}$$

Equation 3: f-test

$$F = \frac{\sigma_1^2}{\sigma_2^2}$$

$$\text{where } \sigma^2 = \frac{\sum(x - \mu)^2}{n}$$

5. Results

This chapter presents the results of the research. For each indicator, the result is presented in tables and or charts and are explained. The plantation number is used in the tables. Table 2 shows what tree species belong to the plantation numbers. The complete table of plantation can be found in paragraph 4.1.

Table 2: plantation number and tree species

nr. Plantation	Species
0	Teca
1	Palo maría
2	Tejeyeque
3	Tejeyeque
4	Teca
5	Tejeyeque
6	Palo maría
7	Teca
8	Palo maría

5.1. Results for Fauna

5.1.1. Results for line transects.

The following show the results of the data obtained from the line transects. The last column in table 3 shows what type of sign was recorded. The signs of all the plantations are compared to the signs of all the reference sites. This shows that for 10 animals signs were recorded on the plantation while the signs for the reference sites was 1. All the observations can be found in appendix VIII. Appendix IX shows some photos of signs, line transect and plotting in the different tree plantations.

One species of bird observed is on the international union for conservation of nature (IUCN) list. It was observed in plantation 4 with Teak (*Tectona grandis*) during the transect observation with a detection distance of ± 30 m. It was the military macaw (*Ara militaris*) fig 17 which is listed as vulnerable in the red list of the IUCN.

Table 3: signs recorded.

Observation	Plantations	Reference sites	type
tatu	X	x (solo cueva)	cueva-camino-huelllas-marca de comida
toucan	X		direct observation
perdiz	X		direct observation
cacare	X		direct observation
ardilla	X		direct observation
jochi	X		hole-path-marks
peji	X		Path- feeding signs
loro	X		Direct observation
carpintero	X		Sound-direct observation
mono	X		sound
total	10	1	



17: military macaw *Ara militaris* photo Denny

The plantations provide the preferred habitat for the species when compared to the reference sites as can be seen in the last column (+ is for plantation, - is for reference site and = is for both). This can be explained when the habitat and diet for the species is considered as can be seen in table 4. It shows the habitat and diet for all the mammal species recorded and for the ground dwelling birds. Since the other (non ground dwelling birds) recorded birds prefer the plantation's canopy over the reference sites they are not included in the table. What is the habitat and diet of the species recorded? The table show what the species prefer for these 2 indicators.

Table 4:habitat and diet for recorded species

species	habitat	diet	
Ardilla	Nest 6 to 10 m above ground among foliage and vines	Nuts, seeds, fruits, fungi and insects	+
Calucha	Borrows and tree trunks near roots	Fruits and seeds	+
Capiguara	Near water	Grasses, aquatic plants, fruits and bark (capibara, 2023)	=
carachupa	Borrows on the ground or trees	Fruit, small animals, garbage	=
Jochi	Forest and agricultural environment near forests	Fallen fruits, seeds, leaves, tubers (Macdonald, 2023)	=
Meloro	forests, secondary growth, and plantations	omnivorous	+
Mono	several types of forests	fruit, leaves and insects, buds and flowers depending on species	+
Oso hormigero	dry forests, including tropical rainforest, savanna, thorn scrubs, but most common near streams and rivers	ants, termites, and bees	=
Peji	burrows	fruit, tubers, palm nuts, ants and termites, carrion, and small vertebrates as frogs	=
Perdiz	nest is located on the ground in dense brush or between raised root buttresses	fruit off the ground or low-lying bushes. Also, small amounts of invertebrates, flower buds, tender leaves, seeds, and roots	=
Perico	Tropical forests, semi-deciduous forests and subtropical lowlands and swamps	strict herbivore that feeds primary cecropia leaves, flowers, and fruits	+
Puerco	rainforests and woodlands, deserts and grasslands	omnivorous	=
Puerco espin	Primary in forests but also in vast tropical grasslands, humid mountainous highlands	cambium layer of some trees, buds, fruits, roots, stems, leaves, blossoms, unripe seeds, and agricultural crops	=
Tatu, nueve bandas	Up to 12 burrows in its range. Forest scrub-brush areas	ants, grubs, worms, termites, tubers, small reptiles, and amphibians.	+
Urina	Forest and grassland	herbivore	=
Venado	Stay in forest and forage in grass and wetlands	herbivore (GRAY BROCKET, 2023)	=
Zorro	Forest and grassland	rodents, crabs, frogs, reptiles, birds, turtles, shrews, and insects, and also consumes eggs, carrion, and some vegetables, seeds, and fruits.	=

Table 5 gives the recordings for plantations with the same tree species put together in the 2nd, 3rd and 4th columns. The last 3 columns present the recording for each zone. The plantations belonging to the species and zones can be found in the first row of the column. There was only one sign for the reference site belonging to plantation 2 and 0 for all the other reference sites. So these are not included in the table.

Table 5: signs on transects grouped by tree species and elevation.

	2,3,5	0,4,7	1,6,8	0,1,2	3,7,8	4,5,6
	Tejeyeque	Teca	Palomaria	low	medium	high
Birds						
Loro		x		x		
Carpintero		x		x		
Toucan			x			x
Perdiz			x			x
Cacare			x			x
mammals						
Tatu	x	x		x	x	x
Ardilla		x		x		
Jochi	x	x			x	x
Peji	x				x	x
Mono		x		x		
Total	3	6	3	5	3	6

5.1.2. Results of interview

Table 6 presents the findings for the fauna occurrence in the research site. It shows the fauna species that occur on reference sites and fauna species that occurs on the plantations. The columns represent all the 9 plantations and 9 reference sites. It shows that 15 fauna species were encountered on the reference sites and 24 in the plantation. The Sorensen similarity index is 0,46. Appendix X gives an overview for all fauna species based on the interviews.

Table 6 total for species reference site the plantations and plantation

Species	Scientific name	Reference site	plantation
birds			
Cacare	Cyanocorax cyanomelas		x
Carpintero			x
Chaicita	Columbina picui	x	
Guaraca	Ortalis guttata		x
Lekeleke		x	
Loro		x	x
Mauri		x	
Perdiz	Nothura maculosa	x	x
Pavas			x
Tojo			x
mammals			
Ardilla	Sciurus ignitus		x
Calucha	Dasyprocta variegata	x	x
Capiguara	Hydrochoerus hydrochaeris	x	x
carachupa	Didelphis marsupialis		x
Jochi	Cuniculus paca	x	
Meloro	Eira barbara		x
Mono		x	x
Mursielago			x
Oso hormigero	Tamandua tetradactyla		x
Peji	Euphractus sexcinctus	x	x
Perico	Bradypus variegatus		x
Puerco	Pecari tajacu	x	
Puerco espin	Coendou prehensilis		x
Tatu, nueve bandas	Dasybus novemcinctus	x	x
Torcaza		x	x
Tordo	Oreopsar bolivianus	x	
Toucan	Bird		x
Urina	Mazama gouazoubira		x
Venado		x	x
Zorro			x
		15	24

Table 7 presents the findings for the data categorised by zone compared to the reference sites. All three plantations that are established in the low zone are put together. This is also done for medium and high zones. The numbers of the plantations can be seen beside the zones in the first row. There is an increase from 9 to 14 for the low zone, 3 to 7 for the medium zone and 7 to 16 for the high zone. The table also shows that the occurrence of fauna species was higher in the high zone. Appendix XI gives an overview the fauna species occurrence grouped by zone.

Table 7: totals by elevation for before and now

Low 0,1,2		Medium 3,7,8		High 4,5,6	
reference	plantation	reference	plantation	reference	plantation
9	14	3	7	7	16

5.2. Results flora inventory

This part presents the data collected with the inventory. The first part is about the layers of trees and seedlings. It is then followed by results for the layer of herbs and grass. The only plantations with climber plants on trees were plantations 4 and 7 both containing Teak.

Trees and seedlings

Table 8 below shows the Shannon Wiener index and Simpson index for of all plantations and reference sites respectively 2,29_ 0,82 and 071_0,31. The species recorded and their total number for all plantations and reference site can be found in appendix XII. The calculations for H and D can be found in appendix XIII.

	Plantation				Reference
D	0,82			D	0,31
H	2,29			H	0,71

Table 8: Shannon wiener and simpson index for plantations and their reference for trees and seedlings

The dominant life form on the plantation was trees with a total abundance of 448 for all plantations and 120 for seedlings. The plantations had a species richness of 38 with and total abundance 568. For the reference sites the species richness was 7 with total abundance of 36. The most common tree species in the plantations were Teak (*Tectona grandis*), Palomaria (*Calophyllum brasiliense*), Tejeyeque (*Centrolobium tomentosum*) and motaku (*Attalea princeps*) fig 18 and table 9. The most common species for seedlings on the plantations were espino blanco (*Acacia sp.*), pata de baca (*Bauhinia sp.*), sp1 and sp13 as shown in fig 19 and table 10. Appendix XII gives an overview of total individuals per species per plantations for seedlings and trees.

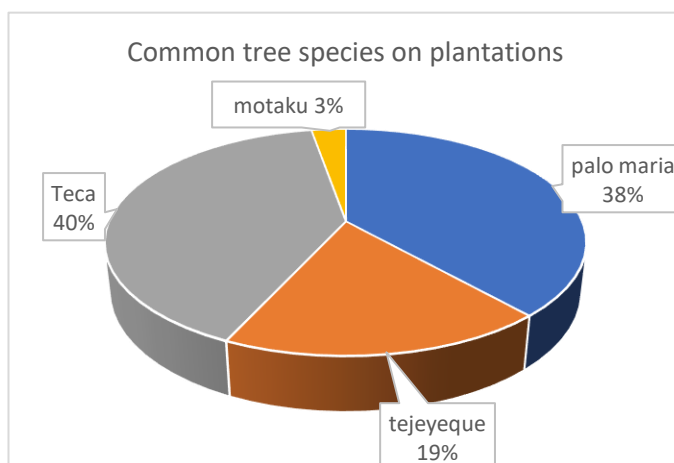
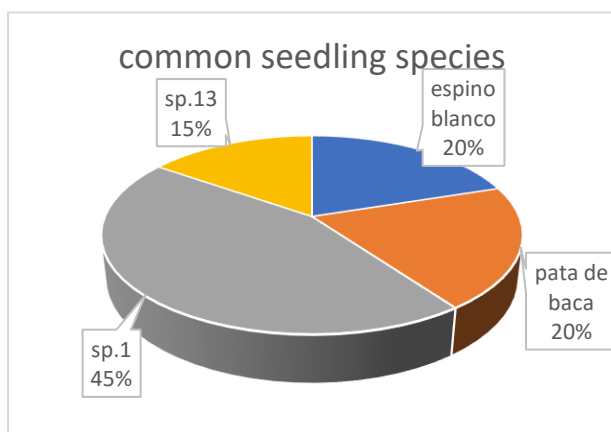


Table 9: total of the 4 most common tree species in the plantations

Scientific	species	total
<i>Calophyllum brasiliense</i>	palo maria	153
<i>Centrolobium. tomentosum</i> (Guillem ex Benth.)	tejeyeque	74
<i>Tectona grandis</i>	Teca	161
<i>Attalea princeps</i>	motaku	11

18: the 4 most common tree species in the plantations.



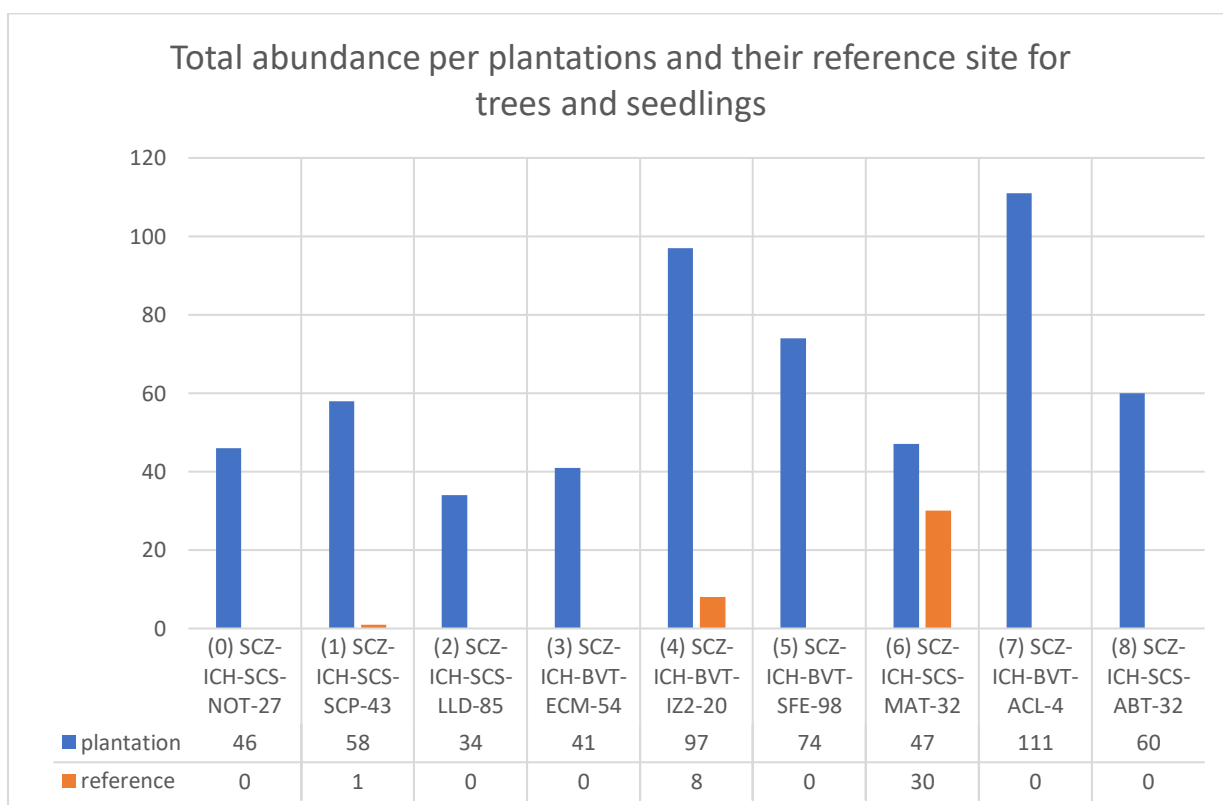
19: the 4 most common seedlings found on the plantations

Table 10: the total abundance of the 4 most common species for seedlings in the plantations

Scientific	species	total
<i>Acacia sp.</i>	espino blanco	17
<i>Bauhinia sp.</i>	pata de baca	17
	sp.1	38
	sp.13	13

Plantation 7 had the highest abundance for seedlings and plantation 2 the lowest. The reference site of plantation 6 had the highest abundance for trees. This was also the only reference site with trees (citrus). The reference site of the plantations 4 and one were the only ones with seedlings resp. 8 and 1 (fig 20).

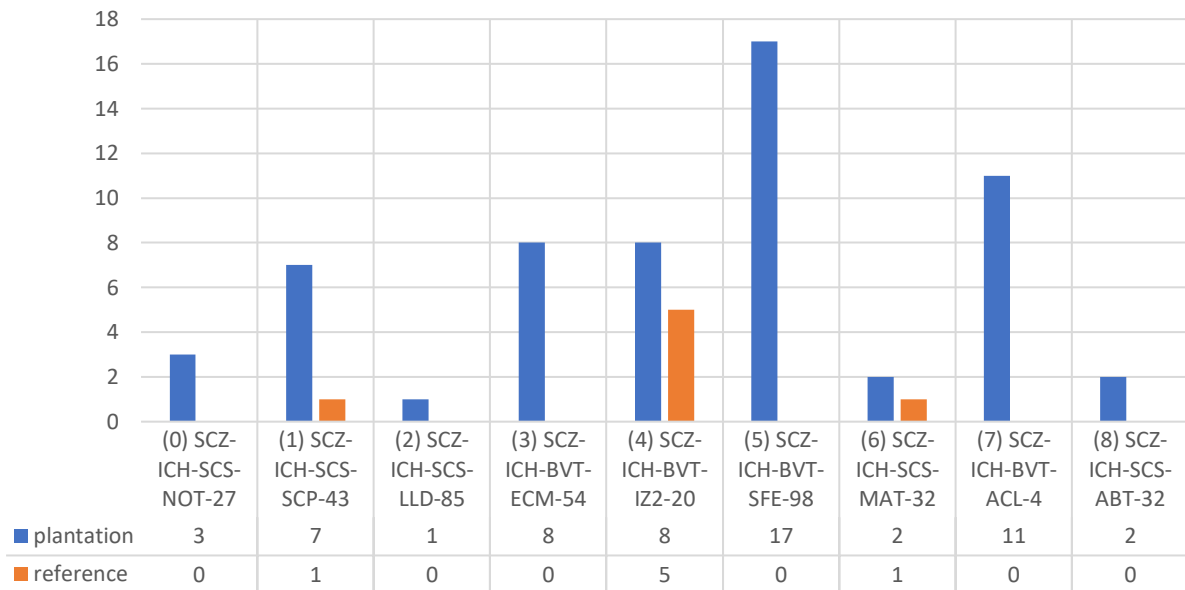
Fig 21 shows the species richness on the plantations for the seedlings and trees. The richness in plantation 5 was the highest.



20: abundance on plantations in comparison to reference sites for trees and seedlings.

Most of the reference sites (0,2,3,5,7 and 8) were not represented in these 2 layers. Reference site 6 had citrus trees and reference 6 and 1 were represented by seedlings. Plantations on the other hand were represented in these layers with plantation 7 having the highest abundance and plantation 2 the lowest.

Species richness per plantations and their reference site for trees and seedlings



21: species richness on plantations and reference site for seedlings and trees.

Table 11 gives the Shannon wiener index and Simpson index calculated separately for each plantation for the trees and seedlings. It shows that plantation 5 has the highest diversity. Table 12 shows the H and D calculated for reference sites that contained seedlings of which only site 4 with H 1,49 and D 0,86 show a number for diversity. This is illustrated in fig 22 and 23 where plantations and reference sites are put together with the indices. When the indices of plantations are compared to indices for reference sites, one can see that only the reference site of plantation 4 is more divers than its plantation. Plantation 2 and its reference site both have a value of 0 and plantations 0,1,3,5,6,7, and 8 are more divers with values of 0,36-0,69-1,37-2,49-0,1 and 0,15 resp. The calculations and values for plantations can be seen in appendices XIV and XV. The calculations for reference sites can be seen in appendix XVI.

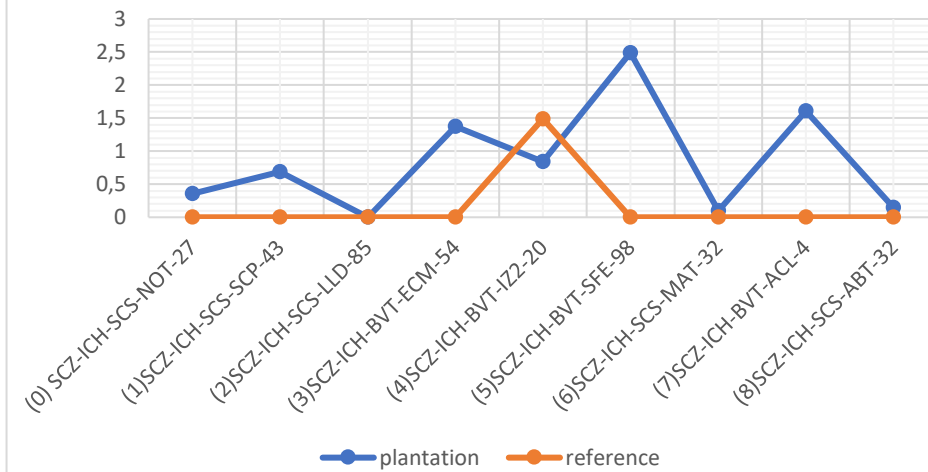
Table 11: H and D for plantations

Plantations	Species	H	D
0	Teca	0,36	0,71
1	Palo maría	0,69	0,29
2	Tejeyequé	0	0
3	Tejeyequé	1,37	0,61
4	Teca	0,84	0,39
5	Tejeyequé	2,49	0,91
6	Palo maría	0,1	0,04
7	Teca	1,61	0,73
8	Palo maría	0,15	0,07

Table 12: H and D for reference sites

Plantation	Past use	H	D
0	Natural pasture	0	0
1	Cultivated area	0	0
2	Cultivated area	0	0
3	Cultivated area	0	0
4	Rice field	1,49	0,86
5	pasture	0	0
6	Citrus	0	0
7	pasture	0	0
8	Cultivated area	0	0

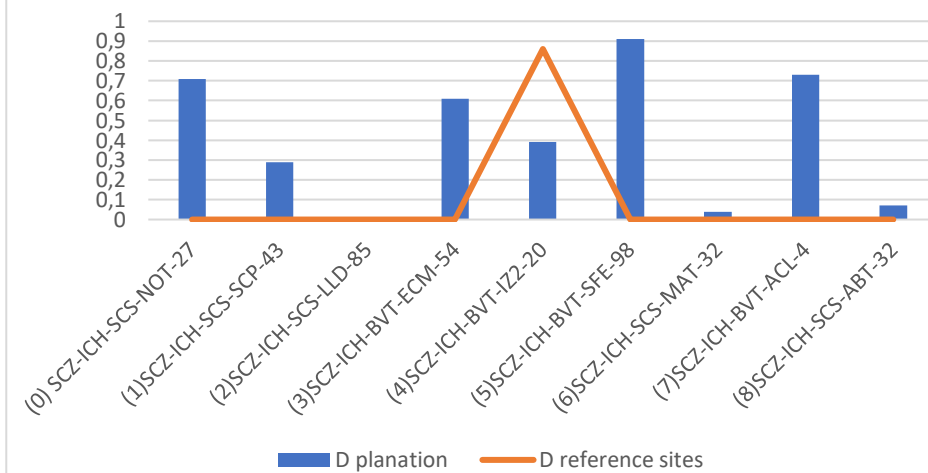
H for plantations and reference sites



22: Shannon wiener

The Shannon wiener index for the plantations is compared to the index of the reference sites. Only the reference site of plantation has a value > 0 and > than its plantation

D for plantations and reference sites



23: Simpson index.

The Simpson index of the plantation is compared to the Simpson index of the reference sites. Only the reference site of plantation 4 has a value > 0

Herbs and grass

Table 13 presents the results for herbs and grasses recorded in plantations and their reference sites. The first row shows the plantation number and code. Row 2-4 show data for reference sites and row 5-7 for plantations. The table shows the total of species recorded in each location. One can see that there were more species of herbs and grasses found in the reference sites than the plantations with the exemptions of plantation 0 and plantation 8. Plantation 0 (Teak) had more species of grass than its reference site and plantation 8 (Palomaria) had more herbs than its reference site.

Table 13: data for herbs and grass plantations and reference sites

Plantations numbers	(0) SCZ-ICH-SCS-NOT-27	(1) SCZ-ICH-SCS-SCP-43	(2) SCZ-ICH-SCS-LLD-85	(3) SCZ-ICH-BVT-ECM-54	(4) SCZ-ICH-BVT-IZ2-20	(5) SCZ-ICH-BVT-SFE-98	(6) SCZ-ICH-SCS-MAT-32	(7) SCZ-ICH-BVT-ACL-4	(8) SCZ-ICH-SCS-ABT-32
Reference sites									
herbs	11	18	5	7	3	11	9	11	9
Grass	4	9	7	5	3	5	6	4	9
Plantations									
herbs	5	9	2	6	2	0	8	8	10
Grass	11	3	0	0	0	0	3	0	4

There was a clear difference in plotting in a reference site and plotting in a plantation. Fig 24, 25 and 26 show the subplots 1m² and 2m² in plantations 2, 7 and 6 with respectively, and tejeyeque (*Centrolobium tomentosum*), teak (*Tectona grandis*) and palomaria (*Calophyllum brasiliense*). There are seedlings besides herbs and grass. The seedlings herbs and grasses are not fully exposed to sunlight. Fig 27 and 28 show subplots 1m² and 2m² in reference sites. In these subplots there are only herbs and grasses to be found.

There was also a difference in vegetation layers between the tree plantations. The plantations with most layers were plantations with tree species tejeyeque (*Centrolobium tomentosum*). This was followed by plantations with Teak (*Tectona grandis*). The plantations with fewer layers were plantations with Palomaria (*Calophyllum brasiliense*).



24: subplots 1m² and 2m² plantation 2, Tejeyeque (*Centrolobium tomentosum*)



25: subplots of 1m² and 2m² in Teca (*Tectona grandis*) plantation



26 : subplots of 1m² and 2m² in plantation 6, Palomaria (*Calophyllum brasiliense*)



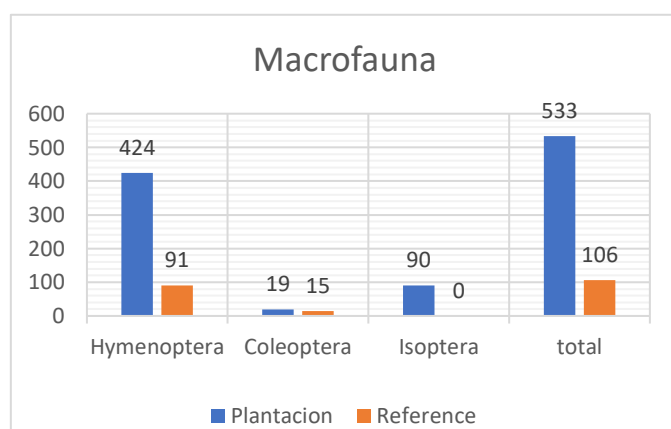
27: subplot 1m² in reference site, pasture



28: subplots 1m² and 2m² in reference site, cultivation

5.3. Results for the macro fauna

The findings for the macrofauna in the plantations and reference sites are presented in this paragraph. Appendix XVII gives an overview of the species recorded in the area and their quantities. Fig 29 shows the totals for the indicator groups ants, termites and beetles recorded in all the plantations and the reference sites. There were no termites found in the reference sites. The indicator species are better represented on the plantations in comparison to the reference sites.



29:macrofauna plantation and reference sites

The t-test was calculated to see whether there was a significant difference between the plantations and the reference sites. To determine what type of t- test to use, the variance was calculated using the f-test two samples for variances. This gave a $p = 0,048$, what meant that there was a significant difference in variances since the value was $< 0,05$. The t-test two samples assuming unequal variances gave values of $t=1,1$, $df=2$, $p=0,38$. The calculations can be found in appendix XVIII.

The Shannon wiener index had given a value of 0,6 for macrofauna on plantations and 0,4 for macrofauna on the reference sites, table 14. Considering that this index varies between 0 and 5 where 0 indicates a community with only one species and 5 a very diverse community, these values are very low. But because the plantations involved are monoculture plantations, meaning plantation with only one tree species, it is interesting that they're still a degree of diversity. The species diversity on the plantations was higher than on the reference sites. The calculations for the indices can be found in appendix XIX.

Table 14: Shannon wiener index for macrofauna

	plantations	ref
H	0,6	0,4
D	0,3	0,2

6. Conclusion

The main question of this research was: How do tree plantations established on farmlands in the Ichilo province of Bolivia benefit biodiversity over time in comparison to biodiversity on reference sites outside of the plantations? The analysis supports the theory that ecological benefits can be achieved with tree plantation in comparison to reference sites with past use pasture and cultivation area.

The data showed an overall correlation in fauna and the land cover, canopy. There were more fauna species encounters on the plantations than on the reference sites which had little to no canopy. Other than cover, trees also produce shelter for fauna.

With the approach of vertical stratification, the reference sites in this research were only represented in the level of grass and herbs. For the other levels being seedlings and trees there were no plants except for the reference site for plantation 4 with values of 0,71_0,31 for H and D. However, the plantations were represented in the level of trees, seedling, grass and herbs. The seedlings and trees together had a H and D of respectively 2,29_0,82. This shows that the diversity for seedlings and trees on the plantations is higher than on the reference sites. Both the plantations and reference sites were represented on the level of grass and herbs. Table 14 show that the species richness in the reference sites are higher than in the plantations.

There was an insignificant difference found for macro fauna in plantations and reference sites with $t=1,1_{df=2}p=0,38$. The H and D for plantations and reference sites were respectively 0,6_0,3 and 0,4_0,2. This shows that there is a higher diversity of macrofauna in the tree plantations compared to the reference sites.

7. Discussion

The aim of this research was to provide data that will be used for certification and to evaluate whether ecological benefits are achieved with tree plantations. The data on plantation is compared to data of reference sites.

The results of the interview can differ from the real situation on the plantations. The outcome depends on the fauna knowledge of each farmer. Bias was minimized by using appendix IV. Species that occurs in the surrounding forest outside of the plantation and farm could have been recorded with the interview. Therefore, the result of the line transects give a better representation of the fauna occurrence in the research areas. One thing to keep in mind while looking at the results for interview is that there is no information recorded for plantation 3. This is a plantation with tree species Tejeyeque (*Centrolobium tomentosum*). The farmer could not be reached for an interview.

The focus of this research was on the occurrence of fauna in the plantations. The results support the findings of (Stephens & Wagner, 2007) in which the fauna diversity on tree plantation was found higher than the fauna diversity on previous land use as pasture or cultivation.

The results for the flora diversity differed with earlier research done in plantations of Arbolivia project by (Altamirano, 2013). That research found 268 plants species belonging to 76 families. The plantations were in a different stage of development (between 3–5-year-old at that time) with herbs as dominating life form (64%). The PPM design was adjusted what meant elimination of the 1*1m quadrants. Another factor that effects the diversity of herbs and grasses is the weeding in the plantation. The diversity of seedlings, herbs and grass in the plantations differs depending on the last weeding of the plantations. Inventory done before weeding could have different results than inventory done after weeding.

(Ayuke, et al., 2009) had found a higher value for Simpson index and Shannon wiener index on plantation forest than fallow/pasture. The findings of this research are in line with the findings of the above. However, (Knapp & Růžicka, 2012) have shown that pitfall design and preservative used effects the results. This means that if other pitfall design is used than the one in this research, the results could differ.

Recommendations

The following are recommendations based on the results of this research. They are meant to further strengthen the arbolivia project's impact on the ecology of the plantations.

- the military macaw (*Ara militaris*), an IUCN red list species with declining population is observed in a plantation 4 (SCZ-ICH-BVT-IZ2-20). Future research should focus on the abundance and conservation of this species and its habitat in the plantations.
- to get better understanding in the influence of tree canopy on the lower layers of vegetation in the plantation future research should aim in investigating the effect of canopy in the light intensity that reaches the lower layers.
- Since this report was limited to investigating the species diversity, future research should focus on the effect and relation of organic matter of the different tree species on the macrofauna on the plantations. The indicator macrofauna species of this research could be used as baseline.

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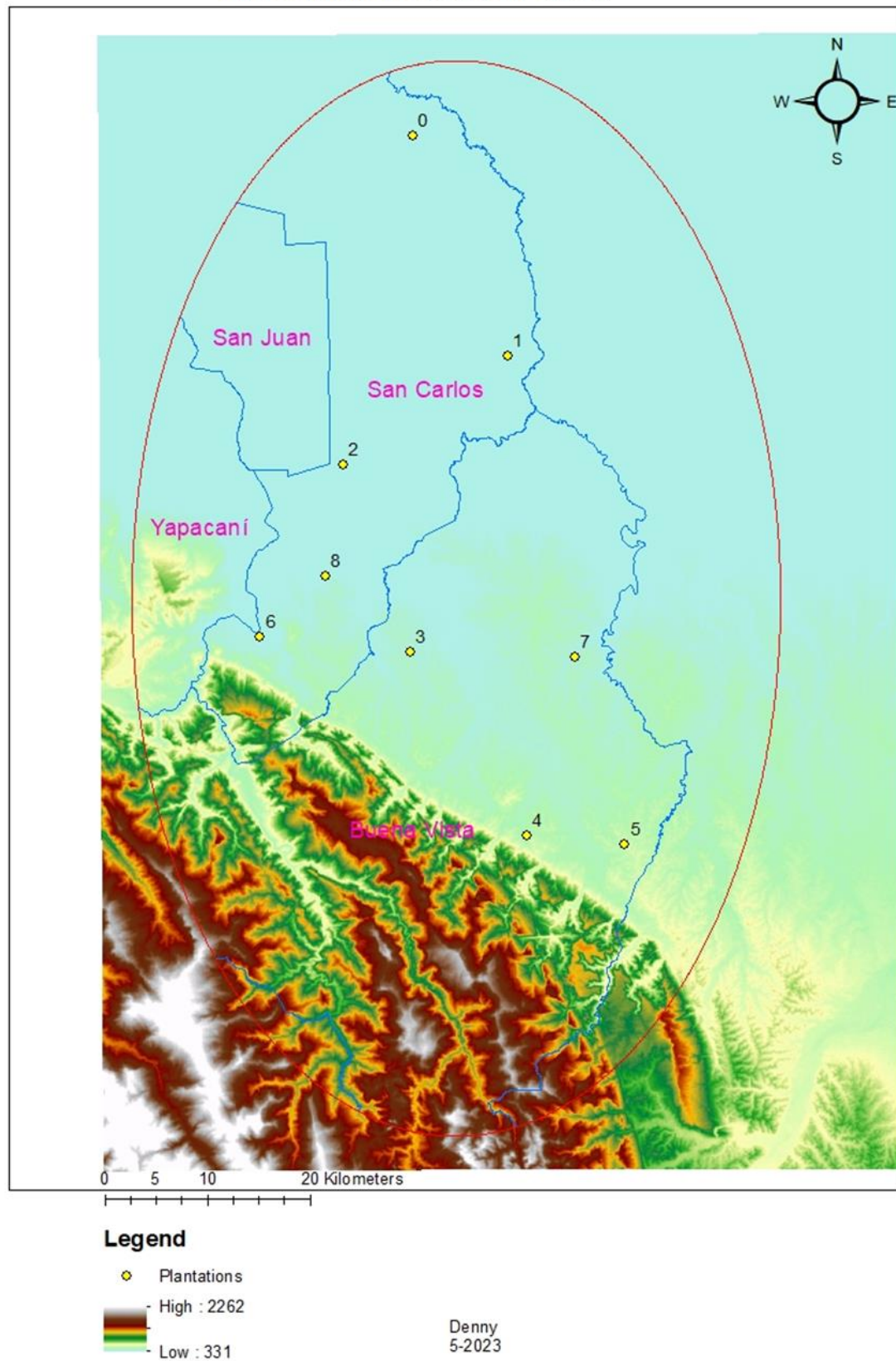
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Appendices

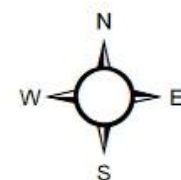
I. Elevation map with plantations

Elevation research area



II. Research area

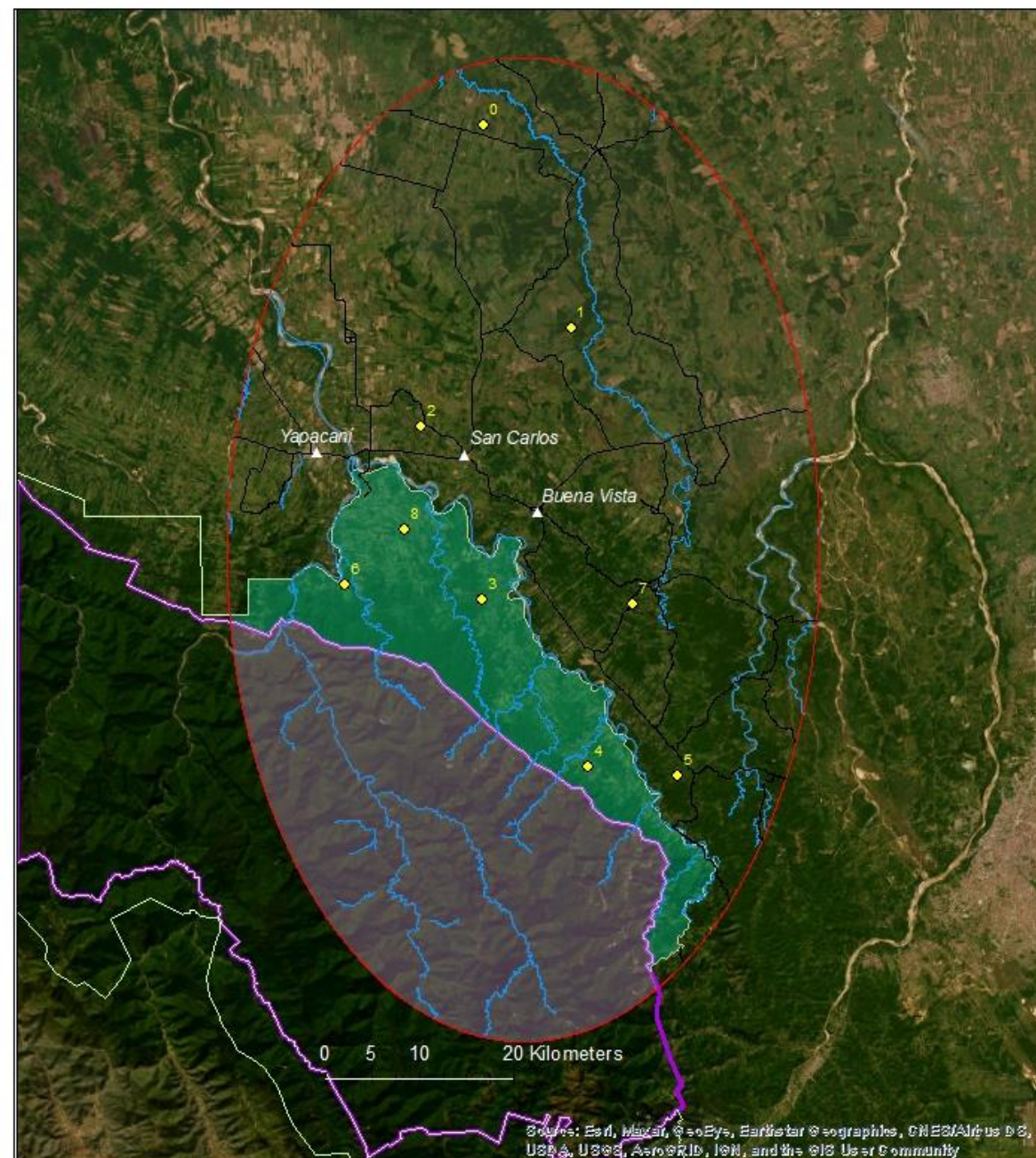
Research area



Legend

- Buena Vista
- San Carlos
- yapacani
- Plantations
- roads_ichilo
- rivers_ichilo
- Amboro national park
- natural area of integrated management

Denny Majokko
5-2023



III. Field form for transects.

Farm		Plantation/ reference	
Transect		Direct observer	
Date		Writer	
Time		Indirect observer	
weather			

	Cue	Species	Camera code	Distance to transect	Remarks
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

IV. Fauna species with prints

34: Collared anteater - *Tamandua tetradactyla*



33: Giant armadillo - *Mirmecophaga tridactyla*



32: Collared peccary - *Pecari tajacu*



35: White lipped peccary *Tayassu pecari*



28: Azara's agouti - *Dasyprocta azarae*



27: Brazilian porcupine - *Coendou prehensilis*



36: giant armadillo - *Priodontes maximus*



37: armadillo de nueve bandas - *Dasypus novemcinctus*



30: El tapir - *Tapirus terrestris*



29: El capibara - *Hydrochoerus hydrochaeris*



38: el euataste armadillo de seis bandas - *Euphractus sexcinctus*



31: lowland paca - *Cuniculus paca*



39: ring-tailed coati - *Nasua narica*



40: morsa hurón - *Eira barbara*



41: el jaguar - *Panthera onca*



44: jaguarundi - *Puma yagouaroundi*



43: cougar - *Puma concolor*



42: ocelot - *Leopardus pardalis*



V. Field form for PPM plot D, trees ≥ 10 cm dap

Proyecto ArBolivia
Planillas de Campo (ver. Ago. 2012)



Formulario 15-C:1/2 PARCELAS PERMANENTES DE MEDICIÓN (PPM)

Nombre del observador: Fecha:

Nombre Apellidos Código PPM Día / Mes / Año

[illegible]

VI. Explanation for parameters mentioned in appendix V.

Proyecto ArBOLIVIA
Planillas de Campo (ver. Ago. 2012)



Formulario 15-E PARCELAS PERMANENTES DE MEDICIÓN (PPM)

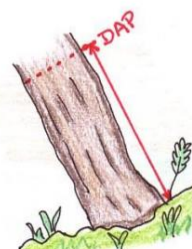
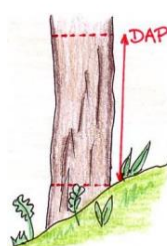
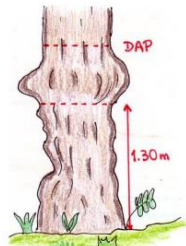
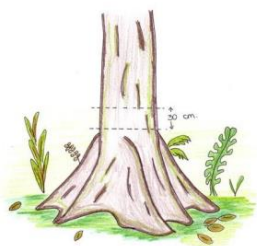
POSICION DE LA COPA		
	1	EMERGENTE
	2	PLENA VERTICAL Luz total de arriba
	3	PARCIAL VERTICAL Algo de luz de arriba (Doseil Mediano)
	4	LUZ LATERAL Algo de luz lateral (Parte superior del Sotobosque)
	5	AUSENCIA LATERAL Sin luz directa (Parte inferior del sotobosque)

FORMA DE LA COPA		
	1	PERFECTA Copa circular
	2	BUENA Copa de forma irregular
	3	TOLERABLE Mitad de la copa
	4	MALA Menos de mitad de copa
	5	MUY MALA Una o pocas ramas

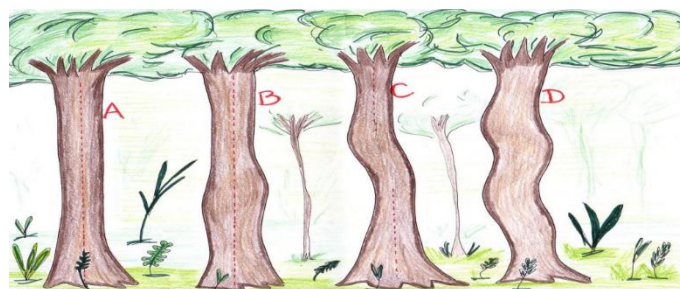
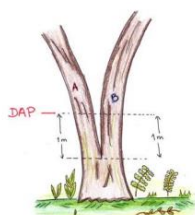
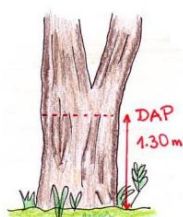
CARACTERISTICAS DEL FUSTE			
CALIDAD	CÓDIGOS PARA FORMA Y DEFECTOS DE FUSTE		
1 Buena	1 Cola de zorro	4 Torcedura basal	7 Enfermo
2 Regular	2 Poco sinuoso	5 Bifurcado	8 Infestado con plaga
3 Mala	3 Muy sinuoso	6 Inclinado	9 Copa asimétrica

COMPETENCIA Y SANIDAD	
COMPETENCIA	SANIDAD
1 Sin o muy poca competencia	1 Árbol sano
2 Regular competencia	2 Árbol enfermo
3 Competencia Fuerte	

VII. Further explanation of tree parameters mentioned in appendix V.



- Si el árbol está bifurcado por encima del DAP, medir a 1.30 m del nivel del suelo.
- Cuando está bifurcado por debajo del DAP, medir a 1 m partiendo de la bifurcación y como si fueran dos árboles separados.



Recto

Algunos defectos

Sinuoso

Totalmente sinuoso

VIII. Line transects recordings

nr	photo code	date	Transect	Plantation nr	Time	distance in cm	Local name	sign	Remarks
1	91642	10/03/2023	norte-sur	2	09:16:42	90	tatu	cueva	
2	91654	10/03/2023		2	09:16:54	0	tatu	camino	
3	92709	10/03/2023		2	09:17:09	70	tatu	cueva	
4	92530	10/03/2023		2	09:25:30	0	tatu	camino	
5	93048	10/03/2023		2	09:30:48	68	tatu	cueva	
6	93801	10/03/2023	este-oeste	2	09:38:02	0	tatu	cueva	
7	93926	10/03/2023		2	09:39:26	0	tatu	cueva	
8	94059	10/03/2023		2	09:40:59	0	tatu	cueva	
9		12/03/2023	norte-sur	6			toucan		direct observacion
10		12/03/2023		6			perdiz		3* direct observation
11		12/03/2023		6			cacare		direct observation
12		16/03/2023	redondo	8	00:00:00		0		
13		17/03/2023	norte-sur	8	00:00:00		0		
14		18/03/2023	este-oeste	8	00:00:00		0		
15		22/03/2023	redondo	1					
16		22/03/2023	norte-sur	1					
17		22/03/2023	este-oeste	1	11:27:00	400	ardilla		direct observation
18	122610	07/04/2023	norte-sur	3	12:26:10	0	jochi	camino	
19	122931	07/04/2023		3	12:29:31	15	jochi	huellas	
20	123122	07/04/2023		3	12:31:22	53	tatu	marcas de comida	
21	123251	07/04/2023		3	12:32:51	0	jochi	camino	
22	123534	07/04/2023		3	12:35:34	110	tatu	cueva	
23	123754	07/04/2023		3	12:37:54	146	jochi	cueva	
24	123929	07/04/2023		3	12:39:29	115	tatu	marcas de comida	
25	124221	07/04/2023		3	12:42:21	0	jochi		
26	124449	07/04/2023		3	12:44:49	0	peji	camino	
27	124556	07/04/2023		3	12:45:56	140	peji	marcas de comida	
28	125343	07/04/2023	este-oeste	3	12:53:43	0	peji	marcas de comida	
29	125557	07/04/2023		3	12:55:57	70	peji	marcas de comida	
30	125702	07/04/2023		3	12:57:02	90	peji	marcas de comida	
31	125815	7/4/223		3	12:58:15	72	tatu	marcas de comida	
32		12/04/2023	redondo	7					
33		12/04/2023	norte-sur	7					
34	94858	12/04/2023	este-oeste	7	09:48:58	30	tatu	cueva	
35	95437	12/04/2023		7	09:54:37	100	tatu	cueva	
36	95613	12/04/2023		7	09:56:13	130	tatu	cueva	
37	95841	12/04/2023		7	09:58:41	50	tatu	marcas de comida	
38	100030	12/04/2023		7	10:00:30	100	tatu	marcas de comida	
39	100436	12/04/2023		7	10:04:36	24	tatu	cueva	
40	100436	12/04/2023		7	10:04:36	120	tatu	cueva	mismo como arriba
41	100816	12/04/2023		7	10:08:16	121	tatu	marcas de comida	
42	144226	14/04/2023	norte-sur	5	14:42:26	80	tatu	marcas de comida	

43	92821	18/04/2023	norte-sur	0	09:28:21	70	tatu	cueva	
44	93438	18/04/2023	norte-sur	0	09:34:38	100	tatu	marcas de comida	
45	93712	18/04/2023	norte-sur	0	09:37:12	50	tatu	marcas de comida	
46	93923	18/04/2023	norte-sur	0	09:39:23	140	tatu	cueva	
47	94129	18/04/2023	norte-sur	0	09:41:29	10	tatu	cueva	
48	94343	18/04/2023	norte-sur	0	09:43:43	120	tatu	cueva	
49	94516	18/04/2023	norte-sur	0	09:45:16	20	tatu	marcas de comida	
50	94954	18/04/2023	este-oeste	0	09:49:54	90	tatu	cueva	
51	95425	18/04/2023	este-oeste	0	09:54:25	100	tatu	huella de pie	
52	95620	18/04/2023	este-oeste	0	09:56:20	110	tatu	cueva	
53	95735	18/04/2023	este-oeste	0	09:57:35	80	tatu	marcas de comida	
54	95843	18/04/2023	este-oeste	0	09:58:43	140	tatu	marcas de comida	
55	95940	18/04/2023	este-oeste	0	09:59:40	10	tatu	marcas de comida	
56	100024	18/04/2023	este-oeste	0	10:00:24	40	tatu	marcas de comida	
57	100305	18/04/2023	este-oeste	0	10:03:05	50	tatu	marcas de comida	
58	100421	18/04/2023	este-oeste	0	10:04:21	5	tatu	marcas de comida	
59	100538	18/04/2023	este-oeste	0	10:05:38	70	tatu	marcas de comida	
60	100625	18/04/2023	este-oeste	0	10:06:25	30	tatu	marcas de comida	
61	100719	18/04/2023	este-oeste	0	10:07:19	70	tatu	marcas de comida	
62		18/04/2023	este-oeste	0		100	Loro		direct observation
63		18/04/2023	este-oeste	0		500	Carpintero		gehoord
64		18/04/2023	este-oeste	0		±1,5km	mono		gehoord
65	100832	18/04/2023	este-oeste	0	10:08:32	50	tatu	marcas de comida	
66	100928	18/04/2023	este-oeste	0	10:09:28	35	tatu	marcas de comida	
67	101028	18/04/2023	este-oeste	0	10:10:28	45	tatu	marcas de comida	
68	101108	18/04/2023	este-oeste	0	10:11:08	80	tatu	marcas de comida	
69	101202	18/04/2023	este-oeste	0	10:12:02	140	tatu	marcas de comida	
70	101319	18/04/2023	este-oeste	0	10:13:19	120	tatu	marcas de comida	
71			redondo	0			0		
72	85640	22/04/2023	norte-sur	4	08:56:40	25	jochi	huellas	
73	85608	22/04/2023	norte-sur	4	08:56:08				
74	90436	22/04/2023	norte-sur	4	09:04:36	70	tatu	cueva	
75	90457	22/04/2023	norte-sur	4	09:04:57	0	tatu	camino	
76	91247	22/04/2023	norte-sur	4	09:12:47	60	tatu	cueva	
77	91401	22/04/2023	norte-sur	4	09:14:01	20	peji	marcas de comida	
78	91730	22/04/2023	norte-sur	4	09:17:30	40	tatu	cueva	
79	91945	22/04/2023	norte-sur	4	09:19:45	40	tatu	cueva	
80	92043	22/04/2023	norte-sur	4	09:20:43	40	tatu	cueva	
81	92128	22/04/2023	norte-sur	4	09:21:28	5	tatu	cueva	
82	92400	22/04/2023	norte-sur	4	09:24:00	0	tatu	camino	
83	92610	22/04/2023	norte-sur	4	09:26:10	80	tatu	cueva	
84			redondo				0		
85			norte-sur				0		
86			este-oeste			40m	ardilla	direct observation	

IX. Photos of line transect, plotting of ppm and signs



*line transect in Teak (*Tectona grandis*) plantation*



*plotting in Palomari (*Calophyllum brasiliense*) plantation. The line transects was relatively easier here.*



*plotting in Tejeyaque (*Centrolobium tomentosum*) plantation.*



feeding signs of armadillo sp.



path of armadillo sp.



hole of armadillo sp.

X. Information of fauna occurrence based on interviews

				(0) SCZ-ICH-SCS-NOT-27		(1) SCZ-ICH-SCS-SCP-43		(2) SCZ-ICH-SCS-LLD-85		(3) SCZ-ICH-BVT- ECM-54		(4) SCZ-ICH-BVT-IZ2-20		(5) SCZ-ICH-BVT-SFE-98		(6) SCZ-ICH-SCS-MAT-32		(7) SCZ-ICH-BVT-ACL-4		(8) SCZ-ICH-SCS-ABT-32	
				Reference	plantation	Ref	Plant	Ref	Plant	Ref	Plant	Ref	Plant	Ref	Plant	Ref	Plant	Ref	Plant	Ref	Plant
		birds	mammals																		
Ardilla	Sciurus ignitus		X										x						x		
Cacarece	Cyanocorax cyanomelas	X					x														
Calucha	Dasyprocta variegata		X					x				x	x	x							
Capiguara	Hydrochoerus hydrochaeris		X									x	x								
carachupa	Didelphis marsupialis		X										x								
Carpintero		X											x								
Chaicita	Columbina picui	X						x													
Guaraca	Ortalis guttata	X					x		x												
Jochi	Cuniculus paca		X	x				x				x		x							
Lekeleke		X																		x	
Loro		X					x	x	x				x		x		x		x		x
Mauri		X						x													
Meloro	Eira barbara		X		x																
Mono			X				x						x	x					x		x
Mursielago			X																		x
Oso hormigero	Tamandua tetradactyla		X		x								x						x		
Pavas		X							x												
Peji	Euphractus sexcinctus		X		x							x	x	x							

Perdiz	Nothura maculosa	X															X			X	
Perico	Bradypus variegatus		X		x																
Puerco	Pecari tajacu		X	x																	
Puerco espin	Coendou prehensilis		X										x								
Tatu, nueve bandas	Dasypus novemcintus		X		x	x		x	x			x	x	x				x	x		x
Tojo		X					x										x				
Torcaza		X						x	x												
Tordo	Oreopsar bolivianus	X						x													
Toucan	bird	X					x														
Urina	Mazama gouazoubira		X										x				x				
Venado			X									x	x								
Zorro			X		x												x				x

XI. Fauna species occurrence based on interviews grouped per zone

		low		Medium		high	
Ardilla	Sciurus ignitus				x		x
Cacarece	Cyanocorax cyanomelas		x				
Calucha	Dasypsecta variegata	x				x	x
Capiguara	Hydrochoerus hydrochaeris					x	x
carachupa	Didelphis marsupialis						x
Carpintero							x
Chaicita	Columbina picui	x					
Guaraca	Ortalis guttata		x				
Jochi	Cuniculus paca	x				x	
Lekeleke				x			
Loro		x	x		x		x
Mauri		x					
Meloro	Eira barbara		x				
Mono			x		x	x	x
Mursielago					x		
Oso hormigero	Tamandua tetradactyla		x		x		x
Pavas			x				
Peji	Euphractus sexcinctus		x			x	x
Perdiz	Nothura maculosa			x			x
Perico	Bradypus variegatus		x				
Puerco	Pecari tajacu	x					
Puerco espin	Coendou prehensilis						x
Tatu, nueve bandas	Dasypus novemcinctus	x	x	x	x	x	x
Tojo			x				x
Torcaza		x	x				
Tordo	Oreopsar bolivianus	x					
Toucan	bird		x				
Urina	Mazama gouazoubira						x
Venado						x	x
Zorro			x		x		x
		9	14	3	7	7	16

XII. Trees and seedlings per plantation

Local name	Life form	(0) SCZ- ICH- SCS- NOT- 27	(1) SCZ- ICH- SCS- SCP- 43	(2) SCZ- ICH- SCS- LLD- 85	(3) SCZ- ICH- BVT- ECM- 54	(4) SCZ- ICH- BVT- IZZ-20	(5) SCZ- ICH- BVT- SFE- 98	(6) SCZ- ICH- SCS- MAT- 32	(7) SCZ- ICH- BVT- ACL-4	(8) SCZ- ICH- SCS- ABT- 32
ambaiba	arbol				3		1			
curupaou	arbol				1		5			
rutaceae	arbol						1			
motaku	arbol	2	3		5		1			
Pajarilla	brinzal					1			3	
pakai	brinzal				2					
palo diablo	arbol		1							2
palo maria	arbol/brinzal		49					46		58
tajibo	arbol		1				1			
tamarindo	arbol		1							
Teca	arbol/brinzal	42				75			44	
tejeyeque	arbol/brinzal			34	25	3	12			
tjonta	brinzal				2			1		
totali	arbol		1							
wallaba	arbol		2							
unknown 4 (malba negra)	brinzal				2	1				
unknown3	arbol				1		1			
unknown2	arbol	2					2			
unknown1	arbol						4			
unknownC	brinzal						2			
unknownB	brinzal						4			
unknownA	brinzal						7			
fabaceae	arbol								2	
espino blanco	arbol						15		2	
pata de baca	brinzal								17	
sp.1	brinzal						5		33	
sp.2	brinzal								3	
sp.3	brinzal								1	
sp.4	brinzal								1	
sp.5	brinzal								2	
sp.6	brinzal								3	
sp.7	brinzal						7			
sp.8	brinzal						4			
sp.9	brinzal						2			
sp.10	brinzal					1				
sp.11	brinzal					2				
sp.12	brinzal					1				
sp.13	brinzal					13				
		46	58	34	41	97	74	47	111	60

XIII. Shannon-Wiener and Simpson index for trees and seedlings for all plantations and all reference sites

Brinzales y arboles			plantation			reference			SIMPSON			
	Plantation	Reference	pi	ln pi	h	pi	ln pi	h	Plantation		Reference	
									n-1	n*(n-1)	n-1	n*(n-1)
Ambaiba	4	0	0,007	-4,956	-0,035	0	0	0	3	12	-1	0
Curupaou	6	0	0,011	-4,550	-0,048	0	0	0	5	30	-1	0
Rutaceae	1	30	0,002	-6,342	-0,011	0,833	-0,182	-0,152	0	0	29	870
Motaku	11	2	0,019	-3,944	-0,076	0,056	-2,890	-0,161	10	110	1	2
Pajarilla	4	0	0,007	-4,956	-0,035	0	0	0	3	12	-1	0
Pakai	2	0	0,004	-5,649	-0,020	0	0	0	1	2	-1	0
palo diablo	3	0	0,005	-5,244	-0,028	0	0	0	2	6	-1	0
palo maria	153	0	0,269	-1,312	-0,353	0	0	0	152	23256	-1	0
Tajibo	2	0	0,004	-5,649	-0,020	0	0	0	1	2	-1	0
Tamarindo	1	0	0,002	-6,342	-0,011	0	0	0	0	0	-1	0
Teca	161	0	0,283	-1,261	-0,357	0	0	0	160	25760	-1	0
Tejeyeque	74	0	0,130	-2,038	-0,266	0	0	0	73	5402	-1	0
Tjonta	3	0	0,005	-5,244	-0,028	0	0	0	2	6	-1	0
Totali	1	0	0,002	-6,342	-0,011	0	0	0	0	0	-1	0
Wallaba	2	0	0,004	-5,649	-0,020	0	0	0	1	2	-1	0
unknown 4 (malba negra)	3	0	0,005	-5,244	-0,028	0	0	0	2	6	-1	0
unknown3	2	0	0,004	-5,649	-0,020	0	0	0	1	2	-1	0
unknown2	4	0	0,007	-4,956	-0,035	0	0	0	3	12	-1	0
unknown1	4	0	0,007	-4,956	-0,035	0	0	0	3	12	-1	0
unknownC	2	0	0,004	-5,649	-0,020	0	0	0	1	2	-1	0
unknownB	4	0	0,007	-4,956	-0,035	0	0	0	3	12	-1	0
unknownA	7	0	0,012	-4,396	-0,054	0	0	0	6	42	-1	0
Fabaceae	2	0	0,004	-5,649	-0,020	0	0	0	1	2	-1	0
espino blanco	17	0	0,030	-3,509	-0,105	0	0	0	16	272	-1	0
pata de baca	17	0	0,030	-3,509	-0,105	0	0	0	16	272	-1	0
sp.1	38	0	0,067	-2,705	-0,181	0	0	0	37	1406	-1	0
sp.2	3	0	0,005	-5,244	-0,028	0	0	0	2	6	-1	0
sp.3	1	0	0,002	-6,342	-0,011	0	0	0	0	0	-1	0
sp.4	1	0	0,002	-6,342	-0,011	0	0	0	0	0	-1	0
sp.5	2	0	0,004	-5,649	-0,020	0	0	0	1	2	-1	0
sp.6	3	0	0,005	-5,244	-0,028	0	0	0	2	6	-1	0
sp.7	7	0	0,012	-4,396	-0,054	0	0	0	6	42	-1	0
sp.8	4	0	0,007	-4,956	-0,035	0	0	0	3	12	-1	0
sp.9	2	0	0,004	-5,649	-0,020	0	0	0	1	2	-1	0
sp.10	1	0	0,002	-6,342	-0,011	0	0	0	0	0	-1	0
sp.11	2	0	0,004	-5,649	-0,020	0	0	0	1	2	-1	0
sp.12	1	0	0,002	-6,342	-0,011	0	0	0	0	0	-1	0
sp.13	13	0	0,023	-3,777	-0,086	0	0	0	12	156	-1	0
sp.14	0	1	0	0	0	0,028	-3,584	-0,100	-1	0	0	0
sp.15	0	1	0	0	0	0,028	-3,584	-0,100	-1	0	0	0
sp.16	0	1	0	0	0	0,028	-3,584	-0,100	-1	0	0	0
sp.17	0	1	0	0	0	0,028	-3,584	-0,100	-1	0	0	0
sp.18	0	0	0	0	0	0		0	-1	0	-1	0
Total	568	36			-2,291			-0,711		56868	0	872
			H	2,29				0,71	322056		N	1260
									0,823		D	0,308

XIV. Shannon-Wiener index calculated separately for each plantation

Plantation	0		1		2		3		4		5		6		7		8	
Species local	pi	ln pi	pi	ln pi	pi	ln pi	pi	ln pi	pi	ln pi	pi	ln pi	pi	ln pi	pi	ln pi	pi	ln pi
ambaiba	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
curupaou	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
rutaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
motaku	0,043478	-3,13549	-0,13633	0,051724	-2,96183	-0,1532	0	0	0	0,121951	-2,10413	-0,2566	0	0	0	0,13514	-4,30407	-0,058163042
Pajarilla	0	0	0	0	0	0	0	0	0	0	0,010309	-4,57471	-0,04716	0	0	0	0,027027	-3,61092
pakai	0	0	0	0	0	0	0	0	0	0,04878	-3,02042	-0,14734	0	0	0	0	0	0
palo diablo	0	0	0	0,017241	-4,06044	-0,07001	0	0	0	0	0	0	0	0	0	0	0	0,033333
palo maria	0	0	0	0,844828	-0,16862	-0,14246	0	0	0	0	0	0	0	0	0,978723	-0,02151	-0,02105	0
tajibo	0	0	0	0,017241	-4,06044	-0,07001	0	0	0	0	0	0	0	0,013514	-4,30407	-0,058163042	0	0
tamarindo	0	0	0	0,017241	-4,06044	-0,07001	0	0	0	0	0	0	0	0	0	0	0	0
Teca	0,913043	-0,09097	-0,08306	0	0	0	0	0	0	0	0,773196	-0,25722	-0,19888	0	0	0	0,396396	-0,92534
tejeyeque	0	0	0	0	0	0	1	0	0	0,609756	-0,4947	-0,30164	0,030928	-3,4761	-0,10751	0,162162	-1,81916	-0,294998666
tjonta	0	0	0	0	0	0	0	0	0	0,04878	-3,02042	-0,14734	0	0	0	0	0,021277	-3,85015
total	0	0	0	0,017241	-4,06044	-0,07001	0	0	0	0	0	0	0	0	0	0	0	0
wallaba	0	0	0	0,034483	-3,3673	-0,11611	0	0	0	0	0	0	0	0	0	0	0	0
unknown 4 (malba negra)	0	0	0	0	0	0	0	0	0	0,04878	-3,02042	-0,14734	0,010309	-4,57471	-0,04716	0	0	0
unknown3	0	0	0	0	0	0	0	0	0	0,02439	-3,71357	-0,09057	0	0	0	0,013514	-4,30407	-0,058163042
unknown2	0,043478	-3,13549	-0,13633	0	0	0	0	0	0	0	0	0	0	0,027027	-3,61092	-0,097592376	0	0
unknown1	0	0	0	0	0	0	0	0	0	0	0	0	0	0,054054	-2,91777	-0,157717337	0	0
unknownC	0	0	0	0	0	0	0	0	0	0	0	0	0	0,027027	-3,61092	-0,097592376	0	0
unknownB	0	0	0	0	0	0	0	0	0	0	0	0	0	0,054054	-2,91777	-0,157717337	0	0
unknownA	0	0	0	0	0	0	0	0	0	0	0	0	0	0,094595	-2,35815	-0,223068711	0	0
fabaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,018018	-4,01638
espino blanco	0	0	0	0	0	0	0	0	0	0	0	0	0	0,202703	-1,59601	-0,323516532	0	0
pata de baca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,153153	-1,87632
sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0,067568	-2,69463	-0,182069404	0	0
sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,027027	-3,61092
sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,009009	-4,70953
sp.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,009009	-4,70953
sp.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,018018	-4,01638
sp.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,027027	-3,61092
sp.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0,094595	-2,35815	-0,223068711	0	0
sp.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0,054054	-2,91777	-0,157717337	0	0
sp.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0,027027	-3,61092	-0,097592376	0	0
sp.10	0	0	0	0	0	0	0	0	0	0	0,010309	-4,57471	-0,04716	0	0	0	0	0
sp.11	0	0	0	0	0	0	0	0	0	0	0,020619	-3,88156	-0,08003	0	0	0	0	0
sp.12	0	0	0	0	0	0	0	0	0	0	0,010309	-4,57471	-0,04716	0	0	0	0	0
sp.13	0	0	0	0	0	0	0	0	0	0	0,134021	-2,00976	-0,26935	0	0	0	0	0
Shannon index			-0,35571		-0,6918		0	0	-1,37275	0	0	-0,84442		-2,485535776	0	0	-0,10297	-1,60953
			0,36		0,69						1,37		0,84		2,49		0,1	1,61
																		0,15

XV. Simpson index for seedlings and trees of the plantations

	0		1		2		3		4		5		6		7		8	
	n-1	n*(n-1)	n-1	n*(n-1)	n-1	n*(n-1)	n-1	n*(n-1)	n-1	n*(n-1)	n-1	n*(n-1)	n-1	n*(n-1)	n-1	n*(n-1)	n-1	n*(n-1)
ambaiba	-1	0	-1	0	-1	0	2	6	-1	0	0	0	-1	0	-1	0	-1	0
curupaou	-1	0	-1	0	-1	0	0	0	-1	0	4	20	-1	0	-1	0	-1	0
rutaceae	-1	0	-1	0	-1	0	-1	0	-1	0	0	0	-1	0	-1	0	-1	0
motaku	1	2	2	6	-1	0	4	20	-1	0	0	0	-1	0	-1	0	-1	0
Pajarilla	-1	0	-1	0	-1	0	-1	0	0	0	-1	0	-1	0	2	6	-1	0
pakai	-1	0	-1	0	-1	0	1	2	-1	0	-1	0	-1	0	-1	0	-1	0
palo diablo	-1	0	0	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	1	2
palo maria	-1	0	48	2352	-1	0	-1	0	-1	0	-1	0	45	2070	-1	0	57	3306
tajibo	-1	0	0	0	-1	0	-1	0	-1	0	0	0	-1	0	-1	0	-1	0
tamarindo	-1	0	0	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0
Teca	41	1722	-1	0	-1	0	-1	0	74	5550	-1	0	-1	0	43	1892	-1	0
tejeyeque	-1	0	-1	0	33	1122	24	600	2	6	11	132	-1	0	-1	0	-1	0
tjonta	-1	0	-1	0	-1	0	1	2	-1	0	-1	0	0	0	-1	0	-1	0
totali	-1	0	0	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0
wallaba	-1	0	1	2	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0
unknown 4 (malba negra)	-1	0	-1	0	-1	0	1	2	0	0	-1	0	-1	0	-1	0	-1	0
unknown3	-1	0	-1	0	-1	0	0	0	-1	0	0	0	-1	0	-1	0	-1	0
unknown2	1	2	-1	0	-1	0	-1	0	-1	0	1	2	-1	0	-1	0	-1	0
unknown1	-1	0	-1	0	-1	0	-1	0	-1	0	3	12	-1	0	-1	0	-1	0
unknownC	-1	0	-1	0	-1	0	-1	0	-1	0	1	2	-1	0	-1	0	-1	0
unknownB	-1	0	-1	0	-1	0	-1	0	-1	0	3	12	-1	0	-1	0	-1	0
unknownA	-1	0	-1	0	-1	0	-1	0	-1	0	6	42	-1	0	-1	0	-1	0
fabaceae	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	1	2	-1	0
espino blanco	-1	0	-1	0	-1	0	-1	0	-1	0	14	210	-1	0	1	2	-1	0
pata de baca	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	16	272	-1	0
sp.1	-1	0	-1	0	-1	0	-1	0	-1	0	4	20	-1	0	32	1056	-1	0
sp.2	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	2	6	-1	0
sp.3	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	0	0	-1	0
sp.4	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	0	0	-1	0
sp.5	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	1	2	-1	0
sp.6	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	2	6	-1	0
sp.7	-1	0	-1	0	-1	0	-1	0	-1	0	6	42	-1	0	-1	0	-1	0
sp.8	-1	0	-1	0	-1	0	-1	0	-1	0	3	12	-1	0	-1	0	-1	0
sp.9	-1	0	-1	0	-1	0	-1	0	-1	0	1	2	-1	0	-1	0	-1	0
sp.10	-1	0	-1	0	-1	0	-1	0	0	0	-1	0	-1	0	-1	0	-1	0
sp.11	-1	0	-1	0	-1	0	-1	0	1	2	-1	0	-1	0	-1	0	-1	0
sp.12	-1	0	-1	0	-1	0	-1	0	0	0	-1	0	-1	0	-1	0	-1	0
sp.13	-1	0	-1	0	-1	0	-1	0	12	156	-1	0	-1	0	-1	0	-1	0
		1726		2360		1122		632		5714		508		2070		3244		3308
	N-1	45	57	33	40	96	73	46	110	59								
	N	2070	3306	1122	1640	9312	5402	2162	12210	3540								
	D	0,17		0,29		0,00		0,61		0,39		0,91		0,04		0,73		0,07

XVI. Shannon wiener index and Simpson index for reference sites

	1		4				6		
	pi	ln pi	pi	ln pi	pi	ln pi	pi	ln pi	
citricus	0	0	0	0	0	0	1	0	0
motaku	1	0	0	0	0	0	0	0	0
sp.14	0	0	0	0,125	-2,07944	-0,25993	0	0	0
sp.15	0	0	0	0,375	-0,98083	-0,36781	0	0	0
sp.16	0	0	0	0,125	-2,07944	-0,25993	0	0	0
sp.17	0	0	0	0,25	-1,38629	-0,34657	0	0	0
sp.18	0	0	0	0,125	-2,07944	-0,25993	0	0	0
			0			-1,49418			0
Shannon index			0			1,49			0

	1		4		6	
	n-1	n*(n-1)	n-1	n*(n-1)	n-1	n*(n-1)
citricus	-1	0	-1	0	29	870
motaku	0	0	-1	0	-1	0
sp.14	-1	0	0	0	-1	0
sp.15	-1	0	2	6	-1	0
sp.16	-1	0	0	0	-1	0
sp.17	-1	0	1	2	-1	0
sp.18	-1	0	0	0	-1	0
total		0		8		870
		N-1		7		29
		N-1		56		870
		D		0,86		0

XVII. Macrofauna

			Plantation				Reference
Order	species	tipo		(0) SCZ-ICH-SCS-NOT-27	species	tipo	
Hymenoptera		atta sp	180				
		ant	33				30
				(1) SCZ-ICH-SCS-SCP-43			
Coleoptera	Pterostichus spp.	beetle	2			beetle	1
	Sphenophorini species	beetle	1				
Hymenoptera	Pachycondyla sp.	ant	4		paraponera sp.	ant	1
	Dolichoderus sp.	ant	1			ant	2
				(2) SCZ-ICH-SCS-LLD-85			
Hymenoptera		ant	1			ant	5
Coleoptera		beetle	1			beetle	2
				(3) SCZ-ICH-BVT- ECM-54			
Hymenoptera		ant	80				10
Isoptera		termite	83				
coleoptera							4
				(4) SCZ-ICH-BVT-IZ2-20			
Hymenoptera		ant	8				13
Coleoptera						beetle	1
				(5) SCZ-ICH-BVT-SFE-98			
Coleoptera		beetle	7				2
Hymenoptera		ant	106				7
Isoptera		termite	7				
				(6) SCZ-ICH-SCS-MAT-32			
Hymenoptera		ants	3				2
Coleoptera		beetles	6				3
				(7) SCZ-ICH-BVT-ACL-4			
Hymenoptera		ant	9				20
				(8) SCZ-ICH-SCS-ABT-32			
Hymenoptera		ant	4				11
Coleoptera		beetle	2				2

XVIII. F-test and T-test macrofauna

F-Test Two-Sample for Variances		
	Plantation	Reference
Mean	177,6667	35,33333
Variance	46770,33	2380,333
Observations	3	3
df	2	2
F	19,64865	
P(F<=f) one-tail	0,048429	
F Critical one-tail	19	
F-Test Two-Sample for Variances		

t-Test: Two-Sample Assuming Unequal Variances		
	Plantation	Reference
Mean	177,6667	35,33333
Variance	46770,33	2380,333
Observations	3	3
Hypothesized Mean Difference	0	
df	2	
t Stat	1,111994	
P(T<=t) one-tail	0,190947	
t Critical one-tail	2,919986	
P(T<=t) two-tail	0,381894	
t Critical two-tail	4,302653	

XIX. Shannon wiener index and Simpson index calculation for macrofauna

	Plantation	Reference	pi	ln pi		pi	ln pi		n-1	n*(n-1)	n-1	n*(n-1)
Hymenoptera	424	91	0,795497	-0,22879	-0,182	0,858491	-0,15258	-0,13099	423	179352	90	8190
Coleoptera	19	15	0,035647	-3,33408	-0,11885	0,141509	-1,95539	-0,27671	18	342	14	210
Isoptera	90	0	0,168856	-1,77871	-0,30035	0	0	0	89	8010	-1	0
total	533	106			-0,6012			-0,40769		187704		8400
									N	283556	N	11235
									D	0,338036	D	0,252336

