UNIVERSITÀ DEGLI STUDI DI PADOVA

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Department of Land, Environment Agriculture and Forestry

Second Cycle Degree (MSc)

in Forest Science

Recommendation of native species for the reforestation of degraded land using live staking in Antioquia and Caldas' Departments (Colombia)

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Summary

Although Colombia is one of the countries with the greatest biodiversity in the world, it has many degraded areas due to agricultural and mining practices that have been carried out in recent decades. The high Andean forests are especially vulnerable to this type of soil erosion. The corporate purpose of ‘*Reforestadora El Guásimo S.A.S.’* is to use wood from its plantations, but it also follows the parameters of the *Forest Stewardship Council* (FSC). For this reason, it carries out reforestation activities and programs and, very particularly, it is interested in carrying out ecological restoration processes in some critical sites. The study area is located between 2000 and 2750 masl and is considered a low Andean humid forest (bmh-MB). The average annual precipitation rate is 2057 mm and the average temperature is around 11 ºC. The soil has a sandy loam texture with low pH, which limits the amount of nutrients it can absorb. FAO (2014) suggests that around 10 genera are enough for a proper restoration. After a bibliographic revision, the genera chosen were *Alchornea, Billia, Ficus, Inga, Meriania, Miconia, Ocotea, Protium, Prunus, Psidium, Symplocos, Tibouchina,* and *Weinmannia*. Two inventories from 2013 and 2019, helped to determine different biodiversity indexes to check the survival of different species and to suggest the adequate characteristics of the individuals for a successful vegetative stakes reforestation.

Keywords: Reforestation, native species, adaptation, vegetative reproduction.

Summary (Italian)

Sebbene la Colombia sia uno dei Paesi con la più grande biodiversità del mondo, ha molte aree degradate a causa delle pratiche agricole e minerarie che sono state realizzate negli ultimi decenni. Le alte foreste andine sono particolarmente vulnerabili a questo tipo di erosione del suolo. Lo scopo aziendale di "Reforestadora El Guásimo S.A.S." è quello di utilizzare il legno delle sue piantagioni, e inoltre seguire anche i parametri del Forest Stewardship Council (FSC). Per questo motivo, svolge attività e programmi di riforestazione e, in particolare, è interessata a realizzare processi di ripristino ecologico in alcuni siti critici. L'area di studio si trova tra il 2000 e il 2750 masl ed è considerata una bassa foresta umida andina (bmh-MB). Il tasso medio annuo di precipitazioni è di 2057 mm e la temperatura media è di circa 11 ºC. Il suolo ha una tessitura terricola sabbiosa a pH basso, che limita la quantità di sostanze nutritive che può assorbire. La FAO (2014) suggerisce che circa 10 generi sono sufficienti per un corretto ripristino. Dopo una revisione bibliografica, i generi scelti sono stati Alchornea, Billia, Ficus, Inga, Meriania, Miconia, Ocotea, Protium, Prunus, Psidium, Symplocos, Tibouchina e Weinmannia. Due inventari del 2013 e del 2019, hanno contribuito a determinare diversi indici di biodiversità per verificare la sopravvivenza delle diverse specie e per suggerire le caratteristiche adeguate degli individui per una riforestazione vegetativa di successo.

Parole chiave: riforestazione, specie autoctone, adattamento, riproduzione vegetativa.

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Table of contents

Index of figures

Index of tables

1. INTRODUCTION

Colombia is the second most diverse country in the world (WWF, 2017), hosting a high number of endemic plant species. The country has a diverse amount of ecosystems, from the coastal (including coral reefs and mangroves) to the high montane regions (the important Andean region). In total, there are 91 ecosystems, 70 of them are natural and the rest are modified (SIAC, 2017). At the same time, these ecosystems bring different income sources to the population such as tourism, food, or plants for medicinal uses (IDEAM, 2014). The ecosystem services in the country are threatened due to land-use change, especially wetlands, mangroves, and freshwater lakes (Ricaurte *et al.,* 2019). Focusing on the Andean region, Ruiz-Agudelo *et al*. (2011) confirm that the ecosystem services with more economic value are the ones related to water resources, followed by biodiversity conservation and recreation and tourism. Just in 2011, the ecosystem services value in this area yielded between USD 106 and 339 trillion (Ruiz–Agudelo & Bello, 2014). Because of all the benefits derived from ecosystem services, they need to be preserved, from coastal areas to mountain regions. For example, highlighting the importance of conserving forest patches, which provides crucial habitats for bird survival which, in turn, allow pollination, seed dispersal, or pest control (Muñoz *et al.*, 2013).

Colombian forests make up 10% of the planet's biodiversity (Baptiste *et al.*, 2017), and they play an important role throughout the country regulating the climate or the hydrological cycles (Instituto Alexander Von Humboldt, 2015). In regards to the division done by Morales *et al*. (2002), forests in Colombia are divided into the following groups: Andean forest (9,108,474 ha), fragmented Andean forest (3,040,711 ha), fragmented basal forests (6,868.,216 ha), Pacific basal forests (4,429,955 ha), Amazonian basal forests (33,506,755 ha), Caribbean basal forests (7,669 ha), Orinoco´s basal forests (20,980 ha), riparian forests (3,907,090 ha), Caribbean special swamp (2,335.,804 ha), Amazonian special swamp (161,186 ha), Andean special swamp (4,976 ha), Caribbean mangroves (66,201 ha), Pacific mangroves (282,448 ha), Pacific islands (1,451 ha), planted Andean forest (15,625 ha) and planted Andean lowland forests (19,777,519 ha). Despite the categories given to the forests, the politics, and their borders, they continue to decrease in size, due to different conflicts and land conversion. Agriculture, livestock, and mining are activities that are present in the country and they are strongly linked with deforestation, affecting the hydrological cycle and biodiversity (Gonzáles, 1979; Wantzen, 2013). From 2001 to 2018 the cover loss was 4.05 Mha which is equivalent to 5% of the forests and 1.6 Gt of CO_2 (Global Forest Watch, 2020). In **Figure 1** it is possible to see the forest cover loss in the country.

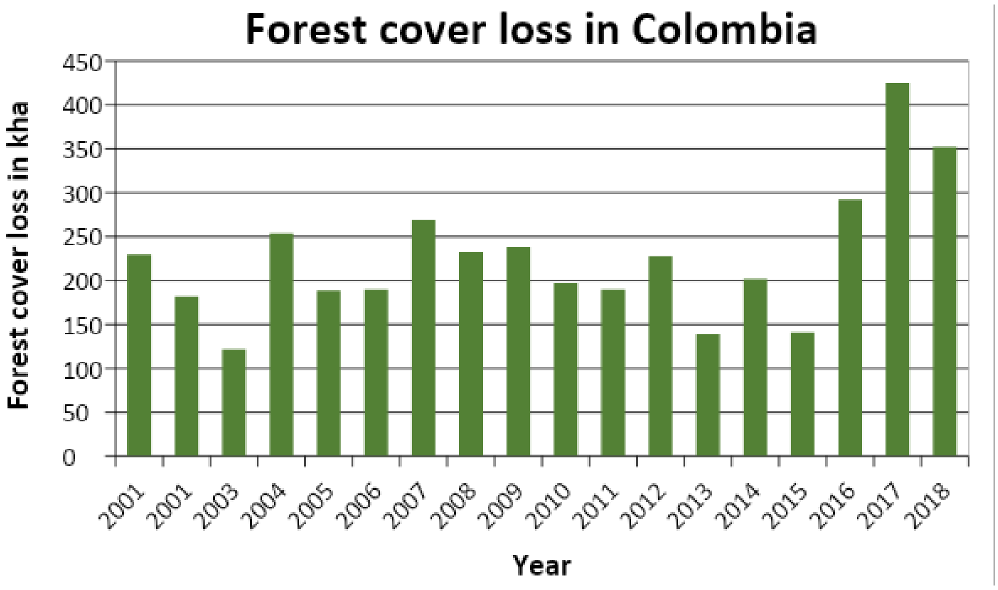


Figure 1. Forest cover loss in Colombia from 2001 to 2018. Source: Global Forest Watch, 2020.

One of the major and growing environmental challenges of this century is reforestation (Bozzano *et al.*, 2014). The main goals are avoiding biodiversity loss, climate change, and desertification, which are connected with poverty around the world (Reid & Swiderska, 2008). Tropical reforestation is considered one important intervention to mitigate climate change due to its potential carbon storage (Locatelli *et al.*, 2015). Because including the reasons mentioned above, there are many enterprises involved in reforestation (and other activities) as ‘Reforestadora El Guásimo S.A.S.’.

‘Reforestadora El Guásimo S.A.S.’, located in Envigado city (Department of Antioquia, Colombia), carries out forestry and logging activities, financed by private enterprises. They have many different plots that must be reforested, with one challenge: the soil is degraded. For this study, just 5 plots are going to be analyzed.

Due to the continuous agriculture and mining (Rincón, 2015) during decades, many areas of the country suffer notable soil degradation. This means a constant soil loss, with the presence of ditches in many places, loss of water, or the presence of invasive species (Spain & Gualdrón,1991; Gutiérrez Bonilla, 2006). All of the above have serious consequences for very vulnerable ecosystems such as the paramos (Novoa Usaquén, 2017).

It should be stated that reforestation is not just planting trees, the trees planted must resist abiotic and biotic stress, so, therefore, it is a process that requires careful planning. Many aspects must be taken into account, among them:

- Abiotic conditions as the temperature, soil pH, organic matter, humidity, or light. They have great importance in determining vegetation patterns as well as their distribution (Pueyo & Alados, 2007).
- Presence of invasive species, that spread all around the areas and often competing with native species (Vila & Weiner, 2004). Measures must be taken to manage present alien species to ensure future conditions. Besides the negative aspects, it should be reminded that not all invasive species are harmful (López, 2016). Nowadays afforestation and reforestation policies should include actions and principles to reduce the impacts of invasive species (Brundu & Richardson, 2016).
- Dispersal agents, as seed dispersal, plays an important role in plant ecology. Different strategies of different species for dispersal must be taken into account, as it is a factor that contributes to the population's growth (Howe & Miriti, 2004). Most of the species in the tropics reach their new places to grow via the gut of animals, which makes us consider that it can appear in the area (Corlett & Hau, 2000).
- Pollination and genetic diversity, considering that self-pollination is a positive aspect to avoid low genetic diversity (Bozzano *et al.,* 2014). It is vital to know about the importance of fragmentation that affects directly to the gene flow, as pollen is the main mode of gene flow in plants (Ellstrand, 1992). Nowadays, forest certification and labeling standards require action to conserve and boost genetic diversity normally using local provenances.
- Seed sources. Seeds should come from primary seed sources, desirably from large populations (normally a population constituted by 100 – 200 individuals should be enough; although in some cases, to ensure the quality of the seeds this number ascends to 400). This is to ensure not only seed quality but quantity. Although it is true that the scale of the project matters (Merritt & Dixon, 2011), appropriate local seed sources are needed to continue with it. As Broadhurst *et al.* (2008) suggested in their study, to obtain a useful genetic diversity it is recommended to obtain seeds from small populations around the reforestation area. As Breed *et al.* (2012) studied, sampling different plots around the study area is recommended to avoid habitat fragmentation impacts, a fact that can have as a result isolated populations with low diversity (Pardini *et al.*, 2005; Bennet, 2004) and other negative aspects that affect biodiversity (Fahrig, 2003; Ferraz *et al.*, 2007).

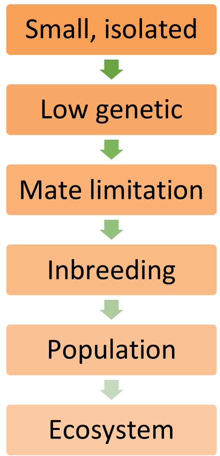


Figure 2. *Impact of low diversity. Own source, an adaptation from FAO (2014).*

- Vegetative methods. These have been used in tropical agriculture and have many benefits such as the speed of the growth (Ezekiel, 2010). There are two main forms of vegetative propagation: (1) cuttings, which are typically 20–40 cm long, taken from young branches or shoots of trees and in some species it has been demonstrated as rapid root growth (Tchoundjeu & Leakey, 1996); and (2) stakes, which are typically 2–2.5 m long. The second method has been widely used throughout southern Mexico and Central America for rangelands recovery (Zahawi & Holl, 2009), it has some advantages over the first method and it has shown some success in Colombian high Andean ecosystems (Polanía pers. comm.). It is the method that has been chosen for the project, as some authors as Díaz-Páez & Polanía (2017) have demonstrated its success in several species, although the process of transplanting is delicated (Sensu Rojas *et al.*, 2004).

All these actions must be linked with others as the soil structure recovery or conteinance of geographical accidents as ravines (Fenton et al., 2008; Jiménez, 2018).

The project aims to select the best species considering all their possible characteristics to reforest the different plots owned by the enterprise using vegetative stakes. This method, that has been successful in many tropical areas has a large number of advantages due to: (i) Fast-growth of the plants, (ii) The rapid production of fruit attracts frugivore animals, and (iii) 'Ready to plant' species (Zahawi, 2005). Adding that one of the most critical steps is the one related to reproduction, animal interactions are an important factor to be considered (Schelhas & Greenberg, 1996).

2. METHODOLOGY

2.1 STUDY AREA

The study area is located in the so-called 'Norte antioqueño', although one of the six plots is located in Caldas' Department (**Figure 4**). As it is possible to recognize in **Figure 3**, the 'Norte antioqueño' is located in Antioquia, which is one of the 32 departments in Colombia with Medellín as its capital. Antioquia is one of the richest biodiversity departments (Bilibio *et al.*, 2011) with two mountain ranges crossing it: the West and the Central Andes. This department has a wide variety of climatic conditions (from tropical to Andean) which facilitates the existence of different habitats (49 ecosystems identified in total) (CORANTIOQUIA, 2009). On the other hand, Caldas´ Department is located on the south of Antioquia´s Department, having a wide range of altitude, 200 – 5,472 masl, which favors the diversity present in the area. Its biodiversity is very abundant but the information about it is incomplete (Castaño *et al.*, 2003).

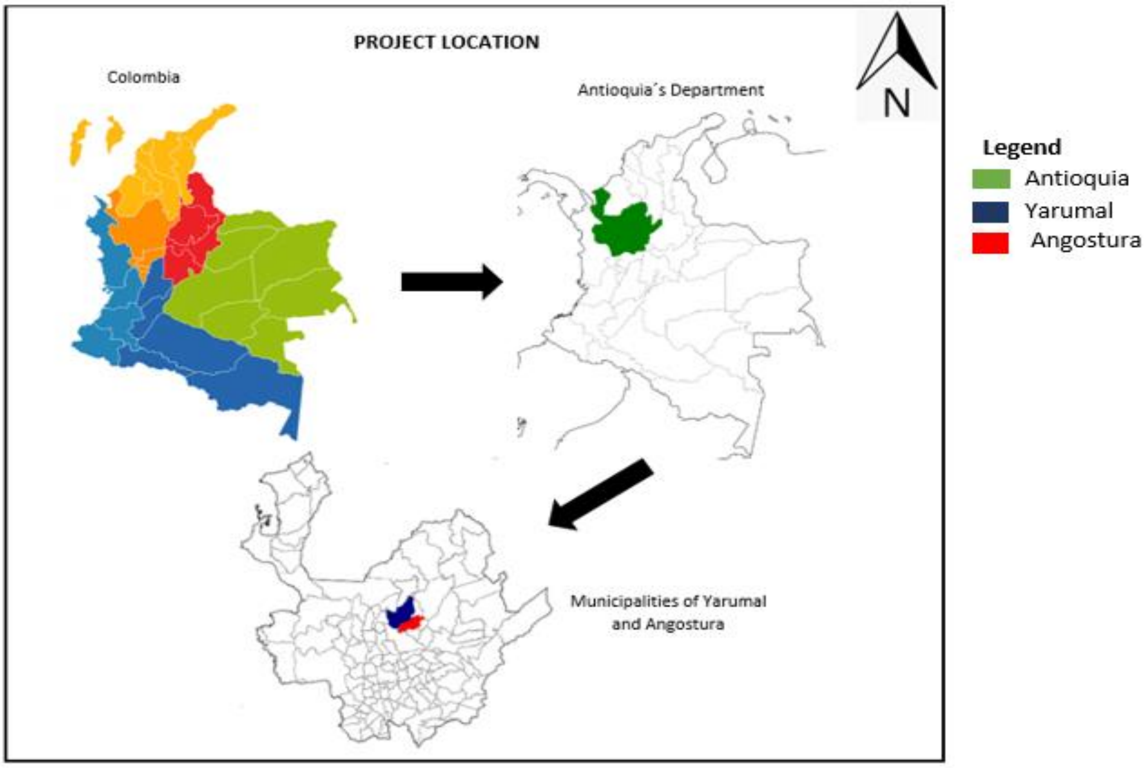


Figure 3. Antioquia's department (green area). Municipalities of Yarumal and Angostura (blue and red area). Own source.

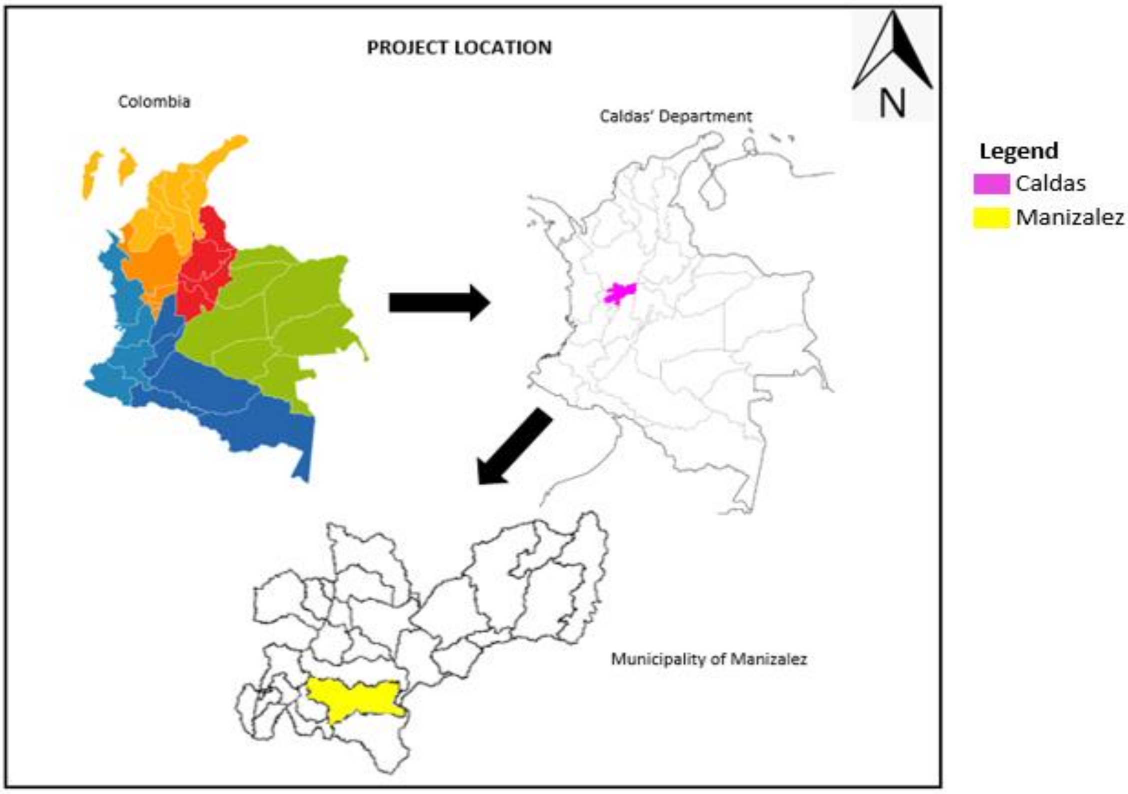


Figure 4. Caldas' Department (pink area) and Municipality of Manizalez (yellow area). Own source.

According to FAO (2000), Colombia is the 7th country in the world with more tropical forests' cover. The aim of conservation, recuperation, rehabilitation, and restoration happens not only at the country level but also at the regional one thanks to the environmental authority or CAR's (Regional Autonomous Corporations; PNDF, 2000). In Antioquia the management areas as it is mentioned before are divided into three groups (National Plan of Restoration, 2015):

- Recovery areas: Severe overuse because of the increment of mining. In total is it possible to find 988,325.63 ha.
- Rehabilitation: Moderate and light overuse, with 896,990.59 ha.
- Restoration: Inadequate use of burnt areas, natural-livestock, and deforestation. This occupies 602,199.76 ha.

In the same way, Caldas' management areas are divided into: (*i*) Recuperation: 267,226.47 ha; (*ii*) Rehabilitation: 106,073.88 ha, and (*iii*) Restoration: 66.013,58 ha. Is it possible to find this division in the National Parks that appear in Antioquia: 'Las Orquídeas' (with a total of 4609,92 ha that follows the activities of recuperation, rehabilitation, and restoration), 'Los Katios' (723.40 ha following restoration activities).

The 'Norte Antioqueño' is going to be the main zone where the study area is located, as well as the 'Reforestadora El Guásimo S.A.S.'. The area has its particular morphology, which has been altered by many factors like temperature, wind, or volcanism (which has produced the mountain ranges lifting; SILVOTECNIA, 2019); highlighting the degradation of the land due to the agriculture in the area during the last decades. The altitude of the study area is going to vary 2,150 - 2,283 masl and all parcels owned by the enterprise have from medium to strong slopes.

High-Andean forest ecosystems are among the first five ones most vulnerable, and their regeneration depends on many factors of the forest itself, as microclimate or topography, as well as its border characteristics (Montenegro & Vargas, 2008). The precipitation in the area has an average of 2,057 mm per year and an average of 11°C regarding the information obtained from the different hydro-meteorological stations from 'Empresas Públicas de Medellín' (EPM, company which is in charge of providing public services in the region).

About the physical characteristics of the soil, the texture is sandy-loam with 50-100 cm of depth and natural-moderate drainage, with low variation comparing it to the neighborhood area, the 'Nordeste Antioqueño' (Tobón, 2004). There are medium levels of organic matter which produce an extreme pH that means low cationic exchanges and low nutrient availability (Echeverri Tafur *et al.*, 2014). Is it probable to find toxicity produced by aluminum (Al) and deficit in phosphorus (P), calcium (Ca), magnesium (Mg), and molybdenum (Mo) (Tobón, 2004).

On the surface of the soil there are outcropping rocks and cracks that produce erosion, sometimes occupying big zones and mostly because of the inappropriate practices that were done in the area, mainly agriculture (SILVOTECNIA, 2019). Regarding the threat of landslide erosion in the area, 'Reforestadora ‘El Guásimo’ S.A.S.' has considered three levels: (*i*) High: Mountain areas with high slope and high precipitation; (*ii*) Moderate: Low mountain areas, moderate slope, and moderate precipitation; and (*iii*) Low: Hills with low slope and low precipitation.

Forestry and agriculture are the main activities in the area, but due to the land conditions, 85% of the land is designated to forests 'production-protection' aptitude, where forests can be managed only if the protection function is maintained. This differs from the ‘protection’ function where just the exploitation of secondary fruits is allowed, and the ‘production’ function where products that are commercialized and used can be obtained (Minambiente, 1996).

‘Reforestadora El Guásimo S.A.S.’ has 10,856 ha involved in the project: 79% of them are located in Antioquia´s department, and inside this percentage, 64% of them correspond to forest plantations, while 26% correspond to native uses with no extraction purposes and 10% corresponds to ‘other uses’ (Cuadrado, 2019). Of the 10,856 ha of forest, 10,650 ha are under FSC certification. Many genera and species are going to be involved in the project, highlighting the main ones: *Rutaceae, Burseraceae, Melastomataceae, Myrtaceae, Fagaceae, Hypericaceae, Phyllanthaceae, Clusiaceae, Chrysobalanaceae, Euphorbiaceae, Rosaceae*, and *Fabaceae*.

Since the objective of the company is the timber extraction, a differentiation between native species and species with some grade of conservation has been done. These species are noted later. Concerning the plots, all of them are low Andean rainforest (bmh-MB) and five of six are located in Antioquia’s Department, but they have many differences concerning altitude (masl), successional stage or slopes:

- Plot 1: It has high and moderate slopes. It is not considered in the project due to the difficulties in identifying the individuals that appear in the plot.
- Plot 2: It is located at an altitude of 2,273 masl and it has high slopes. Its previous use was mining and intensive cattle rising. Its successional stage is 'late secondary', with some slopes dominated by shrubs.

- Plot 3: It is located at an altitude of 2,280 masl and it has moderate and low slopes. Its successional stage is 'late secondary', with some open areas with individuals growing.
- Plot 4: It is located at an altitude of 2,260 masl and it has from low to moderate slopes. Some areas are in a 'late secondary' stage with small individuals, but others are open areas with shrubs. On the slopes, vegetation decreases notably. The trees with the biggest diameter are located in this plot.
- Plot 5: It is located at an altitude of 2,547 masl and it has from moderate to high slopes. This forest is in a 'late secondary' stage but with open areas dominated by shrubs. There are many ferns and there is a notable presence of epiphytes.
- Plot 6: It is located in Caldas´ Department at an altitude of 2,123 masl and it has moderate slopes. This forest is less dense than the other ones. It has dispersed trees and shrubs with a layer of herbaceous individuals.

2.2 FAUNA

Colombia is one of the most biodiverse rich countries in the world. In regards to birds, the country has around 1,865 species (although many of them are endangered or threatened) (CALIDRIS, 2017) and regarding mammals, 518 different species of mammals are present in the country (SIB, 2019). As has been mentioned in the introduction, many trees are successful at dispersal because of the fauna in the area, especially because of the mammals, which transport seeds inside their guts (Corlett & Hau, 2000); although birds are just as important. Animals are involved in almost every step of a plant´s reproduction (Schelhas & Greenberg, 1996). Information from the Global Forest Watch (2016) and established by the IUCN, *Bird Life International* and the UNEP, represents the biodiversity significance and areas with hot spots of biodiversity. The plots of the project are located in areas with high values of the previously mentioned indicators.

2.2.1. Birds

Birds normally base their diet on insects and fruits (Howe, 1986), and as previously mentioned, have an important role in seed dispersal. Some of them move distances of around 20 m or even less, but others move long distances dispersing seeds in a very effective way. They influence the gene flow (Levey *et al*., 2005), avoiding inbreeding among patches. In the Andean region and fragmented high montane forests, birds are important because most species feed on seeds and fruits, and at the same time, they are involved in pollination (Durán & Kattan, 2005). The Global Forest Watch (2016) shows endemic areas. Plot number 6 (located in Caldas' Municipality) is the only one in an endemic area, the rest of the plots are not but surrounded by areas considered 'endemic'.

Many bird species can appear in the study area, and recent studies done around the northern plots of the project show that 101 species (some of them threatened or even endangered) are present in the area. 'Reforestadora El Guásimo S.A.S.' has checked the presence of to species considered as high conservation values: *Scytalopus stilesi* ('tapaculo de Styles') and *Hypopyrrhus pyrohypogaster* ('cacique candela'), both of them belonging to the Passeriformes Order. Even if the information about species in different areas of the Norte Antioqueño and Caldas is not abundant, the orders of birds that appear in Antioquia's and Caldas' Departments can be checked in **tables 4** and **5** respectively.

2.2.2. Mammals

- **Bats (Chiroptera Order)**

Chiroptera is the second mammal´s order which is more diversified (Kasso & Balakrishnan, 2013). It is possible to find around 209 species in Colombia (SIB, 2019), most of them frugivorous and they usually have an important role in seed dispersal of degraded areas (Corlett & Hau, 2000). Bat´s populations are declining constantly in some areas of the world which creates a big problem for agriculture that is affected by insects (Boyles *et al*., 2011). For example, some studies have demonstrated that in Indiana, 150 big brown bats eat 1.3 million insects per year, which contributes to avoiding plagues or pests. If there are bats, the use of pesticides is lower, which is beneficial for the environment. But bats are not just beneficial for agriculture, they are bioindicators. Their populations indicate climate changes or habitat loss´ effects (Jones *et al.*, 2009).

As has been mentioned in many species of plants recognized in the area, bats are important for pollination; although many of them have also importance in seed dispersal (Hodgkison *et al.,* 2003). Law & Lean (1999) demonstrated that bats in Australia's rainforests transported 6 times more pollen than birds. Regarding their diets, Muñoz (1986) shows that most bats eat a combined diet between nectar, insects, pollen, and flower parts. Just a few of them are specialized. López-Castañeda *et al.* (2018) proved that around 1,000 masl the most common ones are insectivores, and nectarivores, and above this altitude they are mostly frugivorous.

Bats in Antioquia are distributed regarding the different environmental characteristics (Calle & Arango, 2003). This Departments shelters 50% of bat's species in the country (López-Castañeda *et al.,* 2018) and the largest variety is distributed between 1000 and 2800 m of altitude (114 species are believed to be present upward 1,000 m), being predominant in humid forests (Moreno, 2018). After revising the list of mammals present in Antioquia's Department of the 'Instituto Alexander Von Humboldt', and choosing the species that are distributed to the north in the range of altitude of our study area (1,800 m upwards) the bats that can appear in the area are listed in **Table 6.** Although some of the species mentioned, such as *Carollia perspicillata*, can adapt across different forest areas and sites, many changes in these environments continue to cause the decline of important populations. (López-Castañeda *et al.,* 2018).

- **Opossums (Didelphimorphia Order)**

Very similar to Marsupials, these nocturnal (Tyndale-Biscoe, 2005) animals (some of them diurnal) are distributed through America and many species are native from the Caribbean region and South America. They are adapted to many different environments, from the rainforests to the dry ones (CABI, 2019), and they also live in disturbed zones (Cable & Martina, 2013). They eat fruits and seeds, helping plant dispersal. Roots and insects are still included in their diet. Diet can change seasonally depending on food availability, so they are omnivores. Their presence is useful in forest areas because they help to pollinate flowers. Their main predator in the Andean region is *Leopardus pardalis.* The list of Opossums that can appear in the study area is listed in **Table 6.**

- **Marsupials (Paucituberculata Order)**

This group is native to Ecuador and Colombia (IUCN, 2019). They are lonely and nocturnal climber animals. They prefer cool areas and they create root channels. Their diet is based mainly on small invertebrates and insects although sometimes they also include fruits (Vallejo & Boada, 2016), which facilitates seed dispersal. Their predators are mainly carnivores as pumas or mountain cats. Due to the small interaction in areas with humans' presence, their study is limited, but *Caenolestes convelatus* is categorized as 'Vulnerable' by the IUCN. This species is listed in **Table 6**.

- **Sloths (Florivora Order)**

Bradypus variegatus are distributed from Honduras to Brazil (Moraes-Barros *et al.*, 2014). This species is a high-canopy folivore and it eats many different plants and types of leaves, so it is found in mature forests (they spend most of the time inside the canopy, without going down, nor even to drink water). Its main predators are jaguars and snakes. It is categorized as 'Least Concern' by the IUCN because of its wide range of distribution, although it is more sensible than other sloth species to disturbed areas (Hayssen, 2010), finally, it is listed in **Table 6.**

- ❖ **Placental mammals (Cingulata Order)**

Dasypus novemcinctus is distributed from Mexico to Brazil, categorized as 'Least Concern' by the IUCN. They live both in dense forests (preferring these) and shrub areas, where they can make their underground burrows (up to 2 m deep). Even if it can be found up to 3,000 m, it does not have much tolerance to cool temperatures (McDonald & Larson, 2011), and it needs sources of water. They are opportunistic feeders, varying constantly their diet. Beetles are their main food components, but they also eat many insects and invertebrates as ants or termites or bird´s eggs. In less amount (more or less a 10%), they consume fruits, seeds, and fungi. *Dasypus novemcinctus* has many natural predators like the jaguar or the black bear, but humans have caused the decrement of them. Nowadays, armadillos are still hunted by humans, especially native tribes. This species is listed in **Table 6.**

- ❖ **Mammals eating ants and termites (Vermilingua Order)**

Tamandua mexicana, distributed through the South of Mexico to Ecuador (Reyes *et al*., 2014) and categorized as 'Least Concern' by the IUCN, is an anteater of medium size which does not eat just ants but bees and termites (Vallejo & Boada, 2016). Even if it has been seeing up to 3,000 m of altitude and in different types of forests, most of the records situate this specie in abundance around 1,000 m (Navarrete & Ortega, 2011). This species main predator is the jaguar (*Panthera onca*) and harpy eagle (*Harpia harpyja*). These species are listed in **Table 6.**

- ❖ **Primates (Primates Order)**

Primates play an important role in tropical ecosystems, mainly because of the seed dispersal (Bufalo *et al.*, 2016), although they are not usually present in degraded landscapes (Corlett & Hau, 2000). The size of the primate makes the difference in the dispersal of the seed (as their diet is based mainly on fruits), the larger the primate the larger the seed that is dispersed such as Bufalo *et al.* (2016) demonstrated in their study. The species named in the following table have different characteristics:

- *Aotus lemurinus:* Categorized as 'Vulnerable' by the IUCN. Their diet is based on fruits and arthropods although they eat also flowers and leaves.
- *Cebus albifrons:* Categorized as 'Endangered' by the IUCN. Most of their diet (80%) is based on plant material while the remaining 20% is based on animal material (Defler, 1979). Their diet is based on leaves, seeds, and some insects (Stone, 2001).
- *Lagothrix lagotricha:* Categorized as 'Vulnerable' by the IUCN.
- *Ateles fusciceps:* Categorized as 'Critical endangered' by the IUCN due to the small number of individuals. Their diet is based on fruits, leaves, seeds, and some insects (Romero, 2018).

Apart from jaguars, ocelots, and harpy eagles (*Harpia harpyja*) as main predators, humans hunt primates, both for the meat and the skin (Romero, 2018). The list of species of this Order is listed in **Table 6**.

❖ **Mammals specialized in eating flesh (Carnivora Order)**

It seems that carnivores do not play an important role in seed dispersal, but even if more studies are done, many seeds have been seen in carnivorous´ feces (Herrera, 1989). It is because, in many cases, fruits are included in their diet (Koike *et al.*, 2008). Apart from this, many plant species have adapted their seeds to be hooked on animals´ skin and be distributed (Traba Díaz *et al.*, 2001). The species that are named in the following table and that appear in the Department where the study is being carried out, they have many different characteristics, starting by their size:

- The smallest ones are *Lutra longicaudis, Eira barbara, Conepatus semistriatus, Nasua nasua,* and *Potos flavus*. All of them are categorized as 'Least Concern' by the IUCN. They have a very varied diet: from fruits to small invertebrates including carrion (Vallejo, 2018).
- With a medium size *Leopardus pardalis* and *Cerdocyon thous,* categorized as 'Least Concern' by the IUCN. *Leopardus pardalis* bases its diet on small mammals as rodents or bats, but it can eat fish or birds. On the other side, *C. thous* has a very varied diet, including, apart from small mammals, invertebrates, and fruits (Vallejo, 2018).
- The biggest one is *Panthera onca,* which is distributed from Mexico to Uruguay, Paraguay, and Brazil; and it is categorized as 'Near threatened' by the IUCN.

They made through both open and close forests (Castellanos *et al.,* 2019). Their diet is based on meat, preferring big animals as sloths (Folivora) or armadillos (Dasypodidae), but they eat small rodents or even snakes. Jaguars are the only ones that have a marked taste for reptiles.

Their populations are declining due to habitat loss (Paviolo *et al.,* 2016) and fragmentation and human activities (Haag *et al.*, 2010). The corresponding species are listed in **Table 6**.

- **Hoofed animals (Artiodactyla Order)**

All of the following species are larger in size animals. They play an important role in seed dispersal as their diet is mainly based on fruits, flowers, and leaves (Bodmer, 1991). *Pecari tajacu* and *Odocoileus virginianus* are categorized as 'Least Concern' by the IUCN and *Mazama Americana* is not categorized due to the deficit of information. Humans hunt them but populations remain stable. Their main predator is the *P. onca* (Weckel *et al*., 2016). These species are listed in **Table 6**.

- **Rodents (Rodentia Order)**

Rodents are distributed all around the world in a very wide range of climates, sometimes climates can be inundated with rodents. Often in forests, rodents are the most abundant group, matching with the bats' population. They play an important role in forest ecology and seed dispersal (Margaletic, 2003). Its importance is not based only on their diet: they get seeds and they transport them far distances until they are hungry, producing a more effective dispersion (Moore, 2007). Because of the many burrows and underground channels they build, they increase soil aeration, water filtration, and nutrients recycling, especially in the superficial parts of the soil (Reynolds & Wakkinen, 1987), which can be an important aspect in disturbed soils.

Rodents are omnivorous, eating mainly fruits, seeds, roots, and leaves (Wood & Singleton, 1994). In forestry, they can produce serious damage in young plants and they transmit diseases to humans.

Although most of the species mentioned in the following table have a small size, *Cuniculus paca*, *Dasyprocta punctata* and *Dinomys branickii* don't. These three, categorized as 'Least Concern' by the IUCN (although *D. branickii* is considered 'Endangered' by the Red List of Mammals from Ecuador), are big and robust rodents. They are present in Colombia, Ecuador, Peru, and Bolivia, although *D. branickii* is also present in Brazil and *Cuniculus paca* in Central America. All of them base their diet on fruits and flowers but they can also eat bark or small stems. They are important in seed dispersion and their burrows are built up to 2 m of depth. Their main predators are panthers, leopards, and pumas (Vallejo & Boada, 2017).

Sciurus granatensis and *Microsciurus mimulus* are chipmunks. They are distributed from Costa Rica to Ecuador (Vallejo & Boada, 2017). Both are categorized as 'Least Concern' by the IUCN. Their main predators are pumas. The rest of the species are small mice that are categorized as 'Least Concern' by the IUCN. Many mammals, reptiles, and birds (as eagles) hunt these small rodents. These species are listed in **Table 6**.

2.3 DATA COLLECTION

In 2013 the plots were established. Thanks to the tool SIG (Geographic Information System) and taking into account the different activities developed by 'Reforestadora El Guásimo S.A.S.' (reforestation, maintenance, and exploitation) the location of the plots were defined. In total, 6 plots of 500 m^2 (0,05 ha) each were defined. The plots themselves were divided into 50 m^2 to facilitate the count of individuals and were delimited by PVC ¾' making the coordinates.

For marking the trees, shrubs, and palms, some individuals with > 1,30 m of height from the floor level were selected. In 2013, aluminum tags 2x9 cm were established on the trees depending on their diameter. The sheets were nailed in the bark with 2 ' nails in trees D> 10 cm. For saplings with D < 10 cm the sheet was established with a copper thread around the trunk. In total, the individuals counted in 2013 where the ones with DAP≥ 10 cm (considered as trees) and the ones between 5 and 10 cm, known as 'latizales'. For the last count in 2019, the individuals were sampled again. The individuals that were measured were the ones with DAP ≥ 10 cm, coinciding with the individuals already measured in 2013 plus the ones that entered in the 'futsal' category during the six year period. New individuals were identified.

For the species identification samples from each tree were collected thanks to a branch cutter and pruning shears. Samples were pressed, alcoholized, and brought to the National University of Colombia (at Medellín) where they were identified in the 'Medel' Herbarium. As has been mentioned, the first plot was not considered due to the lack of individuals' identification.

The location of the gullies and high slopes was determined by different aerial photographs obtained by a drone. Then, a shape was created in QGIS 3.10.5 and the critical points were identified.

Regarding the soil, random sampling was done (just in the Antioquia department) to obtain a total of 32 samples. Two depths were taken into account: 0 - 20 cm and 20 - 40 cm. The data obtained was the following one:

- Bulk density (g/cm^3): obtained by the cylindrical method. This method is used to know the compactness of the soil and it consists on introducing in the soil a metal cylinder (mold of 5 cm of height and 5 cm of diameter) and after filling it, calculate the dry soil mass after a drying process (Håkansson & Lipiec, 2000; Agostini *et al*., 2014). It varies with the soil structure (Chaudhari *et al*., 2013).

  Bulk density= (dry soil (g) x 10)/cylinder volume (cm^3)

- Soil texture: obtained by Bouyoucos method. This method is fast and simple. It is also called the hydrometer method (Beretta *et al*., 2014). The density of particles in suspension is measured by a hydrometer and the clay fraction is estimated after two hours of sedimentation.

- pH: measured by extraction of soil/water (1:1). It indicates if the soil is acid or alkaline (Vásquez & Pola, 2015).

- Available phosphorus (P) (mg/kg): obtained by the Bray II method, which is commonly used in acid soils. The phosphates are dissolved in the acid (Toledo *et al*., 2017).

- Cation Exchange Capacity (CEC)(meq/100g): obtained by ammonium acetate and volumetry. A soil with a low CEC indicated that it is sandy or with a low amount of organic matter (Vásquez & Pola, 2015). Dissolves the carbonates and the interchangeable Mg and Ca are estimated (Rodríguez & Rodríguez, 2002).

- Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+}: obtained by the extraction method with ammonium 1 N and pH 7 and quantification method (atomic absorption), consisting of the absorption of energy of the atoms.

- Al^{+3}: obtained by the extraction method KCl 1M and quantification method (volumetry). The interchangeable cations are replaced by the ammonium (NH_4^+) (Toledo *et al*., 2017). The interchangeable

- Al^{+3} was calculated with the following equation:

$$\% Al^{+3} \text{ saturation} = (Al^{+3} / CEC) * 100$$

- Organic matter (OM): obtained by the humid oxidation method (Walkley Black) and volumetry (quantification method). The first one is used to estimate the oxidizable carbon in the samples (Carreira & Ostinelli, 2010). The second one consists of different reactions where compounds as sulphuric acid or ferrous sulfate intervene (Galvis & González, 2005). The CO_2 ejected due to the high temperatures is measured (Fassbender & Bornemisza, 1987).

$$\% MO = MO * 1.724$$

- Percentage of base saturation: together with the pH, they limit the absorption of the nutrients (Mehlich, 1942). Ca^{+2}, Mg^{+2}, and K^{+} are interchangeable with H^{+} (Vásquez & Pola, 2015).

$$\% \text{ Base saturation} = (\Sigma \text{ Bases Ca, Mg, K} / CEC) * 100$$

2.4 SPECIES SELECTION FOR THE PROJECT PURPOSE

In an ecological restoration project, one of the first and main steps is to select the species, determining which are the ones that have the characteristics to be adapted in the area and which ones can re-sprout or colonize naturally (Bozzano *et al*., 2014). The differences in altitude, temperature, precipitation, or topography are factors that must be taken into account because they influence the type of species that appear in different patches (Lamb *et al.*, 2005).

First, the plants that will be chosen must be native, preferably with availability in nurseries (Terán-Valdez, 2018). Efforts to choose the species will be centered on picking out the ones that are adapted to the range of altitude where the plots are located, the species with high germination rate and fast growth to avoid predation, herbivory or pathogens, easy dispersion, or other positive characteristics such as nitrogen (N) fixation. An emphasis is put on avoiding low-rate germination plants due to their vulnerability and on incrementing genetic diversity. As it is a degraded soil, individuals with the capacity of fertilization or erosion control are important too. Another clue point is to establish the number of families, genus, or species that are going to be planted. FAO (2014) recommends about 10 to facilitate colonization. Sometimes a number of 30-40 can be reasonable, but for our study area, it can be enough with some around 10 genera.

As one of the objectives of restoration is to restore the species composition as it was before (Bozzano *et al.,* 2014), a comparative of the species that were present in the area in 2013 and 2019 has been done.

In this project the area is not as big as other projects, it is not a landscape scale, so a first pilot test is not necessary (Zahawi & Holl, 2009).

As has been mentioned two lists of plants are available to develop the project: individuals that were present in 2013 and individuals that were present in 2019. As they include the number of individuals in both years, they give a clue about the survival of the plants during these 6 years. Therefore, the first step is to focus on the genus/species that have survived during this time-period and examine their characteristics.

Showing the time-scale and the different divisions for the genus and species that survived in the 6 years, a time-tree was obtained thanks to the tool 'Timetree' (timetree.org). **Figure 5** represents it with its main divisions: the main one, Mesangiospermae followed by the other two, Eudocotyledons and Magnoliidae. After this, **Figure 6** and **Figure 7** represent the time-trees of these two main divisions: Eudocotyledons and Magnoliidae.

In total, the families that survived during these 6 years (even with an increment or decrement in their number of individuals) are the following ones: Lauraceae, Rutaceae, Burseraceae, Sapindaceae, Melastomataceae, Myrtaceae, Symplocaceae, Fagaceae, Hypericaceae, Phyllanthaceae, Clusiaceae, Chrysobalanaceae, Euphorbiaceae, Moraceae, Rosaceae, and Fabaceae; with their respective genus: *Ocotea, Zanthoxylum, Protium, Billia, Blakea, Meriania, Miconia, Psidium, Myrthiantes, Symplocos, Quercus, Vismia, Hieronyma, Clusia, Couepia, Alchornea, Croton, Morus, Ficus, Prunus, Inga,* and *Abarema.*

A first selection of the genera and species was done, removing from the selected species the ones that are classified as 'important species' due to their grade of conservation. The information was obtained from the International Union for Conservation of Nature (IUCN), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and Resolution 19/2004 of the Environmental Ministry and Sustainable Development (MADS):

Table 1. Plant species in the study area of Antioquia (Colombia) with their IUCN conservation values. Source: SILVOTECNIA (2019).

SPECIES	CONSERVATION VALUE
Abarema lehmannii	Endemic
Aiphanes sp.	Endangered (MADS endangered spp.)
Chamaedorea pinnatifrons	Least Concern (LC, IUCN)
Clusia multiflora	Least Concern (LC, IUCN)
Cordillera platycalyx	Endangered (EN, IUCN)
Croton magdalenensis	Least Concern (LC, IUCN)
Cyathea sp	Appendix II (CITES), National closure (MADS)
Cyathea bipinnatifida	Appendix II (CITES), National closure (MADS)
Cyathea squamipes	Appendix II (CITES), National closure (MADS)
Eschweilera antioquensis	Least Concern (LC, IUCN)
Eschweilera sp.	Endangered (EN, IUCN)
Geissanthus occidentalis	Endemic
Geonoma orbignyana	Endangered (EN, IUCN)
Guatteria goudotiana	Endemic
Ilex danielis	Endemic
Inga cf. densiflora	Least Concern (LC, IUCN)
Magnolia sp	Critical Endangered (CR, IUCN), National and Regional closure (MADS)
Meriania antioquiensis	Endemic
Ocotea cf. micans	Endemic
Oreopanax albanensis	Endemic
Palicourea demissa	Least Concern (LC, IUCN)
Podocarpus oleifolius	Vulnerable (VU, IUCN), National and Regional closure (MADS)
Quercus humboldtii	Vulnerable (VU, IUCN), National and closure (MADS)
Saurauia chiliantha	Endemic
Schefflera sp. nov.	New species
Stephanopedium sp.	Endangered (EN, IUCN), possibly Endemic
Symplocos phaeoneura	Endemic
Turpinia occidentalis	Least Concern (LC, IUCN)

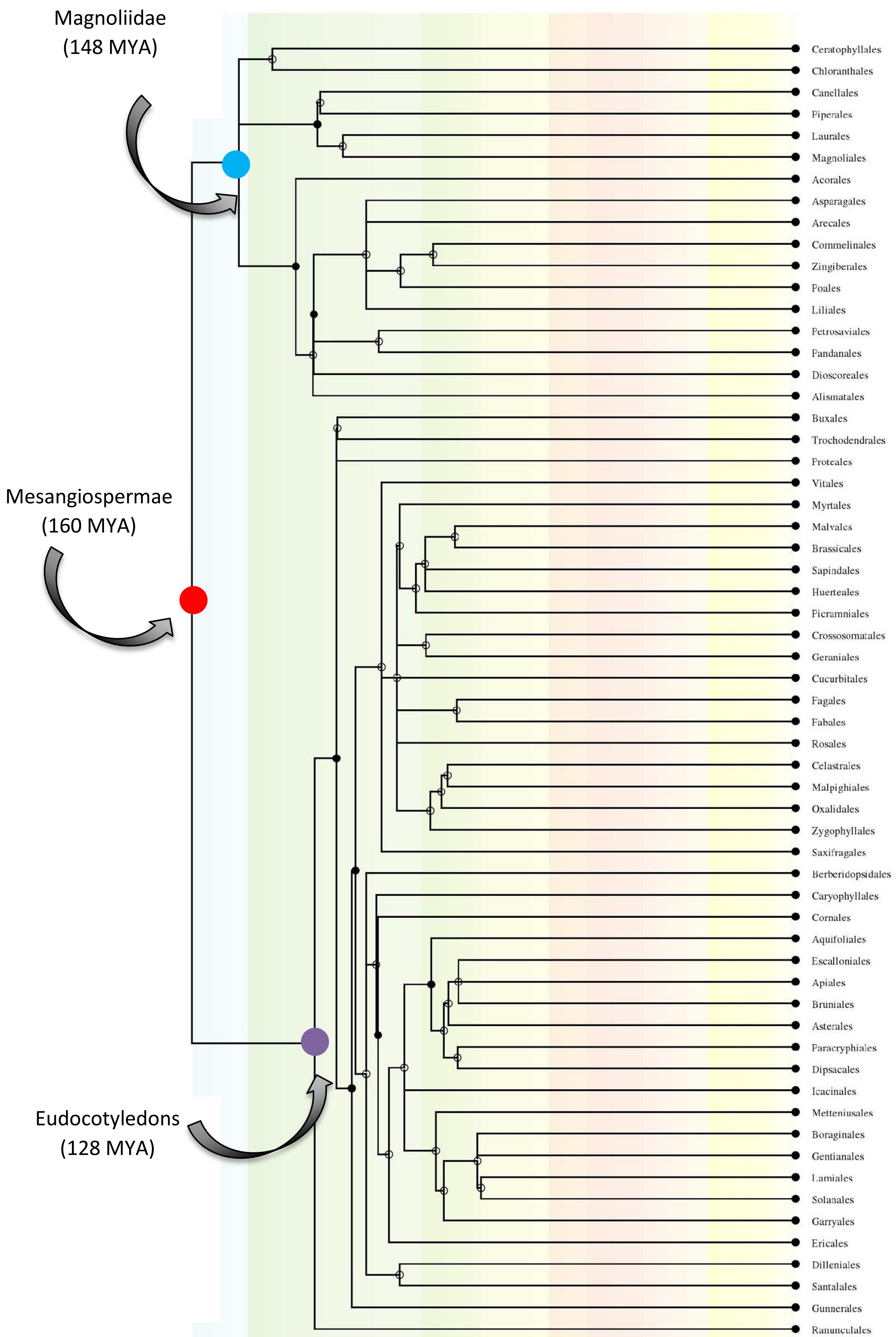


Figure 5. Main division of the Mesangiospermae group (160 MYA). The two main groups that derive from this main one are Eudocotyledons (128 MYA) and Magnoliidae (148 MYA). Source: 'Timetree.org'.

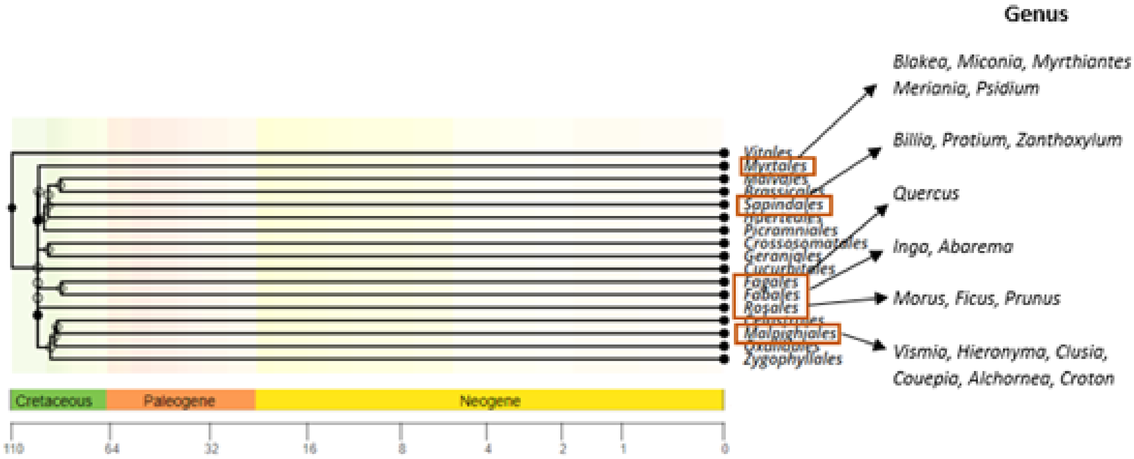


Figure 6. Rosids division. These genus appear in the study area. They own to Myrtales, Sapindales, Fagales, Fabales, Rosales and Malpighiales families. Source: 'Timetree.org'.

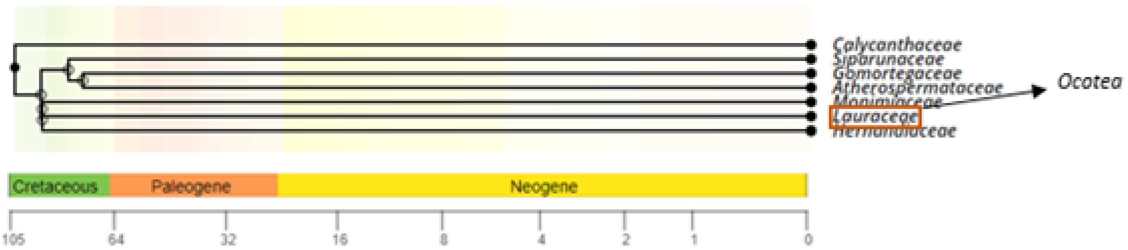


Figure 7. Laurales division. The Ocotea Genus, which appears in the study area, owns to the Lauraceae Family. Source: 'Timetree.org'.

After the bibliographic revision of each of the plants and according to FAO (2014), a number of around 10 genera was selected: *Alchornea, Billia, Ficus, Inga, Meriania, Miconia, Ocotea, Protium, Prunus, Psidium, Symplocos, Tibouchina*, and *Weinmannia*. **Figure 8** shows the morphological, and reproductive attributes (as well as other attributes), those who were given priority, and **Table 2** shows the sum of the following genus' information.

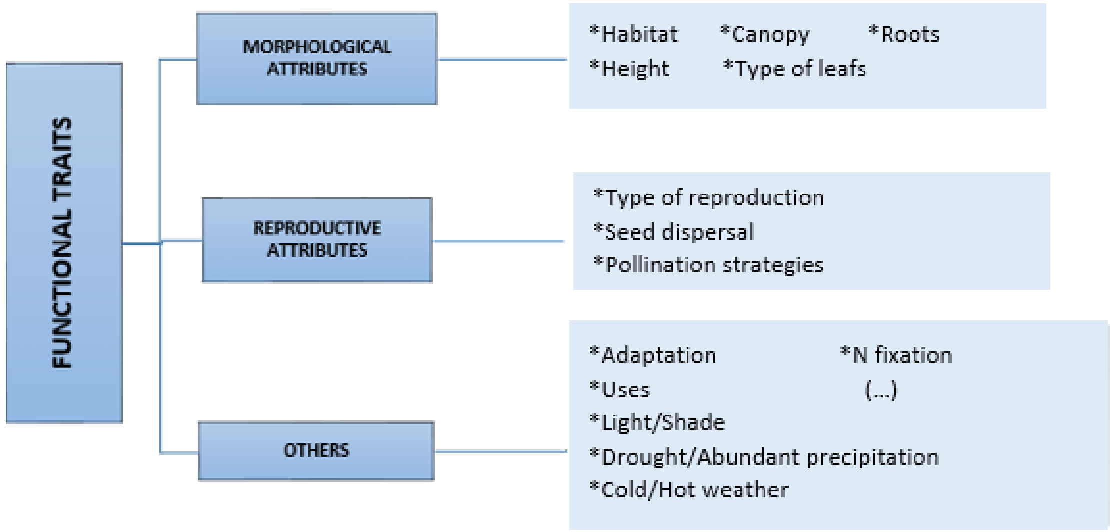


Figure 8. Functional traits. Divided into morphological (habitat, height, canopy, type of leafs and roots), reproductive (reproduction type, seed dispersal and pollination strategies) and other attributes (as N fixation or extreme weather tolerance). Own source.

Another important aspect should be considered: succession, which specifies the species composition over time (Setiawan & Sulistyawati, 2008). **Figure 9** represents the normal development of an area without vegetation until its 'climax vegetation'. Depending on the situation of the stage, different species, pioneer, early successional, late-successional or mature species should be considered, being:

- Pioneer species, that are usually the first ones in colonizing the area, they are mainly shrubs that will be mixed with advanced vegetation (Instituto Alexander von Humboldt, 2017).
- Early successional species, that grow well in high-light environments (as well as pioneer species) (Bazzaz & Carlson, 1982) and that are usually fast-grow species (Instituto Alexander Von Humboldt, 2017).
- Late successional species, which usually have less tolerance to open areas (Bazzaz & Carlson, 1982) in contrast to pioneer and early successional species. Some species are considered to be an indicator of the 'continuity of the forest' (Groven *et al.*, 2002).
- Mature species, which are present in native and well-developed forests, providing ecological resilience (DIEM, 2019).

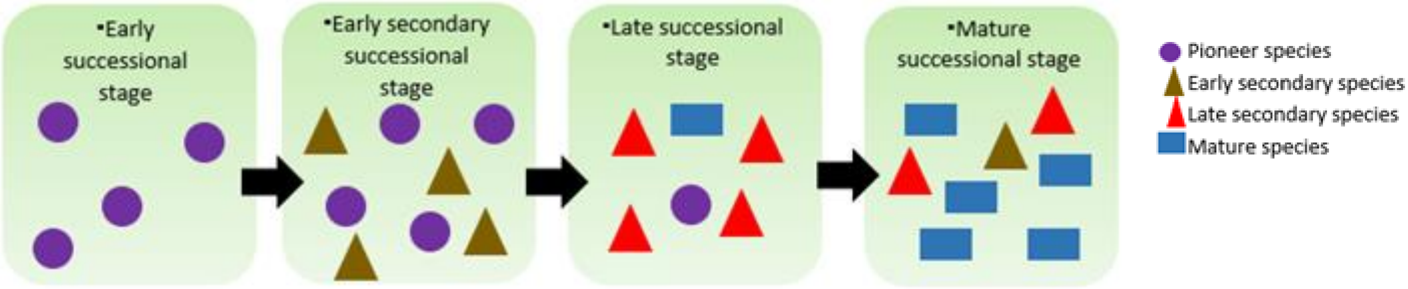


Figure 9. Represents the successional stages up to a mature one. Own source.

The chosen genera, mainly due to their high germination rate, were the following ones:

Alchornea

- Family: Euphorbiaceae.
- *Alchornea* is compounded by trees and shrubs distributed in tropical areas. They have alternate and simple leaves with inflorescences (Macbride, 1951). The center of diversification of this genus is Colombia (Secco, 2004). Species are pollinated by hummingbirds, wind, bats, and insects (Do Socorro, 2017). This genus is used to produce oil and rubber. **Table 7** shows the different species from *Alchornea* Genus that are present in Colombia.
  - *Alchornea verticillata*, present in 4 of the 5 plots.

Billia

- Family: Sapindaceae.
- The genus *Billia* includes trees with opposed trifoliate leaves (Vargas, 2002). In Colombia, only 1 species from this genus is present: *B. rosea.* **Table 8** shows the two different species from the genus. Considering their distribution and that *B. rosea* is native, thus, the species should be the one considered for the project*:*

  - *Billia rosea*: its synonym is *B. colombiana* (Ulloa & Jørgensen, 2001), this species is abundant in the study area and adapted to a wide range of altitudes (0-3000 m) with a height of 15 – 30 m. It has dense foliage, white/pink flowers, and fruits that feed small mammals (UEIA, 2014). It has relevance in feeding mammals and so it is an important factor for seed dispersal. *B. rosea* requires medium luminosity and it can live for more than 60 years. It contributes to considerable amounts of organic matter, is considered appropriate for reforestation. It has a principal root with secondary ones. It is an early secondary species with soil stabilization functions (Terán-Valdez, 2018).

- *Billia hippocastanum*: trees up to 30 m tall distributed from the south of Mexico to Costa Rica (Jharg, 1858). Individuals produce showy fruits that attract rodents. It has slow growth but its timber has industrial uses. Méndez *et al*. (2000) used this species as wind barriers.

Ficus

- ✓ Family: Moraceae.
- ✓ Trees, shrubs, and climber plants form the genus *Ficus*, one of the oldest in the world, with around 800 different species. Individuals have aerial roots that descend into the ground. Fruits attract animals, highlighting the importance of birds and bats on seed dispersal. Nowadays populations are declining and it can be linked with the fact that fig wasps are the only ones capable of fig pollination (Cardona *et al.*, 2013). As it is a wide genus, uses of the plants are very different: many of them are used for medicinal purposes, some of them are used for reforestation (Starr *et al.*, 2003)… The *Ficus* genus has a fundamental role in ecosystems and some of its individuals are pioneer species (Xiang & Chen, 2004). **Table 9** shows the different species form *Ficus* genus that are present in Colombia. Considering the project conditions, we could consider the following ones:
  - *Ficus americana subesp. andicola*: this *Ficus* species is the species that appears in the study area.
  - *Ficus soatensis var*. *bogotensis:* fast growth with dense canopy. Its fruits are important for bees, birds, bats, and foxes. It protects soil from erosion and it has many superficial roots. It is resistant to extreme temperatures and moves.

Inga

- ✓ Family: Fabaceae.
- ✓ The *Inga* genus is compounded by evergreen trees distributed from Mexico to Peru. Individuals are fast-growing trees and soil stabilizers (Allen & Allen, 1981), providing soil fertility. They attract and by nectar secretion (Koptur, 1984) and they are pollinated mainly by nectarivorous birds. Many species create microclimates and some of them are used to create shade, especially in coffee plantations (Siles *et al.,* 2010). The Fabaceae family maintains N in the soil. This Genus in Díaz-Páez & Polanía (2017) showed a low ‘Esbeltez Index’, that as it has been mentioned before shows the tree’s stability. **Table 10** shows the

different species form *Inga* genus that are present in Colombia. Considering the project conditions, we could consider the following ones:

- *Iinga cocleensis, Inga densiflora,* and *Inga sapindoides*, which appear on 3 of the 5 plots. They provide soil stability and fertility (Allen & Allen, 1981).
- *Inga edulis,* which can tolerate many ranges of temperature and types of soil (Huxley, 1992). It has fast growth and high germination rate even in poor soils and roots are capable of capturing nitrogen (N).
- *Inga punctata,* as well as *Inga densiflora* produces lots of nectar which attracts ants, these ones moving nutrients, restructuring soil structure, or changing the pH (Jiménez-Carmona *et al.*, 2015) and at the same time fight against caterpillars (Koptur, 1984).

Meriania

- ✓ Family: Melastomataceae.
- ✓ Trees and shrubs with some hairy branches compound the *Meriania* genus. Colombia has the highest number of species. Individuals produce fruits with capsules and many seeds. The radicular system is often deep (Rodríguez, 1984). Some species appear in natural regeneration (Monteiro, 2017). **Table 11** shows the different species form *Meriania* genus that are present in Colombia. From all the following list, some species that are suggested ones are the following:
  - *Meriania antioquiensis*, which is present in 3 of the 5 plots of the project.
  - *Meriania nobilis,* which obtained a high ‘Slenderness Index’ (an indicator of tree’s stability) in Díaz-Páez & Polanía (2017), which indicates that this species is less robust and more likely to suffer damages by extreme events (León-Sánchez *et al.,* 2019).

Miconia

- ✓ Family: Melastomataceae.
- ✓ The *Miconia* genus is the largest one in Melastomataceae family. Individuals can be found as shrubs or trees up to 10 m tall and with round canopies. Individuals are well adapted to acid soils and disturbed areas. They produce fleshy fruits that attract birds and bats, these two involved in pollination too. Even if they have weak roots to control soil erosion, some of them are used for secondary regeneration of the forests; but in some cases, they become invasive species

(Goldenberg *et al.*, 2008). **Table 12** shows the different species from *Miconia* present in Colombia, from them the suggested are the following ones:

- *Miconia jahnii, M. lehmannii,* and *M. resima* are the ones that appear in the study area. The first one appears in all plots except one and the second one appears just in one plot.

- *Miconia aeruginosa* like *M. asclepiadea* and *M. brevitheca* are pioneer and facilitator species with the capacity of attracting dispersers. On the other hand, *M. clathrantha* does not have the capacity of disperser´s attraction and *M. rivetii* is not a facilitator species, although they own the other characteristics (Terán-Valdez, 2018).

- *Miconia goniostigma is an early secondary species with the capacity of attracting dispersers.*

- *Miconia affinis,* which is an early successional Neotropical tree with the capacity of colonizing exposed high hills (Castilla *et al.*, 2016). Considered as an appropriate specie for degraded areas, it has the capacity of attracting frugivorous and facilitate the seed dispersal.

Ocotea

- ✓ Family: Lauraceae.
- ✓ The genus *Ocotea*, normally present in high altitudes, includes 428 different species. These early secondary individuals are commonly evergreen trees, but also shrubs. Leaves of these plants are simple and alternate with fragrant oil cells. American species have unisexual flowers and one-seed globose fruits. In some species as *Ocotea hartshoriana* and *O. insularis*, roots are adventitious. A common enemy are the caterpillars, but some *Ocotea* species produce chemical responses against them (Kato *et al*., 2019). They are used commercially for essential oils and beverages. Many new *Ocotea* species have been discovered lately (Van der Werff, 2012). **Table 13** shows the different species form *Ocotea* present in Colombia. From them, the suggested ones for the project's purpose are the following ones:
  - *Ocotea benthamiana, O. rufa,* and *O. leucoxylon* are the species present in the study area, abundant (more than 1 or 2 individuals) in 2 of the 5 different plots included in the project.

- *Ocotea floribunda*: an evergreen tree with the medium dense canopy up to 30 m tall (Standley, 1938). It is a late secondary species with a notable capacity of attracting dispersers (Terán-Valdez, 2018).
- *Ocotea cernua*: some authors as Terán-Valdez, (2018) position this species in a range of altitude up to 2,850 m. It is a late secondary species with notable disperser attraction.
- *Ocotea smithiana,* which fits in the range of altitude of the project´s area (2,000-2,300 m), has appeared as a dominant species in montane forests (Caranqui & Pino, 2016).

Protium

- ✓ Family: Burseraceae.
- ✓ This genus is commonly confused with *Tetragastris* because of their similar characteristics. *Protium* individuals own many different characteristics, but in America, a common one is that flowers are mostly unisexual and deciduous (Swart, 1942). *Protium* seems to appear in the woodiest areas (Celis *et al.,* 2016). Most of the trees from this genus appear in primary forests (Daly, 1992), although some of them as *P. heptaphyllum* appears in the secondary ones. It is an important species for reforestation, with medium growth and big open canopy (Arenas, 2007). As Kato *et al.* (2019) suggested in their study because of their results, some *Protium* species could have the ability to respond to enemy-attacks with chemical defenses. Because of its variety of species, this Genus has many uses as the extraction of paint and varnish or fruit collection (Melo *et al.*, 2007). **Table 14** shows the different species form *Protium* that are present in Colombia. Most of the individuals have axial roots (Figueiredo *et al.*, 2007), which usually improve the superficial layers of the soil due to particular growth while at the same time it consumes P and N (Lynch, 2019).

Prunus

- ✓ Family: Rosaceae.
- ✓ *Prunus* species are not fully defined due to a lack of information on the genus (Pérez-Zabala, 2007). This Genus is distributed through the whole continent and it is compounded by trees and shrubs, deciduous or evergreen, depending on the species. Seed dispersal is done mainly by birds due to the fleshy fruits that the individuals produce (Berman & DeJong, 1996). Some species are important due to their economic value and some are used for reforestation after wildfires. **Table 15** shows the different species from *Prunus* present in Colombia. From the

following list, the ones that can be appropriate for the project are the following ones:

- *Prunus integrifolia*, which appears in 1 of the 5 plots, with a representation of just one individual. It is one of the most distributed species from the *Prunus* in the Andean region.
- *Prunus serotina,* with the notable capacity of attracting frugivorous birds as well as bees and hummingbirds (Maecha *et al.*, 2013). Its resistant to low temperatures but it's delicate regarding moves.

Psidium

- ✓ Family: Myrtaceae.
- ✓ This very old genus, distributed over almost the entire continent (Soares-Silva & Proença, 2008) and probably exclusively pollinated by bees, is made up of small trees (7 - 10 m high) (Mani *et al.,* 2011). The dispersion of their seeds can sometimes be relatively easy because many mammals and fruit-eating birds visit them (Soares-Silva & Proença, 2008). In Rotman (1976), the radicular system of the genus is thick and woody. Some species have medicinal properties (González-Espinosa *et al*., 2005) and other ones have economic importance due to their fruits. The most known one is *P. guajava* (Gutiérrez *et al.*, 2008). In the study area, the individual present was not identified, but because of the altitude, it could be *P. guineense* or *P. guajava*. The first one is adapted to many types of soils and it is not very common in Colombia. On the other hand, *P. guajava* is rarely used for reforestation without economical purposes. In Colombia, it has huge socio-economic importance (Coronado, 2014). **Table 16** shows the *Psidium* species present in Colombia.

Symplocos

- ✓ Family: Symplocaceae.
- ✓ The genus *Symplocos* is distributed from the USA to Paraguay. Individuals are evergreen shrubs or small trees. The species is pollinated by insects and seed dispersal is done mainly by bats and birds. Usually, its roots are long and active and they can accumulate aluminum (Al) (Schmitt, 2016). This genus has medicinal uses as well as industrial ones. **Table 17** shows the different species from the genus present in Colombia. Considering the project conditions, we could consider the following ones:

- *Symplocos phaeonerura*, which is abundant in 2 of the 5 plots. It is endemic from the Andean region. Another species of *Symplocos* appeared and because of the altitude, it could be *S. venulasa, S. martinicensis, S. pichindensis,* or *S. mucronata*.

Tibouchina

- ✓ Family: Melastomataceae.
- ✓ The genus *Tibouchina* can be found as a bush (the most common) or tree, up to 25 m high and highly branched; occupying a large area, from Mexico to Argentina and Paraguay (Alameda, 1993). Its flowers are showy and pollinated normally by bees and beetles. This Genus has the capacity of establishment in disturbed areas and polluted soils (Simao & Takaki, 2008). These species are important for reforestation, preferring open areas to grow (Rezende, 2019). **Table 18** shows the different species from the genus that are present in Colombia. From them, the one that has been used more frequently in reforestation studies and projects, and improvement of degraded areas has been *T. lepidota*, present in one of the plots from the study area:
  - *Tibouchina lepidota* is a tree that has a slow growth up to 20 m tall with hermaphrodite flowers and fruit production during most of the year. This species contributes to the improvement of soil and reforestation. Ramirez (2008) choose it for hydrological restoration. Its flowers are used for pigment manufacturing (Betancurt *et al.,* 2008).

Weinmannia

- ✓ Family: Cunoniaceae.
- ✓ The genus *Weinmannia* is the largest of the Cunoniaceae family. It is common in high montane areas. Trees, shrubs, or rarely, climber plants, represent the genus. The leaves of the individuals are opposed and in some cases alternate. Flowers are bisexual or unisexual with white or pink petals and they can form inflorescences. Flowers attract bees, which help for pollination, and seed dispersal is easy (by wind) due to the hairy seeds (Bradford, 1998). Fruits have a capsule or they are nuts. In Díaz-Páez & Polanía (2017) *Weinmannia* was one of the genera that presented an acceptable percentage of survival. **Table 19** shows the different species from the genus present in Colombia. Some of the recommended species for the project are the following ones:
  - *Weinmannia balbisiana*: this species is the one that is present in the study area from *Weinmannia*. It can be found at altitudes between 1,000 and

2,000 m. It is a tree, sometimes difficult to identify due to the different morphologies of its shape and leaves depending on the altitude where it is located (Killip & Smith, 1929).

- *Weinmannia tomentosa*: this species is commonly found in Andean ecosystems in altitudes between 2,800 and 3,436 m. It is a tree that can grow up to 25 m with dense canopy with hairy leaves and hairy seeds for wind dispersal. It is well adapted to slopes and degraded soils. Its rapid germination and adaptation to acid soils (3.3-4.7) make it a competitive and pioneer species (Pullido, 2011). It is commonly used for reforestation and industry (tannins). It is possible to find this species with *Miconia* and *Clusia* Genus.

- *Weinmannia pubescens,* recommended for the restoration of degraded areas (Bobórquez *et al.*, 2011).

- *Weinmannia pinnata,* used in some projects for ecological restoration and hydrological restoration (Ramirez, 2008). It is a late secondary species (Terán-Valdez, 2018).

- *Weinmannia rollotii,* well adapted to high altitudes, and with a high rate of germination (Puetate, 2017) which is a positive aspect taken into account in reforestation projects.

All this information can be summed up:

Table 2. Present genus in the different plots. Centered in genus distributed through America's continent. Their morphological, reproductive and other attributes are included. Own source.

GENUS	***MORPHOLOGICAL ATTRIBUTES***	***REPRODUCTIVE ATTRIBUTES***	***OTHERS***
Alchornea	**From Nicaragua to Brazil* **Trees/shrubs/herbs* **Roots laterally and vertically distributed* **Foliage and leaves depend on environmental conditions*	**Sexual reproduction* **Dispersion by wind, insects, bats and hummingbirds*	**Medicinal uses* **Adaptable to different pH soils* **Some of them potential in ecological restoration*

Billia	**From Mexico to Ecuador *Trees *Dense canopy with 25 cm length leaves *Big principal root with secondary roots*	**Sexual reproduction *Dispersion by gravity and mammals*	**Used as animal food and ornamental plant *Used for reforestation *Slow growth *Long life *It prefers acid soils *Weak transfer *Medium luminosity*
Ficus	**From USA to Bolivia and Venezuela *Trees/shrubs/climbers *Most of species have aerial roots*	**Sexual reproduction *Pollination by wasps*	**Medicinal uses *Fruits attract animals *Populations decreasing *Fundamental role in ecosystems *Some are pioneer species *Some species for reforestation*
Inga	**From Mexico to Peru *Evergreen trees *Some individuals have superficial roots*	** Sexual reproduction. It is cross-pollinated, sexual reproduction *Flowers are visited by nectarivorous birds which transfer the pollen*	**Soil stabilization *Used to create shade in forests *Used to mix it with coffee plantations *Fast-growing trees *Patches can create microclimates *Fabaceae maintain N *Nectar secretion which attracts ants*
Meriania	**From Mexico to Brazil *Trees/shrubs *Often deep roots*	**Sexual reproduction *Pollinated by hummingbirds, bees, rodents, and bats*	**Very diversified in Colombia *Individuals produce lots of seeds *Some species appear in natural regeneration*
Miconia	**From Mexico to Uruguay * Trees/shrubs * Evergreen leafs * Normally superficial root system*	**Sexual reproduction *Pollination by insects *Dispersion by birds and small mammals*	**Short life (up to 35 years) *Fast growth *Used for pylons *Recuperation of degraded land *Medium/high luminosity *In some cases they become invasive*

Ocotea	**Colombia, Ecuador and Peru *Trees/shrubs with simple and alternate leaves *Roots depending on the specie*	**Sexual reproduction, unisexual or hermaphrodite flowers*	**Present in well-developed forest patches *wood is used *Ant´s protection *Early secondary species *Economically used *Chemical responses to individuals *Some species appear in natural regeneration*
Protium	**From Honduras to Brazil *Trees/shrubs *Axial root system*	**Sexual reproduction *Insect-pollinated and bird-dispersal*	**Protium Genus responds to enemies with chemical attacks *Some fruits can be consumed *Some species are used to produce paint and varnish*
Prunus	**From Canada to Brazil *Trees/shrubs, deciduous or evergreen*	**Sexual reproduction *Pollination by insects *Seed dispersal mainly by birds*	**Very different morphologies *Economically important *Some species are used for reforestation after wildfires*
Psidium	**From Mexico to Argentina *Small trees with simple and oppose leaves *Thick and woody roots*	**Sexual reproduction *Pollination only by bees (probably) *Seed dispersal by birds and mammals*	**Medicinal uses *Some fruits commercially important*
Symplocos	**From USA to Paraguay *Evergreen shrubs or small trees with simple and alternate leaves *Normally individuals have long active roots*	**Sexual reproduction *Pollination by insects *Seed dispersal by birds and bats*	**Capacity of capture aluminum (Al) *Medicinal uses *The timber has industry uses*
Tibouchina	**From Mexico to Paraguay and Argentina *Trees or shrubs up to 25 m tall with hairy leaves*	**Sexual reproduction *Bees and beetles pollination*	**Capacity of establishment in disturbed areas and polluted soils *Important Genus for reforestation *It prefers open areas to grow*

Weinmannia	**From Mexico to Peru and Venezuela *Trees or shrubs. The biggest ones 15 m*	**Sexual reproduction *Bees pollination *Wind dispersal*	**It is adapted to many conditions *Recommended for ecological restoration *Fruits in capsules (nuts) *Economically important*

2.5. FIRST STEPS IN REFORESTATION WITH VEGETATIVE STAKES METHOD

Due to the difficulties of many native plants to colonize areas that have been deforested or degraded by activities as agriculture or mining, the reforestation, and restoration of these areas is needed (Weber *et al.*, 2008). The main purpose of these two actions is to preserve the biodiversity and ecosystem services (Vanegas López, 2016). Before starting a reforestation or restoration project, some concepts described by Vanegas López (2016) that can help to achieve the objectives must be clear:

- Rehabilitation: it wants to establish the productivity and other ecological functions introducing some of the animal and plant species that appear originally.
- Restructuring: as the main objective in this activity is to establish the productivity of degraded land, exotic species are introduced, normally in a monoculture way.
- Plant replacement: change in the ecosystem without considering the original composition. Exotic species are commonly used.
- Plant coating or revegetation: this activity aims to recover the original ecosystem, so native plants are used to help the successional stages.

In regard to CONABIO (National Commission for the Knowledge and Use of Biodiversity) (2020) the classification of species according to their distribution and origin is the following one:

- Endemic species: These are only found in a limited geographical area in the world and their presence is important to determine the conservation value of the region where they are present (Romero & Nakajima, 1999). One of the main factors affecting the existence of endemic species is global warming (Malcolm *et al.*, 2006).
- Native species: Those found in determining regions or ecosystems. In reforestation, native species must be prioritized (Programa de Bosques Andinos, 2019).

- Exotic species: These nonnatives are normally introduced. Although they usually cause problems with other species in the area (interfering in their dispersal among others), they sometimes contribute in a positive way to restoration and reforestation projects (Programa de Bosques Andinos, 2019).
- Invasive species: Can be native or exotic, and they are well adapted to the environment with a rapid dispersion and causing damages to ecosystems, economy, and public health (Lee, 2002).
- Exotic invasive species: These are the worst ones once they are introduced in an area, competing or preying with the other native species (Vanegas López, 2016).

The Restoration Group (GREUNAL) of the National University of Colombia (Vargas *et al.*, 2012) suggests information and first steps for ecological restoration:

- Knowledge about the past of the study area. Highlighting the importance of the past of the area that is going to be restored (Higgs *et al.*, 2014), the knowledge about it is essential. In the present project, the plots are degraded due to intensive agriculture and cattle raising in the last decades.

- Detailed information on the plant species, which has also been described above. Many herbaria, such as the National Herbarium of Colombia (COL) or the Regional Herbarium of Antioquia (IAUM) have useful information. Institutes such as the Alexander Von Humboldt (IAvH) or the Environmental and Meteorological Studies (IDEAM) collect practical data.

- It should be taken into account the information about biotic and abiotic conditions. In the biotic conditions, present species or dispersal agents are included (Preston *et al.*, 2008). Concerning abiotic conditions, erosion, topography, and climate are included due to their importance in reforestation and restoration activities (Marden, 2012; Laurance, 2004). In the project, all these aspects have been considered.

- Evaluation of the regeneration potential, where the number of individuals and the successional stages is evaluated. In this case, the species with important conservation values are not chosen due to the future timber extraction in the area. Including them would be against FSC principles, which say that rare, vulnerable, and threatened species must be protected as well as their habitats (FSC, 2006).

- Identify the ecological and socioeconomic tensions. The second one is related to political, economical, and social aspects that can limit natural regeneration (Vargas *et al.*, 2012). According to Vargas *et al*. (2007), the first one is related to three different aspects:

- Stress aspects related to plant dispersion, which is generally caused by fragmentation or habitat loss, but sometimes they are originated by exotic species. Among the most common ones, it is possible to highlight the absence of pollinators or dispersal agents.
- Stress aspects related to plant establishment, which influence in plant's setting processes as germination. There are biotic (as competence among species) and abiotic (as climate) factors that can influence these processes.
- Stress aspects related to plant persistence, which is focused on the plant's growth. There are biotic (as competence among species), abiotic (as climate), and social (as the introduction of invasive species) factors that can influence this process.

- Once the plants are selected, the propagation methods have to be chosen. In the present project, the propagation method is the vegetative stakes one.
- One of the last steps is to facilitate the restoration, including improvements in the area as easing the entrance to the different plots, making them accessible; creating biological corridors for the fauna, enrich soil properties or decompose mechanically the soil. As it has been mentioned before, the elimination of tensioning aspects can be important in some situations. For many projects, removing invasive vegetation species and their radicular system is helpful (Gutiérrez-Bonilla *et al.,* 2017).
- Vargas *et al*. (2012) recommend including population around the area that is going to be reforested or restored to achieve socio-economic benefits.

Concerning the vegetative method that has been selected (vegetative stakes), Zahawi & Holl (2009) consider it an effective method for restoration. Also, this method enhances soil erosion control and biodiversity. The species that are going to be used are native and distributed naturally in the study area (Vanegas, 2016). Pioneer species are recommended for the most degraded areas and early successional stages (Díaz-Páez & Polanía, 2017), facilitating the secondary succession.

In the stakes propagation, not every vegetative part of the plant uses the best vegetative parts are the ones belonging from hardwood, considering hardwood the one that is 1 or more years old (Rojas González *et al*., 2004). Once the vegetative part is obtained, the roots are going to start sprouting, but depending on the species, the speed of the growth is going to change. In some cases, hormonal products can be added. This is the case of the *Azospirillum*, *Rhizobium*, or *Pseudomonas*' bacteria genus (Ronald & Alarcón, 2007). The first one has demonstrated to be the most effective, elongating the radicular system and fixing nitrogen (N). Even if the vegetative stakes method has many advantages, it also has disadvantages:

- Advantages: Easy procedure and low cost (Rojas González *et al*., 2004), conservation of the genetic characteristics and low competition with other species due to the height of the stakes (Díaz-Páez & Polanía, 2017).
- Disadvantages: stakes are susceptible to unfavorable environmental conditions as drought or frost (Rojas González *et al*., 2004) and in some species the survival rate is low. Moreover, for some species, transport is challenging (Zahawi & Holl, 2009).

Considering all this information and all the factors that should be taken into account, this method will be established shortly in the project area.

2.7. DATA ANALYSIS

As it is explained in the beginning, only 5 plots will be analyzed. Species and individuals data were used to make a comparison of the rates between 2013 and 2019 to test the loss or gain of biodiversity on the different plots. Species with significant conservation value were included, and the variation in the number of individuals over time can be checked in the following table:

Table 3. Differences in the number of species with important conservation value during the 6 years time-period. Own source.

PLOT	2013	2019
PLOT 2	12	60
PLOT 3	6	24
PLOT 4	9	24
PLOT 5	10	30
PLOT 6	7	31

The Importance Value Index (IVI) was calculated by 'Reforestadora El Guásimo S.A.S.' with the following formula:

$$IVI=AB\%+F\%+D\%$$

*AB%= absolute and relative abundance
*F%= absolute and relative frequency
*D%= absolute and relative dominance

In all the plots there were 51 families and 91 genera in total, sometimes represented by a single species. The Indexes obtained were the following ones:

- ❖ **Margalef diversity index** (Margalef, 1958), which measures species richness (Gamito, 2010), measuring it independently of the sample size (Moreno, 2001). Values below 2 are considered low diversity areas:

$$D_{Mg}= (S – 1)/ \ln N$$

*S= total number of species
N= total of individuals

- ❖ **Simpson's Diversity Index,** which is a measure of dominance (Somerfield *et al*., 2008). With values from 0 to 1, 1 representing the highest biodiversity. For a better representation, in the graphs, the values are obtained from 1 - ʎ.

$$ʎ = \sum p_i^2$$

*p_i = proportional abundance of the p_i specie, i. e. the number of individuals from the I species divided between the total number of individuals

- ❖ **Mixing coefficient (MC),** which indicates the homogeneity or heterogeneity of a forest (Alvis, 2009). This coefficient facilitates having an idea about the individual's distribution inside the forest (SILVOTECNIA, 2019).

$$MC= S/N$$

* S= total number of species
N= total of individuals

3. RESULTS

3.1 SOIL CHARACTERISTICS

After the soil analysis, the results show that the soil of the different plots is an acid soil, with values of pH between 4.32 and 5.16, which is linked with the low CEC (meq/100g) (with values 1.67-6.1) and the low availability of nutrients (CUCE, 2007).

The % of MO, in this case, has from low to medium values (1.36 to 4.84), although two of them from the same sample at different depths (0 - 20 cm; 20 - 40 cm) were higher: 5.37 and 7.37.

The bulk density (g/cm^3) values go from 1.04 to 1.49 which corresponds to a sandy-loam texture. This increases with the depth, in concordance with many studies as the one from Shwetha & Varija (2015).

Values of P (mg/kg) go from 1.4 to 3.6. As the pH is low, it does not affect the availability of P for the plants because it does not interfere with the way it is with these values (H_2PO_4) (Rosso *et al.,* 2009).

The % Al^{+3} saturation has values from 40.1 to 80.

3.2 SUCCESSIONAL STAGE

Plots are considered by ‘Reforestadora El Guásimo S.A.S.’ to be in a late-successional stage, taking into account the individuals with a Diameter at Breast Height (DBH) $\geq$ 10 cm and the species present in the area. In Plot 2, 44.53% of the trees have a DBH $\geq$ 10 cm. For Plots 3, 4, 5 and 6, the percentages have been 60.52%, 71.79%, 63,41% and 66.10% respectively. Besides, some of the considered genera correspond to early succession stages, such as *Vismia, Psidium, Ocotea, Inga, Schefflera,* or *Weinmannia*.

3.3 SPECIES SELECTION AND REFORESTATION

After the bibliographic revision of the species that appear in the area, **Table 2** shows the 13 best genus to be selected for a reforestation and restoration project with the characteristics of the study area. Many physical characteristics as strong root systems or the capacity to survive in acid soils have been selected for a successful result with the vegetative stakes method.

3.4 IMPORTANCE VALUE INDEX

Every plot has species that give importance to the area due to their conservation value as it is possible to check in **Table 1**.

In 2013 there were 8 genus with important conservation values: *Quercus, Ocotea, Landenbergia, Miconia, Clusia, Alchornea,* and *Inga*. In 2019, the number of genera with important conservation value ascend to 16 as new individuals were measured and identified, including to the previous list the following genus: *Cyathea, Geonoma, Ilex, Clethra, Meriania, Billia, Symplocos* and *Beilschmiedia.*

In 2013 the values of the Index went between 12.89 to 49.27 % with *Quercus* with the highest value, followed by *Ocotea* (18.73%). In 2019, values varied much more than in 2013, going from 1.70 to 12.96 %. The highest value was from the *Quercus* again, followed by *Cyathea* with a much lower value (4.95%).

3.5 BIODIVERSITY INDEXES

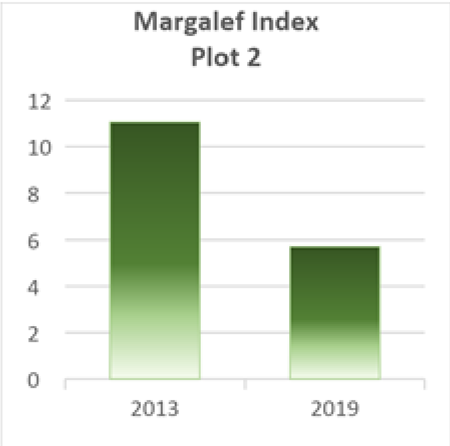


Figure 10. Margalef Index, plot 2. Difference between 2013 (11.06) and 2019 (5.71).

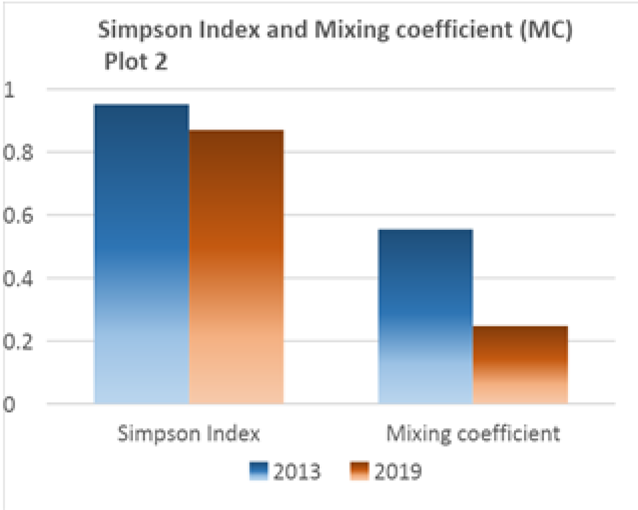


Figure 11. Simpson Index and Mixing coefficient (MC), plot 2. Difference between 2013 (0.0485; 0.5543) and 2019 (0.1293; 0.2477) respectively.

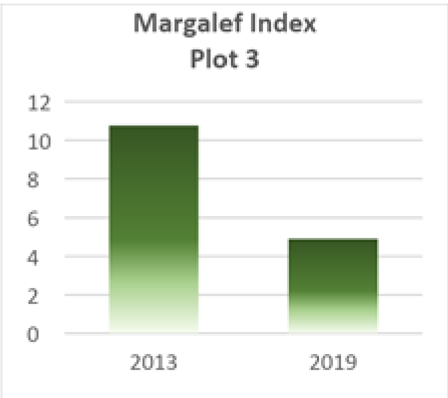


Figure 12. Margalef Index, plot 3. Difference between 2013 (10.76) and 2019 (4.95).

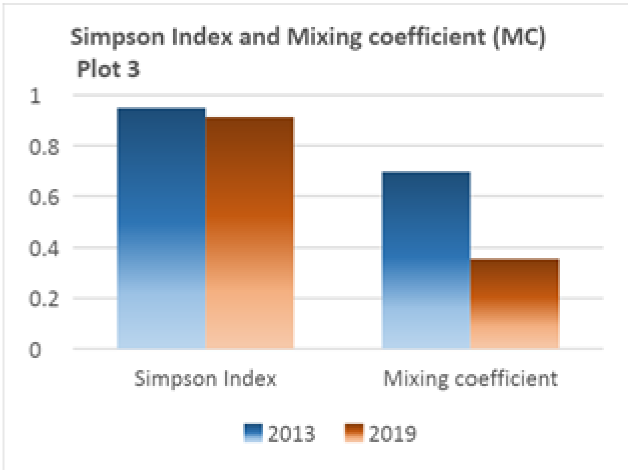
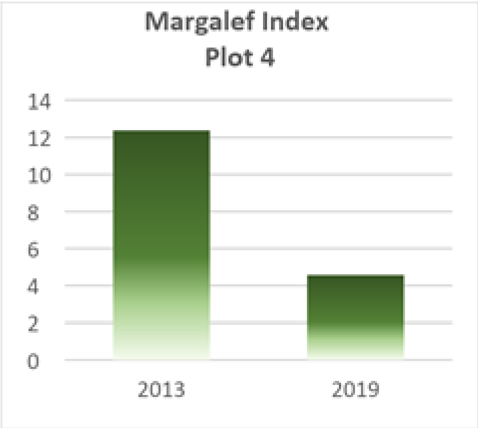


Figure 13. Simpson Index and Mixing coefficient (MC), plot 3. Difference between 2013 (0.0514; 0.6969) and 2019 (0.0873; 0.3559) respectively.



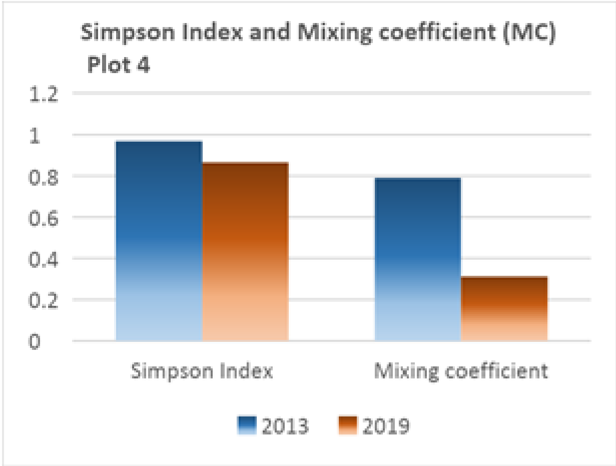
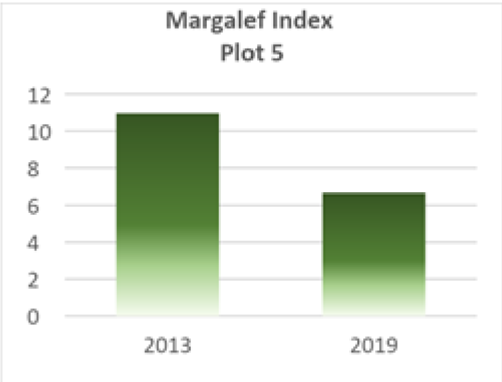


Figure 14. Margalef Index, plot 4. Difference between 2013 (12.38) and 2019 (4.57).

Figure 15. Simpson Index and Mixing coefficient (MC), plot 4. Difference between 2013 (0.0318; 0.7910) and 2019 (0.1352; 0.3125) respectively.



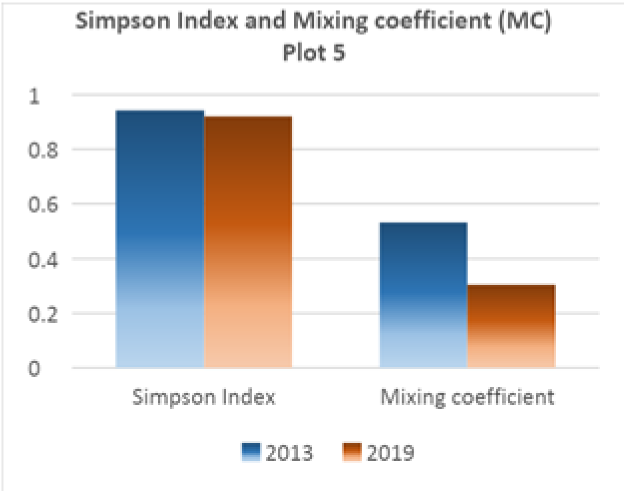
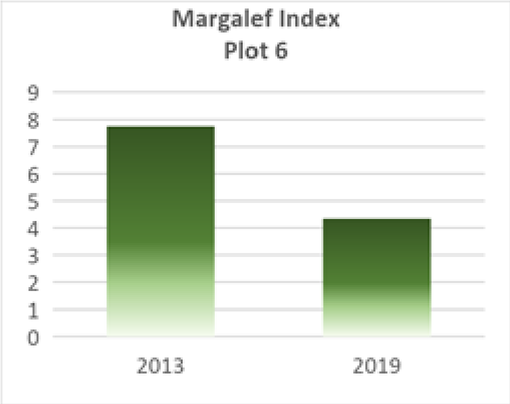


Figure 16. Margalef Index, plot 5. Difference between 2013 (10.96) and 2019 (6.66).

Figure 17. Simpson Index and Mixing coefficient (MC), plot 5. Difference between 2013 (0.0577; 0.5312) and 2019 (0.0795; 0.3047) respectively.



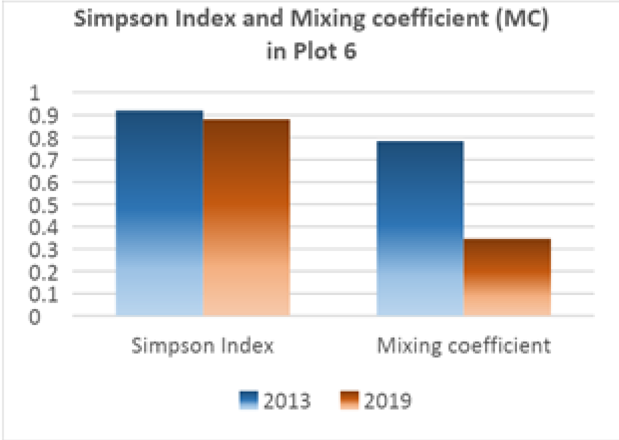


Figure 18. Margalef Index, plot 6. Difference between 2013 (7.75) and 2019 (4.34).

Figure 19. Simpson Index and Mixing coefficient MC), plot 6. Difference between 2013 (0.0815; 0.7837) and 2019 (0.1190; 0.3461) respectively.

Checking the **Figures** of the previous section, the Mixing Coefficient (MC) has been reduced from 2013 to 2019. The largest decrease has been in plot number 4, followed by plot number 6.

For the other indexes, Simpson and Margalef, plots 3 and 5 have been the most stable. Although they indicate the biodiversity loss, species composition is still very similar to that of 2013. The MC has the most remarkable differences.

4. DISCUSSION

Soil degradation in the area due to different activities (Rincón, 2015) has been considered for decades and the environment, which allows the appropriate selection of species for restoration. The local acidic soil does not favour plant growth and, on the contrary, can damage their root system and hinder their growth. Precisely, the high percentage of Al^{+3} saturation may be due to the low pH value (Ulrich & Sumner, 2012) and, together with soil degradation, are the result of long-term activities, such as agriculture and can trigger aluminium toxicity. In turn, they can also lead to low CEC values (Saikh *et al.*, 2008; Hailegnaw *et al.*, 2019), which is directly related to low nutrient availability (CUCE, 2007) and slowed growth of individuals (Tanner *et al.*, 1998). Although a high percentage of organic matter can generate low CIC values, this was not the case in this study. Therefore, soil enrichment or, failing that, the choice of species that produce litter and, in general, the organic matter could, according to Fenton *et al*.

(2008), improve the physical, chemical and microbiological characteristics of the system, as well as favouring natural and biological cycles (Wantzen and Mol, 2013; Instituto Alexander von Humboldt, 2015). This litter production can be somehow linked with the P concentration. The presence of organic matter promotes the presence of microorganisms, which release the phosphorus, nutrient that the plants will take for their nutrition (Darch *et al.,* 2016).

For the aforementioned reason, it is a fact that many abiotic conditions, such as the temperature, which helps in the organic matter decomposition, can determine vegetation patterns (Pueyo & Alados, 2007). Then, species such as the ones from the *Prunus* genus, which are deciduous, or the ones from the Alchornea genus, which have great foliage, have the capacity of improve soil characteristics and, at the same time, the presence of microorganisms and nutrients. Tropical soils do recover faster than temperate soils due to environmental conditions (Six *et al.,* 2002), which makes the study area more manageable. As reforestation is nowadays one of the main activities in the world (Bozzano *et al*., 2014), the improvement of the soil conditions is a clue factor in facilitating the settlement of different tree species, especially the most sensible ones.

As for the successional stages, some secondary stages could be recognized in different plots. It was also possible to recognize pioneer species and some representatives of early stages such as the genera *Ficus* or *Tibouchina*. Although the literature on local species is not abundant, it was possible to select some genera with restoration potential using cuttings, such as *Alchornea, Billia, Ficus, Inga, Meriania, Miconia, Ocotea, Protium, Prunus, Psidium, Symplocos, Tibouchina* and *Weinmannia*. Some of them have even already been tested with this vegetative method (Zahawi and Holl, 2009; Díaz-Páez and Polanía, 2017) RG could take into account some successful results when they are about to perform their process. For example, a suggestion could be how and when to cut the stakes. The selected genera usually thrive in degraded environments, which increases their potential for the study area. As has been said, the vegetative cut method facilitates rapid growth and adaptation of different plant species (Zahawi, 2005) such as the ones from the *Weinmannia* genus (Díaz-Páez & Polanía, 2017). Among the selection requirements, we consider native species, which are often threatened by many types of pressures, such as invasive ones (Vila & Weiner, 2004) and which bring many different benefits to nearby populations (IDEAM, 2014) as well as for biodiversity, such as:

- Conservation value, which is considered necessary due to FSC certification, and which has been evaluated by the company (SILVOTECNIA, 2019),

- Adaptability to altitude, which is a requirement for native and endemic species (Körner, 2007; Pelliser *et al.*, 2012), above all in areas as high as the Andean region, many times affected by extreme temperatures and with unusual species (Novoa Usaquén, 2017),
- Rapid germination rate, which improves the probability of survival of the individual among other positive aspects (FAO, 2014),
- Reproductive capacity in degraded soils (typical of pioneer species and local individuals) (FAO, 2014),
- Production of fleshy flowers and fruits (to attract dispersing species), which facilitate dispersal and prevent low diversity (Tchoundjeu & Leakey, 1996; Howe & Miriti, 2004; Muñoz *et al.,* 2013), and
- Root system adapted to many types of soil and adequate development (Tchondjeu & Leakey, 1996).

Selected genera comply with a list of requirements that make the survival easier for them. For example, *Alchornea* can be adapted to many kinds of soils; *Ficus* attracts animals due to the fruit production; *Inga* and *Miconia* have fast growth, and they ease the soil stabilization, and *Meriania* is capable of producing lots of seeds. All of those characteristics facilitate dispersion and growth. On the other hand, although many of the genera selected have not been tested with the stakes method, their physical characteristics indicate that vegetative reproduction can be successful.

It is worth mentioning the need to rescue the stakes from the sites near the study area, which is possible because all the genera were in the measured plots. Indeed, authors as Zahawi and Holl (2005), Zahawi (2009) and Díaz Páez (2019) recommend bigger stakes for having more survival probabilities, so the size of the individuals should be considered for the process. Also, many of the species do not have a High Conservation Value and can be harvested in the future, as foreseen by the FSC certification standards, under which RG works (FSC, 2006). However, it may be useful to check whether nearby nurseries can provide individuals of these genera to ensure some plant biodiversity and, in consequence, heterogeneity.

In any case, we recommend and suggest taking into account the connectivity of the plots. Each plot represents an isolated patch and the fragmentation of the forests. Fahrig (2003) described fragmentation as "...*a large extension of habitat transformed into isolated and small patches*...", that has negative consequences, especially for vulnerable plant and animal species (Rosenberg, 1997; Fahrig, 2003; Ferraz *et al.*, 2007). Some work (Bennett, 2004; Saura *et al*., 2011) has shown the effects of biological corridors in terms of connecting isolated areas and reducing different impacts, such as species loss or changes in stand composition. Various techniques, such as nucleation techniques, improve the development and expansion of different patches, creating refugees for different animals' species, both mammals and birds that at the same time will take part in the seed dispersal.

In summary, the rapid growth of tropical species improves biodiversity and the dispersal of individuals (Ceccon, 2014), and the increment in the number of individuals during the six years, especially the ones with High Conservation Value, can prove that despite the characteristics (mainly the soil ones) restoration can be possible. A distance of approximately 2.5 km separates plots 2, 3 and 4; plot 5 is 7 km further away, while plot 6 is in another department, almost 185 km away. It is therefore not possible to connect it with the others, but some small species or those adapted to microhabitats will also not be able to exceed the distances indicated above. However, the connectivity between the closest plots is a fact that must be taken into account to improve both genetic diversity and ecological connectivity. The critical point here is to avoid the patches' isolation, which has, in most cases, negative impacts for the biodiversity.
Genetic material must be obtained from nearby individuals, so that the new cuttings (Zohary, 2001; Zahawi and Holl, 2009) inherit the parents' adaptation to the local environment and the advantages of having competed successfully and naturally with others. However, for Kettenring and others (2014), it could be counterproductive to follow a single course of natural selection, which would impoverish genetic diversity. The species highlighted here are present in almost all plots, although some of them are not sufficiently representative. Some genera appear in just one or two plots as is the case of *Psidium*. In that case, if the other plots are too far, the stakes obtained from these species will not be used but will appear just in one plot. Therefore, RG should verify the number of individuals before collecting the stakes.

Erosive elements, such as gullies and steep slopes, as well as soil loss, can be reduced as long as the natural cover is preserved so that the structure of the substrate is maintained (Jepson, 1939; Sarah & Rodeh, 2004). Although some of the genera that have been selected, such as *Inga* and *Miconia* are capable of being adapted in soils that are not well stabilized, Jiménez (2018) suggests recovering the ravines employing:

- Physical isolation, which prevents the entry of animals;
- The control of water flowing from the top of the ravines, for which he proposes to build diversion structures;
- Removing the degraded edges of the ravine to facilitate the establishment of individuals (usually 30 - 40 cm of soil is removed);
- Fill the ravines with sediments and structures;
- Replant native species, preferably fast-growing ones, with dense and robust root systems;

- Reforesting slopes with trees and shrubs with well-developed root systems (Gray, 1996; Chen *et al.*, 2018);
- Transplanting stakes (*sensu* Rojas *et al.*, 2004 and followed by Díaz-Páez and Polanía, 2017).

Species considered rare, threatened or vulnerable deserve special care. It is worth mentioning that "Reforestadora El Guásimo S.A.S." considers some of its units as "High Forest Conservation Value" (HCVF). FSC uses this term for forests that should be managed appropriately, i.e. their "values" should be improved (Jennings *et al*., 2003; FSC, 2006). As a significant number of species with high conservation value were highlighted in the different plots, care must be taken not to remove stakes from them. Besides, control of invasive species should be considered to avoid the damage they can cause (Brundu & Richardson, 2016), often displacing native ones (Vila & Weiner, 2004). In 2013, 8 genera were considered in the list of species with Important Conservation Value. Moreover, in 2019, 16 genera were considered. Among the new ones, it is possible to find species from *Meriania*, *Symplocos* and *Billia* genus. Some species from these genera have also been considered for the vegetative stakes method. Because of this reason, correct identification of the different species must be made to avoid the extraction of material from the genera that have Important Conservation Value and that have a small number of individuals.

The list of species measured in 2019 was longer than in 2013. This fact may have contributed to the variation in the IVI results. In other words, the increase in species in the "tree" category as a result of recruitment in recent years. For example, *Geonoma orbignyana*, which has been classified by IUCN as 'Near Threatened (NT)' (Perdomo *et al.*, 2015) appeared in plots 2, 3 and 4, with 32 individuals. The presence of species with this classification opens up the possibility of conducting utilization studies to preserve the individuals found. Over time, genetic material should be collected to encourage its cultivation in nurseries and ensure its quality (Konnert & Ruetz, 2003; Gregorio *et al.*, 2015). In the last case of rescuing individuals from these categories, it will not be enough to mark and monitor them, but a security perimeter should also be established to prevent future damage.

Biodiversity indices decreased, as did heterogeneity, during the six years between the two measurements. The probable reason is that the samplings (DBH = 5-10 cm) were not measured in 2013, but the trees were measured on both occasions. Since tropical forests tend to show rapid growth and species germinate continuously (Mostacedo & Pinard, 2001; Ceccon, 2014), there is a high density and competition between individuals (da Cunha *et al.*, 2016), many that appeared in the 'sapling' category in 2013 may have been recruited in the 'tree' category in 2019. In any case, consideration should be given to the possibility that the decline in diversity will lead to some homogeneity and eventually damage local genetic diversity (Lechowicz & Bell, 1991; Pardini *et al.*, 2005; FAO, 2014). This fact should be avoided because of the adverse effects, which are harmful in the medium and long term not only to plant species but also to animals.

The five plots in Antioquia presented similar amounts of individuals and species, which logically derives from the fact that they are under the same environmental variables (soil type, altitude, climate, dispersing agents, among others) since the distances between the plots were short. The creation of biological corridors to unite the different plots could significantly increase the biodiversity in the RG plantations. Since Colombia is one of the most diverse countries in the world (Baptiste *et al.*, 2017) and its forests are threatened (Global Forest Watch, 2020) this strategy would simultaneously increase genetic diversity.

5. CONCLUSIONS

Despite the characteristics of the soil, many different species were present on the plots. The degraded soil and the physical and chemical characteristics of the plots make it difficult for individuals to adapt and ultimately make a restoration and reforestation project successful. The features of the species, typical of early and secondary stages of succession, seem to be just enough for an adequate adaptation. Some of the species mentioned (*e.g.* Ficus spp), have been used for reforestation or to promote the growth of other species. Such is the case with *Inga* species. The information described above was useful, but many species distributed throughout the country have not yet been described, for different reasons: similarities with other species, low number of individuals, among others.

Further studies of the physical attributes of species, some of which are abundant throughout the country, should fill significant information gaps. This information can help to overcome reforestation and restoration projects.

Future environmental conditions will be more extreme, and with more native species as well as with more resistant ecosystems, the effects will not be as severe, affecting in a less harmful way the individuals that inhabit different areas. Our results, as well as the contrast with the literature, point to the success of the stake nucleation method in RG lands.

Many species with High Conservation Value were measured in the last sampling which indicates that, regardless of the category where they are included, essential ones are still growing and measures to mitigate their impact and encourage their conservation are needed.

Although the mortality of the stakes can be high at first, continuous monitoring of the vegetative stakes should be done after planting to check the success of the individuals, their different adaptations to the conditions of the study area and to propose corrective measures when necessary.

Information collected can be useful to clarify the different points of view and results that other authors (*i.e.* Zahawi and Holl, 2009; Díaz Páez, 2019) have found growing and planting different genera.

It is also essential to monitor the High Conservation Value species as well as the biodiversity as a whole, which contributes to give unique importance to the studied areas. Moreover, the presence of native plant species provides niches and protection for different animal ones, which can contribute to the conservation of, mainly, those that are threatened or in danger.

More scientific studies will be necessary to preserve these objects of high conservation value, as well as to collect genetic material for nurseries to encourage their reproduction and to recover different areas not only in the study area but also in the rest of the country.

6. BIBLIOGRAPHY

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1. APPENDIX

1.1. Fauna

Table 4. Birds Order in the Norte Antioqueño. Own source.

ORDERS		
Accipitriformes	Cuculiformes	Phaethontiformes
Anseriformes	Eurypygiformes	Piciformes

Caprimulgiformes	Falconiformes	Podicipediformes
Cathartiformes	Galbuliformes	Procellariiformes
Charadriiformes	Galliformes	Psittaciformes
Ciconiiformes	Gruiformes	Strigiformes
Columbiformes	Passeriformes	Suliformes
Coraciiformes	Pelecaniformes	Trogoniformes

Table 5. Birds Order in Caldas' Department. Own source.

ORDERS		
Anseriformes	Coraciiformes	Phoenicopteriformes
Accipitriformes	Cuculiformes	Piciformes
Apodiformes	Falconiformes	Podicipediformes
Caprimulgiformes	Galbuliformes	Psittaciformes
Cathartiformes	Galliformes	Strigiformes
Charadriiformes	Gruiformes	Tinamiformes
Ciconiiformes	Passeriformes	Trogoniformes
Columbiformes	Pelecaniformes	

Table 6. Species of mammals that can appear in the study area. Own source.

ORDER	SPECIES	ALTITUDE (masl)	SPECIES	ALTITUDE (masl)
Chiroptera	*Anoura caudifera*	500 - 2800	*Molossus rufus*	0 - 2600
	A. cultrata	940 - 2600	*Mormoops megalophylla*	0 - 2100
	Artibeus anderseni	1300 - 1900	*Myotis nigricans*	0 - 2800
	A. cinereus	0 - 2000	*Nyctinomops macrotis*	0 - 2600
	A. lituratus	0 - 2600	*Peropteryx macrotis*	0 - 1800
	A. jamaicensis	0 - 2200	*Platyrrhinus aurarios*	800 - 2000

	A. phaeotis	0 - 2760	*P. dorsalis*	500 - 2500
	Carollia brevicauda	2000 - 2760	*P. vittatus*	1120 - 3000
	C. colombiana	1300 - 2000	*Pteronotus parnellii*	0 – 2600
	C. perspicillata	30 - 2000	*Rhogeesa tumida*	0 - 2600
	Chiroderma salvini	0 - 2000	*Sturnira bidens*	1150 - 2800
	Desmodus rotundus	0 - 2125	*S. erythromus*	1500 - 2700
	Enchistenes hartii	0 - 2475	*S. ludovici*	940 - 2100
	Eumops glaucinus	0 – 2800	*S. mordax*	360 – 2100
	Glossophaga soricina	0 – 1800	*Vampyrum spectrum*	0 – 2800
	Histiotus montanus	1500 –3000		
	Lonchophylla robusta	400 - 2050		
Didelphimorphia	*Caluromys derbianus*	0 – 2600	*Didelphis marsupialis*	0 - 2500
	Chironectes minimus	30 – 2100	*Marmosa murina*	800 – 2000
	Didelphis pernigra	2000 - 3500		
Paucituberculata	*Caenolestes convelatus*	2700 – 3600		
Florívora	*Bradypus variegatus*	30 – 2160		
Cingulata	*Dasypus novemcinctus*	0 - 3000		
Vermilingua	*Tamandua mexicana*	0 - 3000		
Primates	*Aotus lemurinus*	0 - 2000	*Cebus albifrons*	0 - 3200
	Ateles fusciceps	0 - 2000	*Lagothrix lagotricha*	0 - 3000
Carnivora	*Cerdocyon thous*	0 - 3400	*Lutra longicaudis*	0 - 2800
	Conepatus semistriatus	0 - 3100	*Nasua nasua*	0 - 3200
	Eira barbara	0 - 2400	*Panthera onca*	0 - 3200
	Leopardus pardalis	0 - 3600	*Potos flavus*	0 - 3000
Artiodactyla	*Mazama americana*	0 - 4000	*Pecari tajacu*	0 - 2800
	Odocoileus virginianus	0 – 4000		
Rodentia	*Cuniculus paca*	0 - 2000	*Rhipidomis latimanus*	1100 - 3000
	Dasyprocta punctata	0 - 3200	*Sciurus granatensis*	0 - 3800
	Dinomys branickii	300 - 3400	*Sigmodon hispidus*	0 - 2600
	Microsciurus mimulus	0 – 3200	*Thomasomys cinereiventer*	2000 – 3500
	Olallamys albicauda	2000 - 3000		

1.2. Flora

Table 7. *Alchornea* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
A. acutifolia	2100-2865	*A. floviatilis*	100-200	*A. leptogyna*	20-2000
A. bogotensis	1800-2600	*A. glandulosa*	20-2450	*A. megalophylla*	500-1700
A. castaneifolia	20-600	*A. grandifolia*	1300-2900	*A.tachirensis*	2000
A. coelophylla	1200-2750	*A. grandis*	50-1100	*A. triplinervia*	120-1000
A. costaricensis	20-750	*A. integrifolia*	400-1700	*A. verticillata*	-
A. discolor	140-2300	*A. latifolia*	200-2800		

Table 8. Existing *Billia* species. Own source.

Species	Altitude (masl)	Species	Altitude (masl)
B. rosea	0-3000	*B. hippocastanum*	950-1750

Table 9. *Ficus* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
F. albert-smithii	200-600	*F.donnell-smithii*	50-230	*F. paraensis*	0-1800
F. americana	0-3000	*Ficus dulciaria*	2000-2800	*F. pertusa*	5-1940
F. apollinaris	400-3000	*F. eliadis*	50-350	*F. piresiana*	200-1250
F. brevibractecata	30-2050	*F. eximia*	600-1850	*F. popayanensis*	1300-1600
F. caballina	100-400	*F. francoae*	500-700	*F. popenoei*	20-1050
F. caldasiana	1200-1900	*F. huilensis*	1950-2900	*F. pulchella*	600
F. calimana	5-500	*F. gomelleira*	500-600	*F. quijosana*	1800-2300
F. carchiana	1800	*F. hartwegii*	0-2250	*F. richteri*	700
F. casapiensis	0-200	*F. hebetifolia*	200-450	*F. rieberiana*	0-1500
F. castellviana	550-2000	*F. insípida*	0-2850	*F. romeroi*	100-1500
F. cervantesiana	1300-2400	*F. krukovii*	1400	*F. schippii*	5-1800
F. citrifolia	0-2400	*F. lauretana*	100-200	*F. soatensis*	1800-3000
F. coerulescens	100-1550	*F. macbridei*	0-1900	*F. turrialbana*	100-500
F. colubrinae	10-20	*F. magdalenica*	30	*F. velutina*	350-3100
F. dendrocida	5-1800	*F. pallida*	0-3000	*F. yoponensis*	0-1810
F. dewolfii	1260-1300	*F. paludica*	0-200		

Table 10. *Inga* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
I. acreana	5-2450	I. heterophylla	20-1500	I. plumífera	120-300
I. acrocephala	30-2250	I. ilta	200	I. polita	0-770
I. acuminata	100-2100	I. ingoides	20-2600	I. pruriens	120-20
I. alata	100	I. interfluminensis	1450-2200	I. pseudoinvolucrata	100
I. alba	90-1025	I. interrupta	255-265	I. psittacorum	35-600
I. auristellae	80-600	I. involucrata	50-300	I. punctata	0-2780
I. barbourii	1700	I. jefensis	30-100	I. rubiginosa	50-490
I. bourgnonii	100-1420	I. lallensis	50-2800	I. ruiziana	0-2150
I. brachyrhachis	90-1200	I. laurina	6-1500	I. saffordiana	0-1250
I. brachystachys	100-160	I. leiocalycina	20-2300	I. samanensis	60-1550
I. capitata	50-1000	I. leonis	1150-1550	I. sapindoides	50-1600
I. cayennensis	50-1800	I. leptocarpa	90-1325	I. sertulifera	5-1420
I. cecropietorum	178-1100	I. longiflora	0-240	I. setosa	340-2180
I. chartacea	0-1000	I. longifoliola	200-300	I. sierrae	1150-2470
I. chocoensis	0-800	I. lopadadenia	100-1650	I. spectabilis	0-2000
I. ciliata	200-2600	I. macarenensis	1700	I. splendens	120
I. cinnamomea	10-2450	I. macrophylla	100-2000	I. stenopoda	100-500

I. cocleensis	40-2700	I. manabiensis	1000-1150	I. stenoptera	100-1200
I. colombiana	500-640	I. marginata	0-2350	I. stipulacea	0-200
I. coragypsea	1800-1900	I. marítima	100-300	I. stipularis	200-600
I. cordatoalata	160-600	I. megaphylla	200-300	I. striata	2000
I. coruscans	0-2200	I. micheliana	750-2430	I. tayronaensis	150
I. cylindrica	50-600	I. mucuna	25-830	I. tenuistipula	0-1650
I. densiflora	20-2000	I. multijuga	0-2370	I. thibaudiana	0-1550
I. dwyeri	198-1500	I. multinervis	50-730	I. ulei	0-200
I. edulis	0-2140	I. neblinensis	250-800	I. umbellifera	20-1600
I. fastuosa	200-2400	I. nobilis	0-2890	I. umbratica	80
I. fendleriana	1700	I. obtusata	0-100	I. ursi	1240-2000
I. feuillei	0-2700	I. oerstediana	60-2800	I. velutina	50-1800
I. filiformis	0-160	I. ornata	800-2350	I. venusta	50-1800
I. goniocalyxs	-	I. panurensis	100-200	I. vera	10-2300
I. gracilifolia	0-100	I. pauciflora	0-200	I. villosissima	200-2500
I. gracilior	10-2200	I. pezizifera	0-1850	I. yocoana	100
I. hayesii	0-150	I. pilosula	100-380	I. yasuniana	50-130

Table 11. *Meriania* species in Colombia. Own source

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
M. acostae	0-100	*M. hernandi*	1900-2200	*M. quintuplinervia*	1600-2500
M. antioquiensis	1300-1850	*M. hexamera*	1200-1800	*M. speciosa*	1300-2400
M. arborea	3000	*M. huilensis*	1900-2800	*M. solendens*	2100-3300
M. barbinensis	1100-3000	*M. lindenii*	1000	*M. steyermarkii*	2600-3600
M. basbrosae	1573-2000	*M. longifolia*	1200-2000	*M. tolimana*	2600
M. capitata	1600-2200	*M. macrophylla*	1200-2600	*M. thanaei*	1500-2000
M. candollei	2300-2700	*M. maxima*	1800-2500	*M. tuberculata*	1200-2800
M. colombiana	2300-2700	*M. maxiae*	-	*M. umbellata*	1800
M. cordifolia	-	*M. nobilis*	1900-3000	*M. urceolata*	400-1500
M. dimorphanthera	-	*M. pallida*	1250-1400	*M. versicolor*	2200
M. fantastica	2000-2800	*M. peltata*	2000-2900		
M. grandidens	400-2700	*M. tomentosa*	2100-2900		

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Table 12. *Miconia* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
M. abbreviata	150 - 300	*M. erioclada*	300-855	*M. perijensis*	2200-3900
M. acalephoides	1000 - 2100	*M. erosa*	2280-2700	*M. phaeochaeta*	600
M. acanthocoryne	1570-2000	*M. eugenioides*	80-700	*M. phaeophylla*	250
M. actinodendron	70-700	*M. filamentosa*	100	*M. phanaerostila*	100-160
M. acuminifera	950-2200	*M. fissa*	180-700	*M. pichinchensis*	2050-3150
M. acutipetala	100	*M. floribunda*	1200-3300	*M. piperifolia*	0-230
M. aenigmatica	2950-3000	*M. frontinoana*	1500-2000	*M. platypoda*	300-500
M. aeruginosa	40-2600	*M. gentryi*	1300-1520	*M. plena*	1200-2780
M. affinis	20-2200	*M. gibba*	1900-2200	*M. plethorica*	2150-3000
M. aggregate	2000-2500	*M. glaberrima*	1720-3000	*M. poecinlantha*	2040-2400
M. aguirrei	2850-3385	*M. gleasoniana*	1500-3950	*M. poeppigii*	60-700
M. alata	220	*M. goniostigma*	25-2350	*M. polynerura*	1800-3580
M. alberti	2500-3000	*M. gossypina*	718-900	*M. popayanensis*	1600-2000
M. albicans	25-2500	*M. goudotti*	160-200	*M. pozoensis*	2400

M. alburosea	2600-3700	*M. gracilis*	0-2200	*M. prasina*	40-2700
M. alternans	70-1500	*M. grandiflora*	710-3000	*M. prasinifolia*	1600-2660
M. alypifolia	2300-3200	*M. gratissima*	80	*M. pseudoradula*	1800-2300
M. amazónica	100-120	*M. hadrophylla*	1650-2640	*M. psychrophila*	2100-3500
M. amblyandra	2490-2770	*M. harlingii*	2300-3630	*M. pterocaulon*	80-1000
M. amnicola	100	*M. hawaii*	1800-2650	*M. puberula*	100-700
M. ampla	50-1020	*M. hematostemon*	2000-2300	*M. pubipetala*	220
M. andreana	1860-2000	*M. heterotricha*	2438	*M. pulvinata*	420-1600
M. anisophylla	900-1100	*M. holosericea*	100-410	*M. punctata*	0-1700
M. annulata	1800-3250	*M. hookeriana*	325	*M. punctibullata*	2370-2390
M. antioquiensis	3000-3310	*M. hymenanthera*	1750-2800	*M. puracensis*	2910-4000
M. aplostachya	80-500	*M. ibaguense*	240-2740	*M. pustulata*	1500-3900
M. aponeura	320-1700	*M. idroboi*	150-850	*M. quintuplinervia*	1910-2890
M. appendialata	100-600	*M. imbricata*	3200-3400	*M. racemosa*	0-400
M. araguenensis	1300-1900	*M. petiolaris*	60-1000	*M. radulifolia*	65-250
M. arboricada	720-1325	*M. inaequalifolia*	400-700	*M. rava*	2950
M. archeri	1300-1800	*M. ingens*	1000-1250	*M. reclinata*	1900-3200
M. argentea	200	*M. insueta*	2670-3000	*M. reducens*	0-2000
M. argyrophylla	350-1000	*M. intricata*	0-1370	*M. resima*	500-3120
M. asclepiadea	1200-2600	*M. jahnii*	2400-2700	*M. reticulata*	500-1940
M. asperrina	1200-3000	*M. jentaculorum*	3100-3300	*M. rhodantha*	1800-2500
M. astroplocama	1260	*M. juruensis*	200	*M. rigens*	3150-3450
M. astroticha	210	*M. kraenzlin*	1400	*M. rivetii*	1900
M. atropilis	2800-3000	*M. lacera*	0-1500	*M. rubens*	
M. aurea	150-1300	*M. laetivirens*	-	*M. rubiginosa*	80-3250
M. aureoides	600	*M. laevigata*	250-730	*M. rubricans*	200-2550
M. barbinervis	50-1650	*M. lamprarrhena*	700	*M. rufescens*	100-1850
M. bella	420-2400	*M. lamprophylla*	30-1120	*M. ruficaly*	0-200
M. benthamiana	0-2700	*M. lasiocalyx*	2000-2200	*M. rugosa*	160-200
M. biappendiculata	2500-3650	*M. lateriflora*	0-2150	*M. salicifolia*	2850-4200
M. biglandulosa	100-300	*M. latifolia*	2700-4040	*M. sandemannii*	488-3600
M. blakeifolia	50-1180	*M. lehmannii*	1600-2600	*M. schlimii*	0-500
M. bordoncilloana	2900-3400	*M. licrophora*	2300-2360	*M. sciurea*	200-600
M. borjensis	57	*M. liesneri*	420-480	*M. semisterilis*	570-600
M. brachycalys	0-1950	*M. ligulata*	0-720	*M. serrulata*	5-2640
M. brachygyna	1300-2650	*M. ligustrina*	2050-3800	*M. setosa*	2100-2300
M. bracteolata	2800-3600	*M. limitaris*	2700-3180	*M. shattuckii*	200-820
M. brevitheca	500-1900	*M. lithophila*	1350-2200	*M. silverstonei*	1700-2160
M. bubalina	100-600	*M. lonchophylla*	50-2670	*M. simplex*	10-700
M. buxifolia	2200-4100	*M. longifolia*	5-2900	*M. smaragdina*	0-2700
M. caesia	1000-3680	*M. longispicata*	250-900	*M. smithii*	1700-2700
M. cannabina	100-340	*M. loreyoides*	50-1850	*M. sneidernii*	1500
M. calvescens	50-920	*M. lourteigiana*	480-700	*M. sordida*	1450
M. capitellata	1900-2500	*M. lugonis*	230-1000	*M. spatellophora*	2300-2330
M. carassana	100-310	*M. luteynii*	2000-2560	*M. spennerostachya*	110-150
M. cataractae	2500-3900	*M. macrantha*	1000-2700	*M. spicellata*	250-1850
M. caucana	190-1100	*M. macrotis*	700-1500	*M. spichigeri*	250-900
M. caudata	1000-2000	*M. magdalenae*	60-700	*M. spinulidentata*	2530-3600

M. cautis	300	*M. majalis*	1800-2800	*M. spinulosa*	1000-2400
M. cazaletti	450	*M. manicata*	2000-2600	*M. spireifolia*	
M. centrodesma	5-2100	*M. marginata*	250-700	*M. sprucei*	200
M. centrodesmoides	1300-1600	*M. maroana*	200-900	*M. squamulosa*	2100-3600
M. centronoides	5-750	*M. matthaei*	340-1150	*M. stenostachya*	100-2700
M. chamissois	260-1530	*M. mazanana*	100-125	*M. stenourea*	1480-1930
M. chionophylla	2880-4250	*M. megalantha*	400-1380	*M. submacrophylla*	160-1000
M. chlorocarpa	2500-3750	*M. mesmeana*	2500-4360	*M. subsessilifolia*	300-1000
M. chrysocoma	2490-2580	*M. micayana*	1600-2800	*M. summa*	1900-3890
M. chrysophylla	70-1440	*M. mímica*	1900-2000	*M. superposita*	2900
M. ciliata	100-1250	*M. minuta*	2000	*M. symplocaceae*	2100
M. cionotricha	5-800	*M. miocarpa*	1800-2750	*M. tamana*	2700-2800
M. cladonia	2000-3300	*M. mirabilis*	1550-1900	*M. tenuis*	1300
M. clatharantha	1500-2100	*M. mituana*	400	*M. ternatifolia*	1530
M. clypeata	1600-1950	*M. mocquerysii*	150-260	*M. tetrasperma*	225-240
M. codomostigma	2100-2800	*M. mulleola*	1200-1300	*M. theizans*	230-3900
M. compressicaulis	2400	*M. multiplinervia*	1850-2900	*M. tinifolia*	2000-3850
M. cordifolia	1200-3820	*M. multispicata*	210-1500	*M. titanophylla*	400-450
M. coronata	1100-2200	*M. mutisiana*	2600	*M. tomentosa*	20-1250
M. coronifera	2530-2800	*M. myriantha*	120-810	*M. toroi*	1400-1500
M. costaricensis	800-2400	*M. myrtillifolia*	2000-3600	*M. tovarensis*	2200-3750
M. crinita	2400-2600	*M. napoana*	225-350	*M. traillii*	200
M. crocea	2600-3380	*M. nervosa*	0-1450	*M. transversa*	5-300
M. cruenta	520-1200	*M. neurotricha*	1800-2300	*M. triangularis*	325-850
M. cuatrecasas	2700	*M. nigripes*	1400-1800	*M. trichophora*	110-115
M. cundinamarcensis	960-3300	*M. nodosa*	3000-3250	*M. trinervia*	0-2400
M. dapsiliflora	1850-1900	*M. notabilis*	450-2200	*M. triplinervis*	50-1150
M. decipiens	120-1850	*M. nutans*	1100-1650	*M. truncata*	75-400
M. decurrens	100-2000	*M. obovata*	2700-3500	*M. tuberculata*	700-2100
M. denticulata	2050-3400	*M. ochracea*	1800-3300	*M. tubulosa*	915
M. desmantha	1600-2080	*M. oinochorophylla*	300-1030	*M. turgida*	2300-3135
M. diaphanea	150	*M. oraria*	20-2180	*M. ulmarioides*	2300-2600
M. difficilis	2000	*M. orchectoma*	2000-3600	*M. umbriensis*	270-600
M. divergens	1600-2200	*M. oreogena*	3200-3510	*M. uribei*	1500-1700
M. dodecandra	775-1950	*M. orescia*	2100-2700	*M. urticoides*	500-2160
M. dolochipoda	1600-2900	*M. pachydonta*	800-900	*M. vallensis*	2500
M. dolichorrhyncha	0-2600	*M.* ***p****aleacea*	0-350	*M. velutina*	1700-3900
M. donaenana	50-1100	*M. pandurata*	-	*M. verrucosa*	3200-3350
M. dorsiloba	50-1100	*M. parvifolia*	2650-3520	*M. versicolor*	1760-3200
M. dunstervillei	2500	*M. paspaloides*	200	*M. violácea*	2000-2500
M. elaeoides	2200-4300	*M. pastoensis*	3200-3500	*M. voronovii*	320-920
M. elata	60-1500	*M. pedicellata*	2000-2400	*M. wurdackii*	2440-3130
M. emendata	100-125	*M. penicillata*	1600-2400	*M. zarucchii*	200
M. eremita	2000-2100	*M. pergamentacea*	2200-2840		

Table 13. *Ocotea* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)

O. aciphylla	50-600	*O. insularis*	1000-2000	*O. sodiroana*	1330
O. ajumary	240	*O. leucoxylon*	-	*O. splendens*	0-300
O. benthamiana	2000-3000	*O. macropoda*	100-800	*O. stubelii*	2500-3000
O. caesariata	2600-3000	*O. oblonga*	200-1600	*O. subterminalis*	-
O. caracasana	-	*O. puberula*	100-1500	*O. sulcata*	100-300
O. celastroides	-	*O. quixos*	310-1250	*O. tabacifolia*	120
O. cernua	0-1400	*O. rhodophylla*	0-250	*O. terciopelo*	2500-2800
O. cissiflora	-	*O. rotundata*	2500-3000	*O. tomentosa*	120
O. cuatrecasasii	1800-2300	*O. rubrinervis*	0-100	*O. tovarensis*	-
O. cymbarum	100-300	*O. rufa*	1600-2500	*O. umbrina*	2700-3000
O. floribunda	1600-2700	*O. sanariapensis*	0-300	*O. valerioana*	500-2500
O. heterochroma	2500-3500	*O. sericea*	1400-3200	*O. veraguensis*	-
O. infrafoveolata	2800-3500	*O. smithiana*	1500-2800		

Table 14. *Protium* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
P. alstonii	100-200	*P. ferrugineum*	12-250	*P. nitidifolium*	160-270
P. alvarezianum	200-300	*P. gallosum*	100-450	*P. nodulosum*	100-750
P. amazonicum	100-450	*P. glabrescens*	100-600	*P. opacum*	100-300
P. amplum	40-600	*P. glomerulosum*	5-300	*P. panamense*	0-250
P. apiculatum	400-800	*P. grandifolium*	200-800	*P. paniculatum*	800-1300
P. aracouchini	50-800	*P. guacayanum*	230-600	*P. pilosissimum*	300
P. buenaventurense	0-150	*P. guianense*	5-500	*P. polybrotyum*	200
P. calenense	100-1100	*P. hebetatum*	100-510	*P. pristifolium*	200-390
P. calendulinun	300	*P. heptaphyllum*	20-600	*P. puncticulatum*	15-350
P. carolense	240-580	*P. klugii*	100-350	*P. ravenii*	0
P. columbianum	25-2000	*P. laxiflorum*	220-450	*P. subserratum*	200-900
P. cranipyrenum	40-100	*P. leptostachyum*	250-800	*P. tenuifolium*	175-1000
P. crassipetalum	110-300	*P. llanorum*	110-500	*P. tovarense*	1820-2500
P. crenatum	500	*P. macrocarpum*	200-300	*P. veneralense*	5-40
P. cundinamarcense	1800-2000	*P. macrophyllum*	100-1290		
P. decandrum	190-220	*P. macrosepalum*	100		
P. divaricatum	100-280	*P. macleodii*	500		
P. ecuadorense	1200-1500	*P. minutiflorum*	250		
P. elegans	200-300	*P. nervosum*	5-300		

Table 15. *Prunus* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
P. antioquensis	1500	*P. huantensis*	-	*P. serotina*	2000-2900
P. buxifolia	2800-3650	*P. integrifolia*	1800-3000	*P. stipulata*	-
P. debilis	-	*P. littlei*	1800-2300	*P. subcorymbosa*	870-2300
P. ernestii	-	*P. megacarpa*	1800-3000	*P. urotaenia*	1960-2950
P. falcate	-	*P. mortiziana*	2000-2900	*P. vana*	-
P. guanaiensis	500-2000	*P. muris*	-	*P. villegasiana*	-

Table 16. *Psidium* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
P. acutangulum	100-850	*P. guajava*	0-2000	*P. guineense*	80-2300
P. densicomun	100				

Table 17. *Symplocos* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
S. bombycina	2900	S. magdalenae	2500-2800	S. quindiuensis	2450-3724
S. crassulacea	1500	S. martinicensis	200-2150	S. trianae	250-400
S. cundinamarcensis	3000-3450	S. mucronata	2150-3000	S. ulei	250-380
S. decorticans	3700-3950	S. nivalis	2800-2380	S. venulosa	2200-2950
S. lehmannii	2300-2850	S. phaeoneura	1800-2380		
S. lutescens	2800-2940	S. pichindensis	1800-2380		

Table 18. *Tibouchina* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
T. andreana	3200-3700	*T. karstenii*	240	*T. pseudotriflora*	1570-2020
T. arthrostemmoides	990-1270	*T. kingii*	1800-2300	*T. reticulata*	3000
T. aspera	0-1000	*T. lepidota*	1000-3000	*T. silverstris*	200-500
T. bipenicillata	600-1100	*T. lindeniana*	955-3600	*T. spruceana*	0-1100
T. catherinae	1500-1800	*T. llanorum*	350-450	*T. stenantha*	1200-1500
T. ciliaris	1400-2300	*T. longifolia*	0-2500	*T. stricta*	2900-3700
T. elegantula	1800-2300	*T. martialis*	1500-3600	*T. striphnocalyx*	200-300
T. erioclada	1100-1900	*T. mollis*	2200-3400	*T. triflora*	400-2000
T. gleasoniana	1400-2000	*T. narinoensis*	200-1800	*T. urvilleana*	1600-2600
T. gracilis	900-2000	*T. paleacea*	2400-3100		
T. grossa	2700-3800	*T. pendula*	1500-1900		

Table 19. *Weinmannia* species in Colombia. Own source.

Species	Altitude (masl)	Species	Altitude (masl)	Species	Altitude (masl)
W. balbisiana	1200-2000	*W. fagaroides*	1200-1800	*W. rollottii*	2250-3450
W. brachystachya	2500-2800	*W. glabra*	1000-2600	*W. tomentosa*	1700-3724
W. corocoroensis	2200	*W. pinnata*	920-3230		
W. elliptica	1800-2500	*W. rogollii*	-		