Green World Journal
ISSN: 2737-6109

CaMeRa Editorial

RESEARCH ARTICLE

Proposal for ecological restoration at the La Belleza Experimental Station (Francisco de Orellana) based on seed dispersal mechanisms.

Leonardo Daniel Cabezas Andrade [1,4] Jennifer Alexandra Orejuela-Romero [2] María Soledad Núñez Moreno [3] Hernán Patricio Tixi Toapanta [3] Erich Gonzalo Guamán Condoy [1]

[1]Yasuní-SDC Group, Escuela Superior Politécnica de Chimborazo (ESPOCH), Sede Orellana, Coca 220150, Ecuador,

[2]Advanced researcher, El Coca, Ecuador

[3]Escuela Superior Politécnica de Chimborazo (ESPOCH), Faculty of Science, Riobamba 060155, Ecuador

[4]Environmental Engineering Career, Faculty of Sciences, Escuela Superior Politécnica de Chimborazo, Sede Orellana, El Coca EC220202, Ecuador.

Correspondencia: alexandra.orejuela@espoch.edu.ec + 593 999 417 384

DOI/URL: https://doi.org/10.53313/gwj72160

Abstract: In the Experimental Station La Belleza (EELB), areas degraded by anthropogenic intervention have been identified, leading to the loss of biodiversity of plant and animal species and to the decrease of ecosystem services characteristic of this area. For this reason, the objective of this study was to propose an Ecological Restoration Plan in the EELB, based on the selection of key species according to seed dispersal mechanisms. For this, the experimental station was divided into five quadrants, a reference ecosystem was defined and a mostly disturbed area. The status of both localities was evaluated, then a botanical inventory was carried out to determine the indices of abundance and equity, using seed traps and bird monitoring for the selection of key species. With the information collected, an Ecological Restoration Plan was elaborated based on three consecutive phases of planting species with different growth rates. The EELB presented 126 botanical species belonging to 50 families: 67 native and 59 exotic, 67 classified as forest (high altitude) and 59 as shrubs (medium and low altitude). The area with the highest intervention showed indices of 1.84 and 0.70 respectively for Shannon and Pielou. The reference ecosystem had indices of 2.85 and 0.85 respectively. In conclusion, an Ecological Restoration Plan was elaborated based on three consecutive phases of planting species with different growth rates: shrub, fast- and medium-growing forest and slow-growing forest. It was recommended to carry out the Ecological Restoration Plan immediately to avoid further degradation of the EELB.

Keywords: Ecological restoration, dispersal, seeds, birds, birds, zocooria

Cita: Cabezas Andrade, Leonardo Daniel Orejuela-Romero, J. A., Núñez Moreno, M. S., Tixi Toapanta, H. P., & Guamán Condoy, E. G. (2024). Proposal for ecological restoration at the La Belleza Experimental Station (Francisco de Orellana) based on seed dispersal mechanisms. Green World Journal, 07(02), 160. https://doi.org/10.53313/gwj72160

Received: 30/July /2024
Accepted: 12/ Aug /2024
Published: 24 /Aug /2024

Prof. Carlos Mestanza-Ramón, PhD.
Editor-in-Chief / CaMeRa Editorial
editor@greenworldjournal.com

Editor's note: CaMeRa remains neutral with respect to legal claims resulting from published content. The responsibility for published information rests entirely with the authors.

1. Introduction

Concern for the conservation and restoration of ecosystems has gained global relevance. The need to address environmental challenges and promote sustainability has led to the implementation of ecological restoration projects in different parts of the world.[1]. At a general level, a worrying loss of biodiversity and environmental degradation has been observed. In addition, human activity, including the expansion of agriculture, deforestation and urbanisation, has generated significant impacts on natural ecosystems [2]As reported by the United Nations, the area of primary forests has decreased by 81 million hectares since 1990, reducing the rate of loss by more than half in the period 2010-2020 compared to the previous decade. [3] . This forest loss has led to the fragmentation of landscapes and a worrying decline in biological diversity [4]

Recent studies show an alarming loss of forests in South America, with a particular focus on Ecuador and its neighbouring areas. In the Madre de Dios region of the Peruvian Amazon, deforestation reached 1698.63 km² between 1999 and 2018, with agriculture accounting for 72.90% of this loss. [5]. Between 2000 and 2022, Ecuador suffered a net reduction of 942,733 hectares, with the Amazon region being the most devastated [6]. In southern Ecuador, deforestation rates increased from 0.75% between 1976 and 1989 to 2.86% between 1989 and 2008, mainly affecting lower altitude areas [7] . [7]. By 2008, about 46% of the original forest cover in southern Ecuador had been converted to other land uses [7]. [7]. Poverty emerges as a key factor driving domestic fuelwood consumption, contributing to deforestation [8] . [8]. These findings highlight the urgent need to implement more effective and regionally adapted conservation policies to combat forest loss in South America.

Ecuador faces multiple pressing environmental challenges, such as deforestation, oil exploitation and agricultural expansion. These activities have left a significant mark on the landscape, affecting the country's biological richness. For example, between 1990 and 2018, native forest cover decreased from 68% to 56%, representing a 12% loss of forested areas. This reduction has caused a noticeable decrease in biodiversity and has altered fundamental ecological processes [9]. In the province of Orellana, the direct impacts of human activities and natural phenomena on the local ecosystem have been observed, caused by the activities described above, which have led to the loss of vegetation cover, the alteration of seed dispersal mechanisms and a decrease in biodiversity.

Ecological restoration in disturbed ecosystems can be promoted through a variety of processes, with seed dispersal being one of the most promising for forest recovery. The creation of dispersal and attraction nuclei enhances interactions between plants and animals, facilitating the colonisation of surrounding areas. [10]. Frugivorous birds are fundamental in passive restoration by dispersing seeds of endemic and primary forest species [11]. Assessing restoration trajectories through mutualistic seed dispersal networks reveals differences between restored and reference forests, highlighting the need for forest management that enhances these interactions [12] . [12]. Characterising forest structure and floristic composition is essential for selecting suitable species for restoration, focusing on primary successional and animal-dispersed species [13]Various research emphasises the importance of understanding seed dispersal mechanisms and plant-animal interactions in designing effective ecological restoration strategies for forest ecosystems.

In this context, the present study aimed to propose an Ecological Restoration Plan at the La Belleza Experimental Station, located in the rural parish of La Belleza in the province of Orellana. Proposal for the selection of key plant species based on seed dispersal mechanisms. This parish has a surface area of 60812.69 hectares, 79.99% of which corresponds to native forests that are at permanent risk of deforestation due to land use change. [14]. To achieve this, a comprehensive assessment of the current state of the station and the referential ecosystem was carried out in order to identify the main environmental issues and determine the challenges facing restoration. In addition, an analysis of the seed dispersal mechanisms present in the region was carried out and an ecological restoration proposal was designed for the La Belleza Experimental Station.

2. Materials and methods

2.1 Study area

The study was carried out at the La Belleza Experimental Station (EELB) belonging to ESPOCH-Orellana located in the parish of La Belleza, province of Orellana. This parish is bordered to the north by the parish of García Moreno, to the south by the parish of Inés Arango and the canton of Tena (Province of Napo), to the east by the parish of Dayuma and to the west by the canton of Loreto and the province of Napo. [15]. The station covers an area of 32.78 ha and is located at coordinates: 273243 East and 9929645.80 North, in Zone: 18 M, at an altitude of 320 m above sea level (Figure 1).

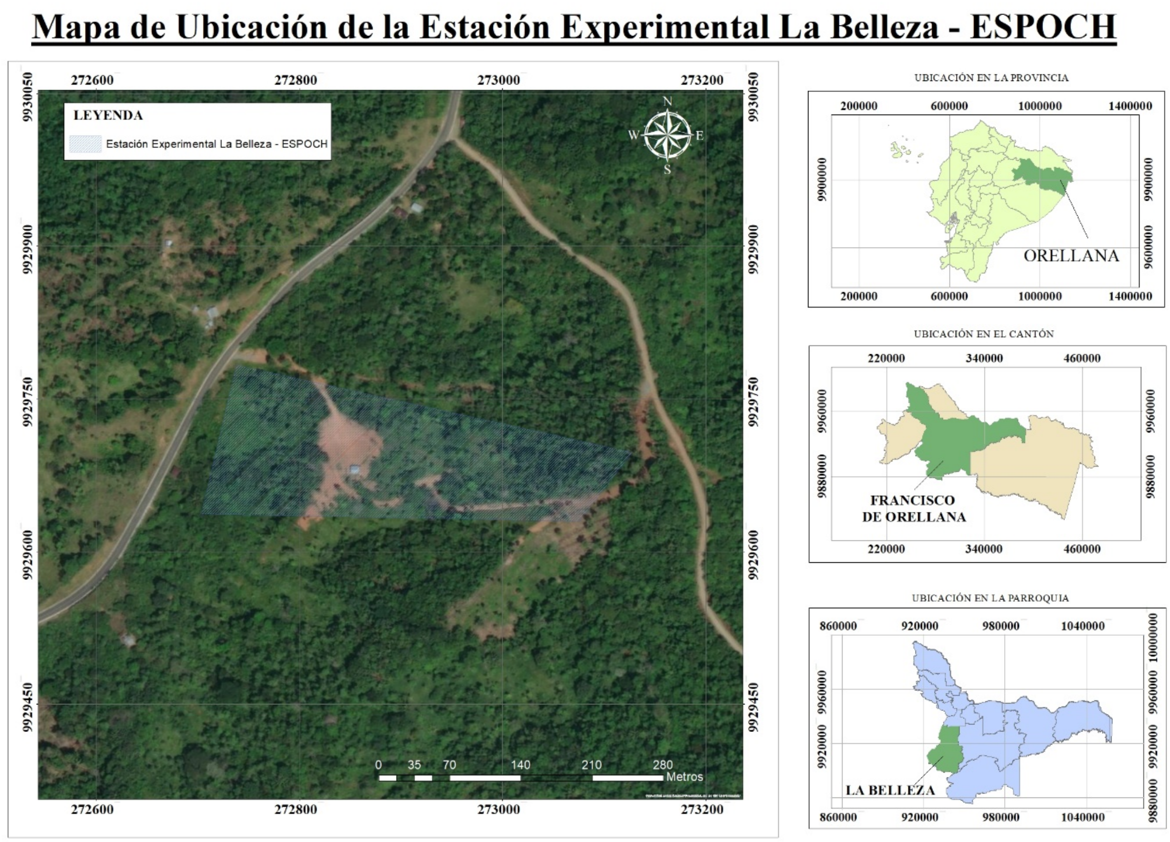


Figure 1. Study location

2.2 Methods

2.2.1 Assessment of current status

To determine the area and the current state of the ecosystem, we used the method implemented by Vargas in his book entitled "Guía Metodológica para la Restauración Ecológica del bosque altoandino" [16]. [16]. First, the reference ecosystem or community was defined. Then, the state of the ecosystem or community was evaluated. This methodology allowed to know in depth the factors related to the degradation of a study area, to define the best reference ecosystem to compare with the degraded area. Providing a broad reference approach for the knowledge of plant species of interest for ecological restoration. [16]

A visual analysis was carried out in the EELB and in the reference ecosystem to identify key features such as vegetation condition, presence of invasive species and soil degradation. The first step was to define the reference ecosystem by investigating palaeoecological work, aerial photos and maps, and characterising adjacent areas to interpret current vegetation dynamics. Subsequently, the current state of the ecosystem was assessed, identifying relevant indicators such as the physical characteristics of the soil, the presence of invasive species and seed dispersal mechanisms. Data collection was carried out through direct observations and physical analysis of the soil, which were compared with reference values to determine the health of the ecosystem. Finally, problem areas were identified through field visits and direct observation, allowing for a comprehensive assessment of the ecosystem and identification of problems.

In the collection of soil samples, the sampling technique established by the Instituto Nacional Autónomo de Investigaciones Agropecuarias (National Autonomous Institute of Agricultural Research) was used. [17] which consisted of digging a 20 cm deep hole in the shape of a "V", from which a portion of soil 2 to 3 cm thick was extracted. This sample was reduced to 5 cm wide, and the process was repeated until 15-20 sub-samples were collected and mixed manually in a bucket. A final sample of one kilogram was then taken and appropriately labelled. The samples were air-dried to remove moisture and plant debris. Physical tests were conducted at LABSU, where soil texture was determined using the pipette technique, which involved shaking a 100 gram sample of soil in 200 ml of water, followed by a 24-hour rest to measure the thickness of the sand, silt and clay layers. Soil colour was determined visually under natural light by comparing the sample with the Munsell chart. Electrical conductivity was measured in a 1:5 solution of soil and water, using a conductivity meter to record the values required for soil analysis.

2.2.2.2. Identification of key species

Methods based on the Ministry of Environment's (2015) "Flora and Vegetation Inventory Guide" were used to determine the key species in the EELB and its reference ecosystem. This process included the elaboration of an ethnobotanical inventory and the identification of seed dispersal mechanisms, essential to identify key species in the ecosystem. In addition, the techniques of Orozco [18] and Arias [19]who implemented artificial perches and seed traps, respectively, to monitor seed dispersal, especially by birds. These methodologies provided a comprehensive approach to the identification of key plant species in the ecological restoration of the tropical dry forest, ensuring the collection and exhaustive analysis of the flora present in the EELB.

The activities carried out included direct observation and collection during field visits, where plant species present in the EELB and the reference ecosystem were identified and collected. Species identification was carried out through detailed observations of their morphological characteristics, such as size, leaf shape, stem type and presence of flowers or fruits. To ensure accurate identification, field guides, identification manuals and reliable digital resources were used, complemented by taking photographs and collecting samples when necessary. In addition, the number of individuals per species was recorded, classifying them according to their origin (native, forest or shrub) and their growth rate (slow, medium or fast). Complementary documentation included photographic capture of the plants in their natural environment and labelling of collected samples, ensuring their traceability for further analysis. This meticulous approach ensured that all key species were correctly identified and documented for study and conservation.

To understand the status of the study area, the Shannon and Pielou diversity indices were used, based on the botanical inventory carried out. The Shannon index measures diversity by considering the relative abundance and richness of species in a community. This index is crucial for assessing biodiversity, as higher values (above 3) indicate a community with high diversity, suggesting a balanced and healthy ecosystem. Conversely, values below 2 reflect low diversity, which may indicate conservation problems or an ecosystem in disequilibrium. The following formula was used to calculate this index:

$$H = \sum_{i=1}^{S} (Pi)(log_n\, Pi)$$

Where:
H = Species diversity index
S = Species number
Pi = Proportion of the sample corresponding to species i
Ln = Natural logarithm

Pielou's Evenness Index (J'), on the other hand, was used to assess the evenness of species distribution within the community. This index is a measure of evenness, with values ranging from 0 to 1. A value of 1 indicates that all species have similar abundance, representing a situation of maximum evenness, which is ideal in terms of ecological stability. In contrast, a value close to 0 suggests that some species are much more abundant than others, which may indicate an imbalance in the ecosystem. The formula used to calculate the Pielou index was:

$$J' = \frac{H'}{\ln(S)}$$

Where:
H': is the Shannon-Wiener index
S: is the total number of species present.

For the division of quadrants at the La Belleza Experimental Station (EELB), ArcGIS software was used to evenly distribute the study area. Initially, an internal section corresponding to a motorway and the station boundary was eliminated, generating two sub-areas. From these, midpoints were established and bisectors were drawn to divide the area into six quadrants. Quadrant A was identified as the most disturbed area due to the presence of a construction site and agricultural, fishing and deforestation activities. In contrast, quadrant E was designated as the reference ecosystem, as it is located within the EELB, has not been affected by anthropogenic activities and is located far from quadrant A. For the botanical inventory, four 5x5 metre plots were randomly selected within each quadrat. This approach allowed an accurate assessment of the degree of intervention and conservation in the different quadrats, establishing a solid basis for analysing the impact of human activities on biodiversity and ecosystem structure in the EELB.

2.2.2.1 Dispersal by birds

Through a literature review, information was collected on the plant species inventoried and their seed dispersal mechanisms. With this information, the dispersal mechanisms were characterised, analysing key characteristics such as the type of fruit and the fruiting season. For species with zoochoric dispersal, we followed the methodology of Orozco [18]which included monitoring perches for 60 minutes at two intervals: from 09:00 to 11:00 a.m. and from 15:00 to 18:00 p.m., during weekends over three months. Avian species were identified by photographic records for detailed analysis. Artificial perches, consisting of 2.50 m high wooden poles, with a 60 cm bar fixed at right angles, were constructed and installed at a depth of 30 cm, leaving a final height of 2.20 m. Artificial seed traps were also set up to trap the seeds. Seed traps measuring 50x50 cm were also placed 40 cm above the ground surface, with one trap under the perch and another two metres away. These structures were placed in less dense areas of the forest to facilitate observation and photography of the birds. This approach allowed a detailed study of seed dispersal mechanisms, optimising the identification and understanding of ecological interactions in the study area.

2.2.2.2.2 Seed Collection and Identification

Seed traps were established under flowering and fruiting trees, using four wooden poles and a tarpaulin 60 cm above ground level. During fruiting seasons, fortnightly sampling was carried out for three months, following a route that covered all the traps. The collected seeds were placed in numbered bags and transported to the Science Laboratory of the ESPOCH-Sede Orellana for processing. For morphological and taxonomic identification, fertile plant samples were collected from each vegetation type and the ESPOCH Digital Herbarium was used. Species that could not be digitally identified were sent to the Herbario Politécnica Chimborazo (CHEP) for classification. Seeds extracted from each parent tree were labelled with detailed taxonomic information. In some cases they were identified to species level and data on their dispersal type and habitat were recorded. This approach allowed not only to identify key species in seed dispersal, but also to better understand the ecological dynamics at La Belleza Experimental Station, providing a solid basis for the conservation and management of biodiversity in the study area.

2.2.3 Development of the Ecological Restoration Plan

The Ecological Restoration Plan was based on the Porras approach. [20]which proposes a three-phase planting of native species over several years. The first phase includes fast-growing species, followed by intermediate-growing species, and finally, slow-growing species that require shade for their development. The plantation design was adapted to the topography, soil type and reference vegetation, mimicking the spatial distribution of a natural area rather than a conventional forest plantation. This approach promotes a more natural integration with the environment. Key planting steps were established: site preparation, layout, staking, determination of planting distance, number of individuals to be planted, hollowing, planting, maintenance and monitoring activities to ensure the success of the project. A detailed schedule of activities was also developed to guide the ecological restoration process. In addition, a budget was calculated that included costs for labour, plant material, tools and inputs, ensuring an efficient and sustainable use of resources. This comprehensive plan not only establishes a solid foundation for ecosystem restoration, but also ensures that recommended best practices are followed to achieve the area's conservation and recovery objectives.

3. Results

3.1 Current status of the study area

During the field visits and the initial phase of the research, the study area was divided into five quadrants. Quadrant A was designated as the "most disturbed area" due to its proximity to the main road, the presence of a building, road and car park. Plantations and grazing have been carried out in this area in past years. In addition, this quadrant showed low diversity and equity indices (Figure 2). On the other hand, quadrant E was selected as the "reference ecosystem" within the EELB, due to its medium diversity index, a higher equity index and its location further away from quadrant A, which resulted in less anthropogenic intervention, see Figure 2.

Figure 2. Spatial distribution of quadrants of the EELB

Through the botanical inventory, Shannon indices were determined, which are shown in Figure 3A. Quadrant A had the lowest diversity with an index of 1.84, corresponding to a low species diversity. While, quadrant B had the highest species diversity with an index of 3.05 corresponding to high species diversity. The Pielou indices were also calculated (Figure 3B), where it can be seen that the equity of quadrant A is lower than the others with a value of 0.70. This shows that there are not as many individuals per species as in the other quadrants. Quadrant B, on the other hand, presented the highest amount of equity in terms of individuals, with a value of 0.86. According to the botanical inventory carried out, quadrant E had a Shannon diversity index of 2.695, which is interpreted as a medium diversity. The main species in terms of number of individuals were *Mostera oblicua*, *Inga edulis* and *Desmodium molliculum*, with 80, 22 and 20 individuals respectively. Quadrant A (mostly disturbed) had a Shannon diversity index of 1.843, which is interpreted as low diversity. The main species by number of individuals were *Miconia elata*, *Cordia alliodora* and *Cedrela odorata*, with 60, 15 and 11 individuals respectively.

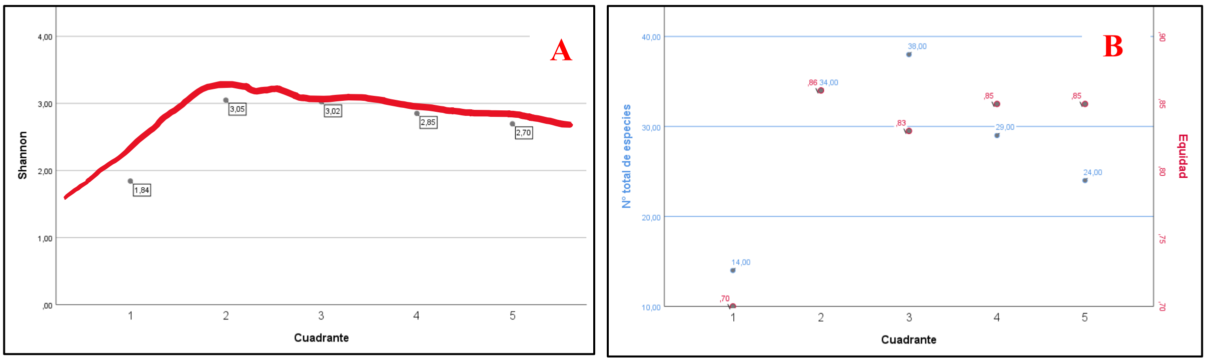


Figure 3. (A) Shannon index per quadrant, (B) Peilou index per quadrant.

3.2 Key species

Table 1 lists the species found during the inventory, where 126 species were found, belonging to 50 families, 49 identified and one undetermined, with a total of 1475 individuals inventoried. Of the total number of species inventoried, 67 species were identified as native to the country, while 59 are non-native (exotic). In addition, these were catalogued according to their size, with 67 species classified as forest species (arboreal = high altitude) and 59 species classified as shrubs (shrubs, ferns and herbaceous = medium and low altitude), this classification helped in the establishment of the species for the Ecological Restoration Plan. Finally, considering forest species as the main species performing different types of dispersal due to their larger vertical size. They were catalogued according to their growth speed, a key aspect for the restoration plan, resulting in 13 slow-growing, 24 medium-growing and 24 fast-growing species.

Table 1. Botanical Inventory of the EELB

Family	Species	Quantity	Native	Size	Growth
Araceae	*Adelonema wallisíi*	3	No	Shrub	
Araceae	*Aglaonema modestum Achott ex Engl.*	6	No	Shrub	
Araceae	*Alocasia brisbanensis*	30	No	Shrub	
Commelinaceae	*Amischotolype hispida*	10	No	Shrub	
Dryopteridaceae	*Anisocampium niponium*	9	No	Shrub	
Annonaceae	*Annona cherimola*	5	Yes	Forestry	Slow
Thymelaeaceae	*Aquilaria synensis*	1	No	Forestry	Slow
Arecaceae	*Arecacea*	2	Yes	Forestry	Slow
Aristolochiaceae	*Aristolochia trilobata*	5	Yes	Shrub	
Moraceae	*Artocarpus altilis*	6	No	Forestry	Quick
Annonaceae	*Asímina triloba (l.) Dunal*	3	Yes	Forestry	Slow
Aspleniaceae	*Asplenium scolopendrium l.*	1	No	Shrub	
Cyclanthaceae	*Asplundia rigida (Aubl) Harling*	33	Yes	Shrub	
Cyclanthaceae	*Asplundia utilis oerst. Harling*	3	No	Shrub	
Arecaceae	*Astrocaryum chambira Burret*	6	Yes	Forestry	Slow
Arecaceae	*Astrocaryum standleyanum*	5	Yes	Forestry	Slow
Anacardiaceae	*Astronium graveolens*	5	Yes	Forestry	Quick
Arecaceae	*Bactris simplicifrons*	48	Yes	Forestry	Quick
Poaceae	*Bambusa vulgaris*	45	No	Forestry	Quick
Fabaceae	*Bauhinia variegata*	2	No	Forestry	Quick
Melastomataceae	*Blastus cochinchinensis*	9	No	Shrub	
Asteraceae	*Blumea balsamifera*	12	No	Shrub	
Moraceae	*BroSímum rubescens taub*	3	Yes	Forestry	Medium
Arecaceae	*Calamus thysanolepis*	1	No	Shrub	
Marantaceae	*Calathea lutea*	27	Yes	Shrub	
Salicaceae	*Casearia pitumba*	6	Yes	Forestry	-
Urticaceae	*Cecropia obtusifolia Bertol*	3	Yes	Shrub	
Urticaceae	*Cecropia peltata L.*	2	Yes	Forestry	Quick
Meliaceae	*Cedrela odorata*	11	Yes	Forestry	Quick
Arecaceae	*Chamaedorea Ernesti - augusti*	42	Yes	Shrub	
Arecaceae	*Chamaedorea tepejilote*	10	No	Shrub	
Araceae	*Cladium bicolor*	5	Yes	Shrub	
Euphorbiaceae	*Cleidion veillonii McPherson*	4	Yes	Shrub	
Melastomataceae	*Clidemia hirta*	15	Yes	Shrub	
Polypodiaceae	*Coccoloba acuminata*	8	Yes	Shrub	
Gesneriaceae	*Codonanthopsis*	32	Yes	Shrub	
Combretaceae	*Combretum illairii*	18	Yes	Shrub	
Melastomataceae	*Conostegia xalapensís*	10	Yes	Shrub	
Boraginaceae	*Cordia alliodora*	15	Yes	Forestry	Quick
Euphorbiaceae	*Croton urucurana*	3	Yes	Forestry	Quick
Lauraceae	*Cryptocarya concinna*	2	Yes	Forestry	Quick

Cyclanthaceae	*Cyclanthus bipartitus*	22	Yes	Shrub	
Marattiaceae	*Danaea nodosa*	20	No	Shrub	
Urticaceae	*Dendrocnide urentissima*	2	No	Shrub	
Fabaceae	*Desmodium molliculum*	20	Yes	Shrub	
Araceae	*Dieffenbachia nitidipetiolata Croat & Grayum*	115	Yes	Shrub	
Dilleniaceae	*Dillenia suffruticosa (griff.) Martelli*	18	No	Shrub	
Malpighiaceae	*Diplopterys cabrerana*	15	Yes	Shrub	
Cyatheaceae	*Dryopteris formosana*	46	Yes	Shrub	
Annonaceae	*Duguetia cadaverica huber*	1	Yes	Shrub	
Annonaceae	*Duguetia spixiana*	11	No	Forestry	Slow
Araceae	*Endocomia macrocoma ssp prainii*	30	Yes	Forestry	Slow
Rosaceae	*Eriobotrya japonica*	12	No	Forestry	Quick
Myrtaceae	*Eugonia multirimosa*	4	No	Forestry	Medium
Euphorbiaceae	*Euphorbia umbellata*	5	No	Forestry	Medium
Arecaceae	*Euterpe edulis*	7	No	Forestry	Slow
Cyclanthaceae	*Evodianthus funifer (Poit.) Lindm.*	12	Yes	Shrub	
Lecythidaceae	*Grias peruviana Miers*	8	No	Forestry	Medium
Meliaceae	*Guarea costata*	11	Yes	Forestry	Medium
Meliaceae	*Guarea kunthiana*	8	Yes	Forestry	Medium
Annonaceae	*Guatteria amplifolia Triana & Planch*	48	Yes	Forestry	Medium
Sapindaceae	*Guayas*	5	No	Forestry	Medium
Lecythidaceae	*Gustavia hexapetala*	2	Yes	Forestry	Quick
Heliconiaceae	*Heliconia monteverdensis*	3	Yes	Shrub	
Marantaceae	*Heliconia stricta huber*	2	No	Shrub	
Costaceae	*Hellenia speciosa*	34	Yes	Forestry	Medium
Araliaceae	*Heteropanax fragans*	11	No	Forestry	Quick
Anacardiaceae	*Poison ivy*	2	No	Shrub	
Fabaceae	*Igna nouragensís poncy*	2	No	Forestry	Quick
Fabaceae	*Inga acreana harms*	18	Yes	Forestry	Quick
Fabaceae	*Inga edulis*	22	Yes	Forestry	Quick
Fabaceae	*Inga feuilleei (pacay)*	3	Yes	Forestry	Quick
Arecaceae	*Iriartea deltoidea Ruiz & Pav.*	63	Yes	Forestry	Slow
Rubiaceae	*Isertia rosea*	6	No	Shrub	
Bignoniaceae	*Jacaranda copaia*	6	Yes	Forestry	Medium
Lythraceae	*Lafoensia punicifolia*	2	No	Forestry	Slow
Polypodiaceae	*Leptochilus ellipticus*	11	Yes	Shrub	
Sapindaceae	*Litchi chinensis*	4	No	Forestry	Slow
Polypodiaceae	*Loxogramme salicifolia*	2	Yes	Shrub	
Orchidaceae	*ludisia discolor*	4	No	Shrub	
Fabaceae	*Macrolobium*	2	Yes	Forestry	Quick
Marantaceae	*Maranta*	3	Yes	Shrub	
Sapindaceae	*Matayba scrobiculata*	15	Yes	Forestry	Quick
Sapindaceae	*Melicoccus bijugatus*	2	No	Forestry	Quick
Euphorbiaceae	*Clandestine melliosma*	1	No	Forestry	Medium
Melastomataceae	*Miconia elata*	60	No	Forestry	Medium
Malvaceae	*Microcos paniculata*	4	No	Shrub	
Amaranthaceae	*Moradilla*	1	Yes	Shrub	
Marantaceae	*Oblique flycatcher*	80	No	Shrub	
Malvaceae	*Ochroma pyramidale*	10	Yes	Forestry	Medium
Lauraceae	*Ocotea floribunda*	6	No	Forestry	Quick
Urticaceae	*Oreocnide frutescens*	1	No	Shrub	

Melastomataceae	*Oxyspora paniculata*	2	No	Forestry	Medium
Malvaceae	*Pachira quinata*	2	No	Forestry	Medium
Lauraceae	*Persea caerulea*	1	Yes	Forestry	Medium
Araceae	*Philodendron inaequilaterum*	9	No	Forestry	Quick
Marantaceae	*Phrynium pubinerve*	1	No	Shrub	
Piperaceae	*Piper longepetiolatum*	5	No	Shrub	
Marantaceae	*Pleiostachya pruinosa*	22	Yes	Shrub	
Lauraceae	*Pleurothyrium insígne*	4	Yes	Forestry	Medium
Dryopteridaceae	*Polystichum acrostichoides*	7	No	Shrub	
Sapindaceae	*Pometia*	2	No	Forestry	Quick
Urticaceae	*Pouroma bicolor*	1	Yes	Forestry	Medium
Urticaceae	*Pourouma cecropiifolia*	8	No	Forestry	Medium
Sapotaceae	*Pouteria coriacea*	3	Yes	Forestry	Medium
Burseraceae	*Protium aracouchini*	2	Yes	Shrub	
Undetermined	*Pseudodissochata*	1	No	Shrub	
Rubiaceae	*Psychotria nervosa Sw.*	8	Yes	Forestry	Medium
Sapotaceae	*Pycandra balansae (Baill) Swenson & Munzigner*	20	No	Forestry	Medium
Fagaceae	*Quercus michauxii Nutt*	6	No	Forestry	Quick
Annonaceae	*Rollinia mucosa*	9	Yes	Forestry	Medium
Acanthaceae	*Sanchezia*	41	Yes	Shrub	
Euphorbiaceae	*Sapium sp.*	5	Yes	Forestry	Medium
Melastomataceae	*Scaphosepalum*	2	Yes	Forestry	Medium
Arecaceae	*Socratea exorrhiza (Mart.) H. Wendl*	5	Yes	Forestry	Medium
Fabaceae	*Spatholobus suberectos*	11	No	Shrub	
Annonaceae	*Stenanona costaricensís*	2	Yes	Shrub	
Dilleniaceae	*Tetracera sarmentosa*	1	No	Shrub	
Byttnerioideae	*Theobroma bicolor*	2	No	Forestry	Medium
Malvaceae	*Trichospermum galeottii*	2	Yes	Forestry	Slow
Melanthiaceae	*Trillium cuneatum*	7	No	Shrub	
Sapindaceae	*Tuckeroo*	4	No	Forestry	Medium
Urticaceae	*Urera baccifera*	2	No	Shrub	
Asteraceae	*Vernonia amygdalina*	1	No	Shrub	
Rubiaceae	*Wendlandia uvarifolia*	2	No	Shrub	
Salicaceae	*Xylosma oligandra donn. Sm*	7	Yes	Forestry	Medium

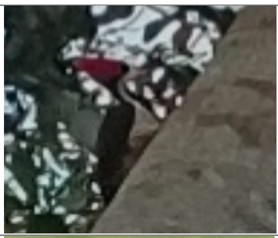
3.2.1. Plant species found in seed traps

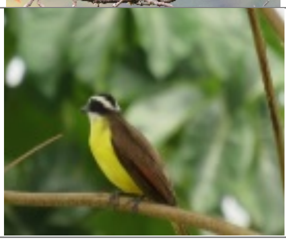
In the seed traps, under the trees and near the bird perches, 23 species of seeds belonging to 13 families were found. Of the species found, 13 were native to the country, 7 were non-native and 2 could not be determined. In addition, 21 forest species and 2 shrub species were found. In addition, 3 slow-growing, 7 medium-growing, 5 medium to fast-growing, 6 fast-growing and 2 indeterminate species were identified. The native species found in the seed traps were considered key species, as their proliferation will allow an abundant flow of seed dispersal by animals, which will favour the natural restoration of the intervened areas of the station and its surrounding areas, leading to an increase in the diversity of fauna.

3.2.2. Birds found in the study area

According to Table 2, 12 bird species belonging to 8 families were found. The environmental conditions and the sensitivity of the species did not allow us to observe the feeding of the seeds to determine the plant species related to each bird.

Table 2. Inventory of birds in the EELB

Image	Common name	Scientific name	Family
	Red-crested Woodpecker	*Campephilus melnoleucos*	Picidae
	Turtledove smooth-breasted	*Columbina minuta*	Columbidae
	Red Kemp's ridley	*Columbina talpacoti*	Columbidae
	Lesser spotted dogfish	*Crotophaga ani*	Cuculidae
	Yellow-bellied honeycreeper	*Dacnis flaviventer*	Thraupidae
	Benteveo Medium	*Myiozetetes similis*	Tyrannidae
	Squirrel Cuckoo	*Piaya cayana*	Cuculidae

	Blue-headed parrot	*Pionus menstruus*	Psittacidae
	Large bicoloured swallow	*Progne sinaloae*	Hirundinidae
	Cacique dorsirrufo, oropendola variable	*Psarocolius angustifrons*	Icteridae
	Catan Parrot	*Pyrrhura hoffmanni*	Psittacidae
	Tropical tyrant	*Tyrannus melancholicus*	Tyrannidae

To determine the key species in the Ecological Restoration of the EELB, species were selected based on three main criteria: being native to Ecuador, being present in the botanical inventory, and having more than 20 individuals per species. Following these criteria, Table 3 lists the species according to their importance. The native species identified in the seed traps were listed first, followed by the species inventoried in general. In total, 27 key species were identified. Of these, most disperse their seeds by gravity, while 19 species, whose fruits are food, are dispersed by animals, including mammals and birds. Finally, three species are dispersed by wind, as their seeds are small and light. This selection is crucial to guide restoration actions, ensuring the reintroduction and conservation of species that are vital for the stability and diversity of the ecosystem in the EELB.

Table 3. Selected key species

Scientific name	Quantity	Native	Size	Growth	Dispersion
Species found in seed traps					
Iriartea deltoidea	63	Yes	Forestry	Slow	Gravity, animals
Ochroma pyramidale	10	Yes	Forestry	Quick	Gravity, wind
Jacaranda copaia	6	Yes	Forestry	Quick	Gravity, wind
Apeiba glabra		Yes	Forestry	Quick	Gravity, animals
Astrocaryum urostachys		Yes	Forestry	Quick	Gravity, animals

Chimarrihs glabriflora		Yes	Shrub		Gravity, animals
Euterpe precatoria		Yes	Forestry	Medium	Gravity, animals
Guazuma ulmifolia		Yes	Forestry	Quick	Gravity, animals
Oenocarpus bataua		Yes	Forestry	Medium	Gravity, animals
Phytelephas		Yes	Forestry	Slow	Gravity, animals
Terminalia amazonia		Yes	Forestry	Medium	Gravity, animals
Theobroma subincanum		Yes	Forestry	Medium	Gravity, animals
Zanthoxylum tachuelo		Yes	Forestry	Medium	Gravity, animals
Inventoried species					
Dieffenbachia nitidipetiolata	115	Yes	Shrub		Gravity, animals
Bactris Simplicifrons	48	Yes	Forestry	Quick	Gravity, animals
Guatteria amplifolia	48	Yes	Forestry	Medium	Gravity
Dryopteris formosana	46	Yes	Shrub		Gravity, animals
Chamaedorea	42	Yes	Shrub		Gravity, animals
Sanchezia	41	Yes	Shrub		Gravity, animals
Hellenia speciosa	34	Yes	Forestry	Medium	Gravity
Asplundia rigida	33	Yes	Shrub		Gravity, wind
Codonanthopsis	32	Yes	Shrub		Gravity
Endocoma macrocoma	30	Yes	Forestry	Slow	Gravity
Calathea lutea	27	Yes	Shrub		Gravity, animals
Cyclanthus bipartitus	22	Yes	Shrub		Gravity
Inga edulis	22	Yes	Forestry	Quick	Gravity, animals
Pleiostachya pruinosa	22	Yes	Shrub		Gravity
Desmodium molliculum	20	Yes	Shrub		Gravity, animals

3.3 Ecological restoration plan

The ecological restoration project covers an area of 10.5 hectares in quadrant A of the EELB, an area that has been largely disturbed by agricultural activities. The proposed restoration was divided into three sequential phases. In the first phase, the aim is to generate diverse ecological conditions that meet the requirements of the species that will be introduced in subsequent phases. This will be achieved by planting pioneer species, classified as shrubs due to their rapid growth. Species that will contribute to improving soil conditions, regulating pH and generating organic matter. It will also increase the soil's moisture retention capacity, ensuring an adequate water supply for the more demanding species that will be introduced in later phases. Planting should coincide with the rainy season in the eastern region of Ecuador, favouring the growth and development of the plants. The species selected for this phase were strategically chosen to ensure the long-term success of the restoration project, they include: *Chimarrhis glabriflora, Dieffenbachia nitidipetiolata, Dryopteris formosana, Chamaedorea, Sanchezia, Asplundia rigida, Codonanthopsis, Calathea lutea, Cyclanthus bipartitus, Pleiostachya pruinosa, Desmodium molliculum.*

The second planting phase (Phase 2) is scheduled to take place three years after the initial phase, once the vegetation established in Phase 1 has reached adequate development and soil conditions have improved. This will coincide with the rainy season in the Amazon, which will optimise the growth of the planted species. At this stage, fast- and medium-growing forest species will be introduced, which will not only complement the habitat configuration, but will also play a crucial role in conditioning the ecosystem. These species will prepare the environment for the future introduction of slow-growing forest species, which have more specific and sensitive requirements. The selection of these species for the second phase is fundamental to ensure the continuity of the ecological restoration process and the creation of a resilient and diversified ecosystem, the following species are included: *Jacaranda copaia, Ochroma pyramidale, Apeiba glabra, Astrocaryum urostachys, Euterpe precatoria, Guazuma ulmifolia, Oenocarpus bataua, Terminalia amazonia, Theobroma subincanum, Zanthoxylum tachuelo, Bactris simplicifrons, Guatteria amplifolia, Hellenia speciosa, Inga edulis.*

In the last phase of the Ecological Restoration Plan, it is expected that the vegetation planted in the previous phases will have reached an optimum level of development, with significant improvements in soil conditions, especially in terms of pH and humidity. With medium-sized individuals already established, slow-growing forest species will be planted. These species, known for their ability to thrive in shaded conditions, will be essential to consolidate the restored ecosystem. Their introduction will complete the restoration process, contributing to the long-term stability and resilience of the area, including the following species: *Iriartea deltoidea, Phytelephas, Endocomia macrocoma.* With this strategy, the aim is to establish a diverse and balanced vegetation that favours the stability and resilience of the restored ecosystem over time.

3.3. Planting design

For the design of the plantation in the intervention area, a combination of the radial and free planting methods was used, complemented with a perimeter plantation, following the guidelines of Porras [20]. As shown in Figure 4, the perimeter planting (red line) was intended for species dispersed by mammals and birds, with a separation of 5 m between plants, interspersing species according to their growth phase. Favouring the movement of animals and seed dispersal from the outside to the inside of the area. The radial method, represented by a green line, was applied to the Phase 1 species, also with a 5 m spacing between plants, distributing them evenly from a central point. This design optimises the uptake of resources such as sunlight and nutrients, as well as facilitating maintenance and monitoring. Meanwhile, it mimics natural seed dispersal patterns. Finally, the random or free planting method, indicated by yellow and black stars, was implemented for Phase 2 species, which were planted at a minimum spacing of 10 m apart, interspersing species. For Phase 3 species, planted in the Phase 2 gaps, also at 10 m spacing. This approach seeks to replicate the natural distribution of species, ensuring seed dispersal that emulates natural ecological conditions, helping to foster biodiversity and resilience of the restored ecosystem.

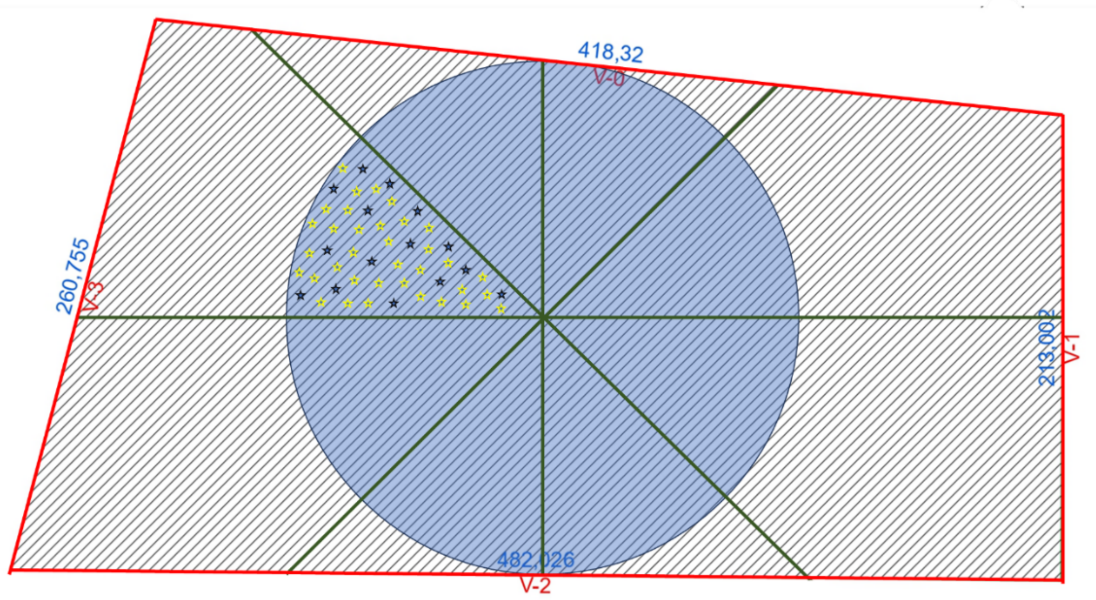


Figure 4. Planting design

3.3.2 Ecological Restoration Plan Steps

Land preparation for ecological restoration includes an initial cleaning and adjustment of the soil pH by applying calcitic lime ($CaCO_3$) in quantities of 1 to 1.3 tons per hectare, according to Molina's recommendations [21]. [21]. The plot is laid out with colour-coded stakes to mark the planting lines and facilitate the organisation of the work. It is estimated that, in order to cover the perimeter and the radii of the intervened area, as well as to complete the irregular polygon of 105,300 m², approximately 2652 plants will be needed, distributed in the three restoration phases. The planting holes should be 40 cm deep and 30 cm in diameter, allowing for optimal root development. Fertilisation is adjusted according to a previous soil analysis, recommending the application of 100 g per plant of granular fertiliser in the proportion 10-30-10, mixed with the soil at the bottom of the hole.

The planting process requires the use of stakes to ensure the vertical growth of the plants, preventing bending of the stems. Subsequent maintenance includes fertilisation, pest control, and replanting in case of plant mortality. The importance of invasive species management is emphasised, using natural, chemical or manual methods as necessary. Continuous maintenance during the first three years is crucial to the success of the project. Regular monitoring, with monthly assessments, will measure growth, survival, and other key indicators, such as natural regeneration and wildlife reintroduction, ensuring that the restoration plan achieves its stated objectives.

4. Discussion

In this research the Shannon diversity index was applied with reported values ranging from 1.84 to 3.05. It allowed the evaluation of species richness and evenness at the La Belleza Experimental Station. Campo & Duval, Moreno et al. worked in diverse ecosystems such as tropical forests, dry forests, montane forests and moorlands using this index together with others such as Simpson and Pielou to evaluate plant diversity [22][23]. These studies found different levels of diversity, from medium to high, depending on the ecosystem and location. Thus, in the EELB the tropical forest presented a Shannon index of 2.695 indicating medium diversity similar to that reported by Pla et al.[24]. Pielou's evenness index was used to assess the distribution of plant species, with values ranging from 0.70 to 0.86 in agreement with those reported by Campo & Duval. These indices, combined with other ecological measures, provided information to propose conservation and management strategies.

The inventory of native and exotic plant species with different growth rates and dispersal mechanisms in the EELB shows native species with favourable adaptive processes to different conditions. This makes it possible to propose an ecological restoration project considering different functional traits such as size, growth rate and dispersal. Cogollo et al. discuss the importance of certain factors that provide relevant information such as local knowledge, the amount of propagules available and the state of the recovery areas [25]. These factors should be considered in the selection of species to be reintroduced. This research as well as Bustamante & Zalles agree on the importance of native species in ecological restoration processes and the need for short-, medium- and long-term monitoring to ensure the successful recovery of the most degraded or intervened areas [26].

In forest restoration, seed dispersal by birds plays a fundamental role, contributing to the increase of biodiversity and the natural regeneration of disturbed areas. This research and studies carried out in Mexico and Colombia show the capacity of birds to disperse seeds of native and endemic species in primary and secondary forests, preceding forest succession[11],[27]. The use of artificial perches increases seed dispersal by attracting birds as reported by Villate-Suárez & Cortés Pérez [28]. A direct relationship has been found between the size of seeds consumed and the beak length of frugivorous birds, as stated by Ladrón de Guevara et al., Native plant species collected in seed traps are considered key species in natural restoration, contributing significantly to the increase of the seed dispersal mechanism. Calderón et al. emphasise that the success of plant propagation is a result of the faunal diversity in the intervened areas [27].

Ecological restoration allows mitigating the negative effects of anthropogenic activities on degraded ecosystems. This research and those carried out by Gil-Leguizamón et al. and Olaya-Angarita et al. emphasise the importance of implementing restoration actions in degraded areas using native species to increase biodiversity. Restoration should include the evaluation of the current state of the ecosystem, the selection of suitable species, and the continuous monitoring of the restoration process in its different stages. Species such as Chimarrhis glabriflora, Dieffenbachia nitidipetiolata, Dryopteris formosana, Chamaedorea, Sanchezia, Asplundia rigida, Codonanthopsis, Calathea lutea, Cyclanthus bipartitus, Pleiostachya pruinosa and Desmodium molliculum were identified as key in restoration processes in tropical forests affected by anthropic disturbances.

5. Conclusion

The La Belleza Experimental Station has Shannon diversity indices ranging from 1.84 to 3.05, showing low, medium and high botanical diversity. Pielou's equity indices range from 0.70 to 0.86, grouping areas with a greater number of individuals per species than others. The mostly disturbed area presented indices of 1.84 and 0.70 respectively for Shannon and Pielou; while the reference ecosystem presented indices of 2.695 and 0.85, respectively.

The EELB presented 126 botanical species belonging to 50 families, of which 67 are native and 59 exotic, 67 classified as forest (high altitude) and 59 as shrubs (medium and low altitude). Of the total number of species inventoried, 18 native species were selected with a large number of individuals found (>20), all of which are dispersed by gravity, four by mammals, four by birds and three by wind.

An Ecological Restoration Plan was drawn up for the "mostly disturbed area" consisting of three consecutive phases, where in the first phase shrub type species (medium and small size with fast growth) that improve soil conditions will be planted, which are: *Chimarrhis glabriflora, Dieffenbachia nitidipetiolata, Dryopteris formosana, Chamaedorea, Sanchezia, Asplundia rigida, Codonanthopsis, Calathea lutea, Cyclanthus bipartitus, Pleiostachya pruinosa and Desmodium molliculum*, then the medium-growing forest species to strengthen the soil structure: *Jacaranda copaia, Ochroma pyramidale, Apeiba glabra, Astrocaryum urostachys, Euterpe precatoria, Guazuma ulmifolia, Oenocarpus bataua, Terminalia amazonia, Theobroma subincanum, Zanthoxylum tachuelo, Bactris simplicifrons, Guatteria amplifolia, Hellenia speciosa and Inga edulis*; finally, the slow growing forest species that need optimal soil: *Iriartea deltoidea, Phytelephas and Endocomia macrocoma.*

Author contributions: The authors participated in all sections of this manuscript.

Funding: The authors fully funded the study.

Conflicts of interest: The authors declare that they have no conflicts of interest.

References:

1. ONU Un Acuerdo Mundial Para Proteger La Biodiversidad y Evitar Otra Pandemia, El Llamado de Los Líderes En Histórica Cumbre.
2. González, L.; Granda Moser, V.; Torres Romero, S.; Muñoz Chamba, L.; Aguirre Mendoza, Z. Contexto e Implicaciones de La Restauración Ecológica y de Paisajes. *Bosques Latitud Cero* **2024**, *14*, 123–136, doi:10.54753/blc.v14i1.2088.
3. Naciones Unidas Vida de Ecosistemas Terrestres. In; pp. 52–53.
4. FAO Una Nueva Perspectiva. Evaluación de Los Recursos Forestales Mundiales 2020.
5. Alarcon Aguirre, G.; Canahuire Robles, R.R.; Guevara Duarez, F.M.; Rodríguez Achata, L.; Gallegos Chacón, L.E.; Garate-Quispe, J. Dinámica de La Pérdida de Bosques En El Sureste de La Amazonia Peruana: Un Estudio de Caso En Madre de Dios: . *Ecosistemas* **2021**, *30*, 2175, doi:10.7818/ECOS.2175.
6. Barros-Diaz, C. *Estado Actual de La Cobertura Arbórea de Ecuador y Sus Regiones Naturales. Oportunidades Para Mejorar Los Programas de Conservación*; 2024; Vol. 21; ISBN 0000000307277.
7. Tapia-Armijos, M.F.; Homeier, J.; Espinosa, C.I.; Leuschner, C.; de la Cruz, M. Deforestation and Forest Fragmentation in South Ecuador since the 1970s – Losing a Hotspot of Biodiversity. *PLOS ONE* **2015**, *10*, e0133701.
8. Caicedo, M.; Vallejo, M.C.; Carrasco, F. La Pobreza Como Determinante Del Consumo Doméstico de Leña y Su Efecto En Los Bosques Del Ecuador. *Bosque (Valdivia)* **2019**, *40*, 205–216.
9. Sierra, R.; Calva, O.; Guevara, A. La Deforestación En El Ecuador, 1990 – 2018: Factores, Promotores y Tendencias Recientes. *Ministerio de Ambiente y Agua del Ecuador, Ministerio de Agricultura del Ecuador, en el marco de la implementación del Programa Integral Amazónico de Conservación de Bosques y Producción Sostenible. Quito, Ecuador* **2021**, 216.
10. Martí, X.G.; Gallego, P.P.F. La Creación de Núcleos de Dispersión y Reclamo Como Modelo de Restauración Ecológica Forestal.; 2013.
11. Hernández-Ladrón, I.; Rojas-Soto, O.R.; López-Barrera, F.; Puebla-Olivares, F.; Díaz-Castelazo, C. Dispersión de Semillas Por Aves En Un Paisaje de Bosque Mesófilo En El Centro de Veracruz, México: Su Papel En La Restauración Pasiva. *Revista Chilena de Historia Natural* **2012**, *85*, 89–100, doi:10.4067/S0716-078X2012000100007.
12. Castro, A.; Parrado-Rosselli, Á. Evaluación de La Trayectoria de La Restauración En Un Bosque

Andino a Través de Redes Mutualistas de Dispersión de Semillas. *Colombia forestal* **2021**, *24*, 108–122, doi:10.14483/2256201X.15618.
13. Roa García, C.E.; Torres-González, A.M. Caracterización Florística y Estructural Como Línea de Base Para La Restauración Ecológica de Bosques En La Microcuenca Del Río Barbas, Colombia. *Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales* **2021**, *45*, 190–207, doi:10.18257/raccefyn.1167.
14. Gobierno Autonomo descentralizado de la Provincia de Orellana Plan de Desarrollo y Ordenamiento Territorial de Orellana. **2023**.
15. GADPR LA BELLEZA. *Actualización Del Plan de Desarrollo y Ordenamiento Territorial de La Parroquia Rural La Belleza*; 2019;
16. Orlando, V. *Guía Metodológica Para La Restauracion Ecologica Del Bosque Altoandino*; 2007; ISBN 9789587019087.
17. INIAP *Muestreo de Suelos Para Análisis Químico Con Fines Agrícolas*; 2006;
18. Orozco Romero, D. ¿Las Perchas Artificiales Simples Para Aves Aumentan La Lluvia de Semillas En Un Pastizal Del Bosque Seco Tropical En La Mesa de Los Santos, Santander, Colombia?, 2018.
19. Arias Barbosa, Y.V.A. Caracterización de La Lluvia de Semillas En Unidades de Manejo Priorizadas Para La Restauración Ecológica Del Bosque Seco Tropical, 2019.
20. Porras Mora, G. Plan de Restauración Ecológica En La Finca La Lucha, San Cristóbal de Desamparados, San José, Costa Rica, 2018.
21. Muñoz Araque, R. de J. *El Análisis de Suelos y Su Interpretación.*; 2008;
22. Campo, A.M.; Duval, V.S. Diversidad y Valor de Importancia Para La Conservación de La Vegetación Natural. Parque Nacional Lihué Calel (Argentina). *Anales de Geografía de la Universidad Complutense* **2014**, *34*, 25–42, doi:10.5209/rev_AGUC.2014.v34.n2.47071.
23. Moreno, C.E.; Barragán, F.; Pineda, E.; Pavón, N.P. Reanálisis de La Diversidad Alfa: Alternativas Para Interpretar y Comparar Información Sobre Comunidades Ecológicas. *Revista Mexicana de Biodiversidad* **2011**, *82*, 1249–1261, doi:10.22201/ib.20078706e.2011.4.745.
24. Pla, L.; Matteucci, S.D. Intervalos de Confianza Bootstrap Del Índice de Biodiversidad de Shannon. *Revista De La Facultad De Agronomia De La Universidad Del Zulia* **2011**, *18*.
25. Cogollo Calderón, A.M.; Velasco Linares, P.; Manosalva, L. Functional Characterization of Plants and Their Utility in the Selection of Species for the Ecological Restoration of High Andean Ecosystems. *Biota Colombiana* **2020**, *21*, 1–15, doi:10.21068/c2020.v21n01a01.
26. Bustamante, T.Z.J.I. *De La Parcela Al Paisaje: Restauración Forestal En Los Andes Ecuatorianos*; ISBN 9789978675328.
27. Calderón, C.; Múnera, M.A.C.; Ramos, J.M. Potencial Del Banco de Semillas y La Lluvia de Semillas En La Restauración Natural de La Estación de Monitoreo de Biodiversidad Del Centro de Investigaciones Amazónicas Macagual (Florencia-Caquetá, Colombia).; 2009.
28. Villate-Suárez, C.A.; Cortés-Pérez, F. Las Perchas Para Aves Como Estrategia de Restauración En La Microcuenca Del Río La Vega, Tunja, Boyacá. *Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales* **2018**, *42*, 202–211, doi:10.18257/raccefyn.625.