

Tree Biodiversity in Boyacá, A Comprehensive Assessment of Species Richness, Evenness, and Ecosystem Services

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Abstract

The present study addressed the analysis of tree agrobiodiversity of 36 productive systems in the municipalities of Belén, Busbanzá and Cómbita, located in the department of Boyacá, Colombia. The research was developed through a detailed census of tree individuals in areas of one hectare, using biodiversity indices such as Shannon-Wiener, Simpson and Margalef to evaluate the structure and composition of plant communities. In addition, comparative statistical analysis was implemented using the Tukey test with a significance of 5% to identify significant differences between the municipalities. The results revealed notable variability in biodiversity indices, with Shannon values ranging between 1.60 and 2.05, indicating heterogeneous ecosystem complexity. On the other hand, Simpson's index, fluctuating between 0.14 and 0.26, suggests a relatively balanced distribution of species. In relation to the floristic composition, families such as Myrtaceae, Fabaceae and Betulaceae stood out, with predominant species such as *Alnus acuminata* (Alder) and *Eucalyptus globulus*. Multiple uses of the species were identified, finding that between 41% and 43% have medicinal properties, while 35-47% have timber and ornamental applications. The study's conclusions highlight the importance of developing integrative conservation strategies that recognize the resilience of high Andean ecosystems. The need to combine traditional knowledge with modern sustainable management practices is emphasized, considering the influence of factors such as altitude and agricultural practices on local biodiversity.

Keywords: Forestry, Biodiversity, Ecosystem, Productive System, Sustainability.

Introduction

Agrobiodiversity is understood as the set of biotic elements that interact within agroecosystems and provide various goods and services to humanity (León, 2014). In recent years, the value of ecosystem services has gained renewed importance due to the challenges posed by the COVID-19 pandemic (DiMaio et al., 2020), the threat of climate change (Cárdenas and Tobón, 2016), and the increase in demand for goods and services (Egal & Berry, 2020). The services that agrobiodiversity provides to ecosystems are vast (Phalan et al., 2011), and include aspects such as pollination, biological pest control (Cusser et al., 2016), soil erosion mitigation (Wan et al. 2013, cited by Lian et al 2021), carbon sequestration, and preservation of native biodiversity (Jarvis et al., 2008), as well as the promotion of cultural and recreational values (Landis, 2017), among others.

The agrobiodiversity present in production systems allows resources to be obtained in different periods: short, medium and long (Rosales-Adame et al., 2014). This diversity promotes a series of interactions that favor the development of morphological and biological adaptations, helping species to resist adverse environmental conditions (Gillison et al., 2013). Farmers take advantage of these characteristics, which can be instrumental in creating climate change adaptation strategies through climate-smart agriculture practices (Cámara-Leret et al., 2019).

In this sense, tree agrobiodiversity is fundamental for the functioning of ecosystems and is considered a key attribute to characterize plant communities (Mena et al., 2019). Species diversity refers to the number of species per unit area, with two main factors: richness (total number of species) and equity (number of individuals of a particular species). Agrobiodiversity assessments are carried out using indices that measure both species richness and the distribution of individuals among them. Among the most widely used indices are

those of Shannon-Wiener, Simpson and Margalef (Villareal et al., 2004). The Margalef index allows estimating the biodiversity of a community by analyzing the number of individuals of each species in relation to the total number of individuals in the sample evaluated, which is crucial to measure the number of species in a sample unit (Valdés et al., 2018). On the other hand, the Simpson index assesses the richness of organisms through dominance analysis (Soler et al., 2021), while the Shannon index estimates the probability of finding a specific individual in the ecosystem, taking into account both species richness and the relative abundance of each species (Juárez et al., 2016).

In this context, the objective of this research was to analyze the tree agrobiodiversity indices of the municipalities of Belén, Busbanzá and Cómbita located in the department of Boyacá using the variables of Abundance, Relative Abundance, Specific Richness, Margalef Index, Shannon Index and Simpson Index.

Methodology

Location and Sample

This research was developed in 36 production systems in the municipalities of Belén, Busbanzá and Cómbita located in the department of Boyacá (Colombia). Table 1 presents the main agroecological characteristics of the three municipalities.

Table 1. Agroecological characteristics of municipalities

Municipality	Altitude (masl)	Average temperature (°C)	Precipitation (mm year)	Production systems
Bethlehem	2.650	14	1.340	12
Busbanzá	2.472	15.2	2.273	12
Cómbita	2.825	13	1.292	12

Source: Authors

To determine the abundance of tree species in the studied production systems of the municipalities of Belén, Busbanzá and Cómbita (Boyacá), a multifaceted methodological approach was carried out. Initially, the census of the tree individuals present in each sample unit in an area of one hectare was carried out, following the protocols established by Magurran and McGill (2011). Through this process, the absolute abundance of each species was quantified and the basis for analysis of the community structure was provided. Importantly, accuracy in taxonomic identification and counting of individuals is crucial to the validity of subsequent results (Gotelli & Colwell, 2011).

Once the field data were collected, diversity indices were calculated that provide information on different aspects of the community structure.

Biodiversity indices

Specific Wealth (S)

Forest species diversity is a key indicator for assessing biodiversity in forest ecosystems. This is defined by the total number of species present in a community or ecosystem. To obtain this index, the number of species of trees and shrubs present in a specific forest area within a study region is added, which allows the variety of species that inhabit a given space to be measured. The formula used to calculate species richness was as follows:

$$S = \sum_{i=1}^n n_i$$

Where:

S is the richness of species,

n_i is the number of individuals of species I,

n is the total number of species present in the study area.

The richness of forest species can vary according to geographical location, type of forest, environmental and disturbance factors. Meanwhile, this indicator must be analyzed in the context of the specific production system being evaluated.

Simpson Index

It was used to measure the biodiversity of plant species in a habitat; In other words, the abundance of each species reflects the probability that two randomly chosen individuals within the same area belong to the same species. This indicator varies between 0 and 1, where values close to 1 indicate less diversity in the habitat, while values close to 0 indicate greater diversity, according to Magurran and McGill (2011). It was calculated as follows:

$$D = \sum_{i=1}^S (n_i / N)^2$$

Where:

S is the total number of species present,

n_i is the number of individuals of species i ,

N is the total number of individuals in the sample.

Shannon-Wiener index (H')

Also known as the Shannon index or Shannon-Wiener index, it is a measure of species diversity widely used in biodiversity studies, including forest ecosystems. This index measures the amount of information contributed by each randomly selected individual in a community of known species (S). It analyzes the informative content of each individual in randomly obtained samples, where the total number of species (S) is known. In addition, diversity may include a calculation of uncertainty when trying to predict to which species a randomly chosen individual would belong within a sample with S species and N individuals (Magurran and McGill, 2011).

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

Where:

S is the total number of species present,

p_i is the proportion of individuals of species i with respect to the total number of individuals (relative abundance)

The value of H' increases as the number of species increases and individuals are more evenly distributed among them. Typical H' values in natural ecosystems vary between 0.5 and 5, with higher values (above 3) indicating greater species diversity.

In the context of forest ecosystems, the Shannon-Wiener index allows quantifying the diversity of tree and shrub species present in a forest. Higher H' values indicate greater richness and evenness of plant species, which is associated with more mature and ecologically stable forests. This index is very useful for comparing forest species diversity between different forested areas or for assessing changes in diversity over time in the same forest, as a result of disturbances or management practices.

The Margalef Index, or Margalef Biodiversity Index (DMg)

The Margalef Index, or Margalef Biodiversity Index (DMg), is a tool used in ecology to estimate diversity in a community, considering the numerical distribution of individuals of each species in relation to the total number of individuals present in the sample analyzed. This index allows the biodiversity of a population to be calculated based on the number of individuals and the distribution of the different species according to the number of individuals observed in the sample (Margalef, 1972; Moreno, 2001).

$$DMg = (S - 1) / \ln(N)$$

Being:

S = number of species

N = total number of individuals

$\ln$ denotes the Neperian logarithm of a number.

The value of the DMg index can range from zero to a positive number. A value of zero suggests that only one species is present in the sample, while higher values indicate greater biodiversity. Generally speaking, a DMg greater than 2 is associated with low biological diversity, while values greater than 5 reflect high biodiversity in the region.

Data analysis

The means of the forest biodiversity indicators of the three municipalities were compared using the Tukey test with a 5% probability of error and the statistical software SPSS v. 24 was used.

Results and Discussion

When comparing the three municipalities, Busbanzá presents the highest abundance with respect to Belén and Cómbita, indicating the highest number of individuals per species. In relation to relative abundance, Cómbita differs from the other two municipalities ($p < 0.05$) indicating a lower proportion of species in this municipality. Busbanzá has the greatest diversity of species, being statistically different from the other municipalities. The Margalef Index reflects the relative richness of species, with May in Cómbita indicating a greater number of species by number of individuals compared to Belén and Busbanzá. For the Shannon Index, Cómbita presents a more balanced community with the highest average. The Simpson Index showed similar behavior among the three municipalities. For Belén, the average was higher, indicating a slight trend towards the dominance of some species. Table 2 presents the results of the multipurpose forest biodiversity indices for the municipalities of Belén, Busbanzá and Cómbita.

Table 2. Comparison of the averages of the biodiversity indicators in the three municipalities

Biodiversity Index	Bethlehem		Busbanzá		Cómbita		P - value
	Stocking	OF	Stocking	OF	Stocking	OF	
Abundance	28,67	10,577	35,5	20,92	20,9	7,60	0,56
Relative abundance	8,7250	3,21364	10,816	6,3713	0,083	,0302	0,000
Specific wealth	6,67	2,995	10,5	5,08	8,7	1,35	0,034
Margalef Index	1,6883	0,84161	1,613	0,5632	2,584	,3697	0,001
Shannon Index	1,6050	0,53482	1,648	0,3485	2,052	,1558	0,012
Simpson Index	0,2650	0,15466	0,222	0,0860	0,142	,0237	0,21
Average altitude (masl)	2.994,17	137,461	2.512,5	38,86	2.916,1	134,20	0,64

SD: standard deviation. Source: Authors

The data collected show that Belén maintains an average abundance of 28.67 species (SD=10.577), a value that, as Rangel-Ch (2015) points out, represents a characteristic pattern of high Andean ecosystems subjected to moderate environmental pressures. This abundance, when contextualized with its high average altitude of 2,994.17 meters above sea level (SD=137.461), suggests a remarkable resistance and adaptation of plant communities to the extreme conditions of the high tropical mountains.

The specific richness observed in Belén ($M=6.67$, $SD=2.995$), although lower than that of neighboring municipalities such as Busbanzá, reflects what Bernal et al. (2019) describe as a typical pattern of "altitudinal compression of ecological niches". This phenomenon suggests an evolutionary specialization of the species present, adapted to the particular microclimatic conditions of the region.

The Margalef Index ($M=1.6883$, $SD=0.84161$) and the Shannon Index ($M=1.6050$, $SD=0.53482$) reveal an ecological community with moderate structural complexity. As Villarreal et al. (2004) argue, these values indicate an ecosystem that, despite anthropogenic pressures, maintains a significant capacity for resilience. The Simpson Index ($M=0.2650$, $SD=0.15466$) suggests a moderate dominance of certain species, a phenomenon that Moreno (2018) associates with ecosystems in the process of adapting to gradual environmental changes.

Comparison with neighboring municipalities such as Busbanzá and Cómbita reveals interesting patterns of spatial variation in biodiversity. Castaño-Urbe (2017) suggests that these differences can be attributed to what he calls "altitudinal edge effects", where elevation acts as an ecological filter that determines the composition and structure of plant communities. This phenomenon becomes particularly evident when one considers that Belén is located at a significantly higher altitude than Busbanzá, which according to a study carried out by Rangel-Ch. et al. (2005), can explain the observed variations in diversity patterns.

The significance of these findings is magnified when considering the context of global climate change. According to Bitter et al. (2021), high mountain plant communities, similar to those present in Bethlehem, can serve as early indicators of regional environmental changes, as well as the combination of moderate diversity indices and significant relative abundance suggests that these ecosystems maintain an adaptive capacity that could be crucial for their long-term survival.

The implications of these findings are profound for the conservation and management of high Andean ecosystems. Preserving these unique assemblages of species requires an approach that recognizes both the importance of altitudinal gradients and the influence of human activities on landscape configuration. As Bernal et al. (2019) point out, the effective management of these ecosystems must be based on a deep understanding of the interactions between biotic and abiotic factors that determine the observed biodiversity patterns.

The ecological uniqueness of Bethlehem, evidenced by its biodiversity indices and altitudinal position, underlines the importance of developing specific conservation strategies for high mountain ecosystems. Continuous monitoring of these ecological parameters, together with the implementation of protective measures adapted to local conditions, will be crucial to ensure the persistence of these valuable ecosystems for future generations.

The variability in biodiversity indices between farms within each municipality suggests that farm-level management practices have a significant impact on local biodiversity. Heterogeneity in agricultural management practices has a significant impact on biodiversity conservation. As Perfecto and Vandermeer (2015) argue, landscape mosaics created by different management practices sustain diverse biological communities. This perspective is reinforced by the findings of Kremen and Merenlender (2018), who demonstrate that well-managed agricultural landscapes can function as effective biological corridors and buffer zones for conservation. Empirical evidence suggests that diversifying farming systems not only benefits biodiversity, but also improves ecosystem resilience. For example, Tscharntke et al. (2021) found that heterogeneous landscapes provide multiple ecosystem services, including natural pollination and biological pest control.

Altieri and Nicholls (2017) emphasize that agricultural systems with high diversity and low dominance are more resilient to environmental disturbances and climate changes, providing more stable and diverse ecosystem services.

Mathez-Stiefel et al. (2020) suggest that biodiversity conservation in Andean agricultural landscapes requires an approach that integrates traditional knowledge with sustainable management practices, considering the particularities of each locality and its socio-ecological context.

With regard to families, genera, and species, their frequency is listed in Figure 1.

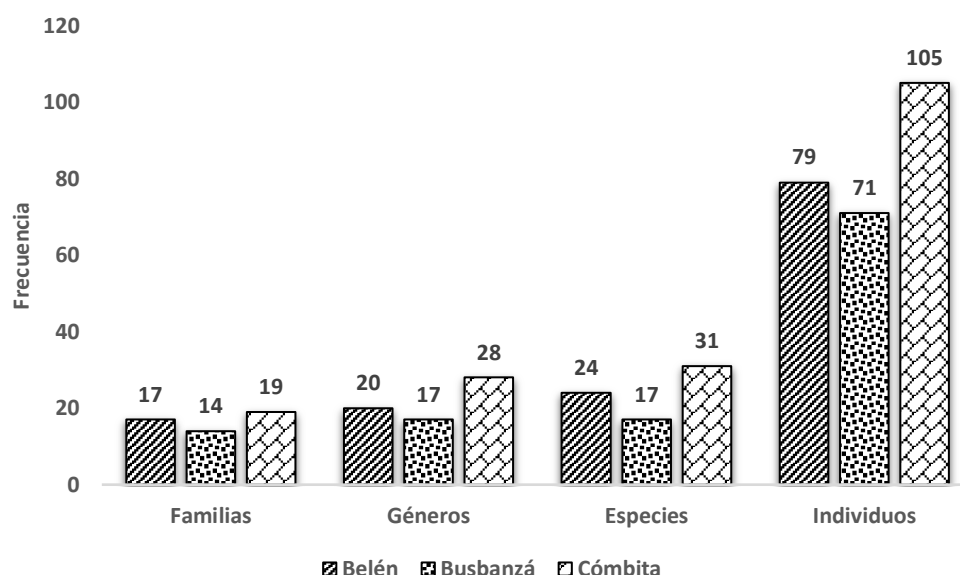


Figure 1. Frequency of families, genera, species and individuals in the three municipalities. Source: Authors. In original language Spanish

The most frequent families were Myrtaceae, Fabaceae and Myrtaceae for the municipalities of Belén, Busbanzá and Cómbita respectively. It is noteworthy that the families Myrtaceae, Adoxaceae, Fabaceae, Rosaceae, Solanaceae were present in the three municipalities (Table 2).

Table 3. Frequency of families identified in the three municipalities

Bethlehem		Busbanzá		Cómbita	
Family	Frequency	Family	Frequency	Family	Frequency
Myrtaceae	14	Fabaceae	15	Myrtaceae	18
Betulaceae	9	Myrtaceae	14	Rosaceae	17
Adoxaceae	8	Pinaceae	11	Betulaceae	11
Cunoniaceae	8	Betulaceae	7	Fabaceae	9
Pinaceae	8	Salicaceae	6	Pinaceae	8
Fabaceae	6	Oleaceae	5	Salicaceae	7
Rosaceae	6	Solanaceae	4	Melastomataceae	5
Miricaceae	4	Asteraceae	2	Solanaceae	5
Clusiaceae	3	Moraceae	2	Cupresaceae	4
Primulaceae	3	Adoxaceae	1	Adoxaceae	3
Fagaceae	2	Lauraceae	1	Caricaceae	3
Lauraceae	2	Rosaceae	1	Miricaceae	3
Solanaceae	2	Rutaceae	1	Passionflower	3
Cupresaceae	1	Saxifragaceae	1	Asteraceae	2
Eleocarpaceae	1			Fagaceae	2
Meliaceae	1			Saxifragaceae	2
Oleaceae	1			Eleocarpaceae	1
				Euphorbiaceae	1
				Sapindaceae	1

Source: Authors

In relation to genera (Table 4), *Alnus* was the most representative for the municipalities of Belén and Cómbita, while *Eucalyptus* for Busbanzá. For their part, the genera *Alnus*, *Eucalyptus*, *Acacia* and *Prunus* were present in the three municipalities.

Table 4. Frequency of genders identified in the three municipalities

Bethlehem		Busbanzá		Cómbita	
Gender	Frequency	Gender	Frequency	Gender	Frequency
<i>Alnus</i>	9	<i>Eucalyptus</i>	11	<i>Alnus</i>	11
<i>Eucalyptus</i>	9	<i>Pinus</i>	11	<i>Eucalyptus</i>	9
<i>Pinus</i>	8	<i>Acacia</i>	8	<i>Myrcia</i>	8
<i>Weinmannia</i>	8	<i>Alnus</i>	7	<i>Pinus</i>	8
<i>Acacia</i>	6	<i>Caesalpinia</i>	7	<i>Acacia</i>	7
<i>Sambucus</i>	6	<i>Salix</i>	6	<i>Salix</i>	7
<i>Myrcianthes</i>	5	<i>Fraxinus</i>	5	<i>Rubus</i>	6
<i>Prunus</i>	5	<i>Cestrum</i>	4	<i>Hesperomels</i>	5
<i>Morella</i>	4	<i>Acca</i>	2	<i>Miconia</i>	5
<i>Clusia</i>	3	<i>Ficus</i>	2	<i>Cupressus</i>	4
<i>Myrsine</i>	3	<i>Montanoa</i>	2	<i>Morella</i>	3
<i>Laurus</i>	2	<i>Citrus</i>	1	<i>Passiflora</i>	3
<i>Quercus</i>	2	<i>Escallonia</i>	1	<i>Sambucus</i>	3
<i>Solanum</i>	2	<i>Myrcianthes</i>	1	<i>Vasconcellea</i>	3
<i>Viburnum</i>	2	<i>Persea</i>	1	<i>Brugmansia</i>	2

<i>Cedrela</i>	1	<i>Prunus</i>	1	<i>Cestrum</i>	2
<i>Cupressus</i>	1	<i>Sambucus</i>	1	<i>Erythrina</i>	2
<i>Fraxinus</i>	1			<i>Escallonia</i>	2
<i>Hesperomels</i>	1			<i>Polylepis</i>	2
<i>Vallea</i>	1			<i>Prunus</i>	2
				<i>Pyrus</i>	2
				<i>Quercus</i>	2
				<i>Solanum</i>	2
				<i>Dodonaea</i>	1
				<i>Euphorbia</i>	1
				<i>Piptocomia</i>	1
				<i>Syzygium</i>	1
				<i>Vallea</i>	1

Source: Authors

The most frequent species were: for the municipalities of Belén and Cómbita *acuminata* Kunt and for Busbazá *globulus* Labill. Meanwhile, the species identified in the three municipalities were: *acuminata* Kunt, *melanoxylon* R.Br., *patula* Schiede ex Schltdl & Cham., *persica* (L) Batsch.

Table 5 lists the species and their frequency for the municipality of Belén.

Table 5. Frequency of identified species and their use in Bethlehem

Species	Common name	Frequency	Use
<i>acuminata</i> Kunth	Alder	9	Medicinal, ornamental
<i>globulus</i> Labill.	Eucalyptus	9	Medicinal, wood
<i>Kunth fagaroides</i>	Naranjillo	8	Fruity, gloomy
<i>melanoxylon</i> R.Br.	Aromo, Black Guayacán	6	Wood, ornamental
<i>leucoxylla</i> (Ortega) McVaugh	White Guaiacan	5	Wood, ornamental
<i>Schiede patula</i> ex Schltdl. & Cham.	Colombian Pine	4	Wood, reforestation
<i>Peruvian</i> Kunth	Andean myrtle	4	Medicinal, ornamental
<i>pubescens</i> (Humb. & Bonpl. ex Willd.) Wilbur	Seven Hides	4	Ornamental, reforestation
<i>radiata</i> D.Don	Radiata pine	4	Wood, reforestation
<i>guianensis</i> (Aubl.) Kuntze	Stick beans	3	Food, traditional medicine
sp		3	
<i>betaceum</i> Cav.	Tree tomato	2	Fruit
<i>humboldtii</i> Bonpl.	Wax laurel	2	Ornamental, traditional medicine
<i>nigra</i> L.	Walnut	2	Wood, medicinal (traditional)
<i>nobilis</i> L.	Laurel	2	Seasoning, medicinal
<i>persica</i> (L.) Batsch	Peach	2	Fruity, ornamental
<i>Ehrh serotina</i> .	Cherry tree	2	Wood, ornamental
<i>triphyllum</i> Benth.	Wild beans	2	Diet (legume)
<i>buxifolia</i> Koehne	Tattletale	1	Ornamental, medicinal
<i>chinensis</i> Roxb.	Urapan	1	Food, medicinal

<i>goudotiana</i> (Decne.) Killip	Curupay	1 Wood, medicinal (healing)
<i>Lusitanica</i> Mill.	Portuguese Cypress	1 Ornamental, wood
<i>odorata</i> L.	Cascarillo	1 Medicinal
<i>stipularis</i> L.f.	Water lily	1 Ornamental, medicinal

Source: Authors

The data collected for Belén allowed the identification of 18 species of flora relevant to the region, each with particular characteristics and uses. In terms of frequency of appearance, the Alder (*Alnus acuminata* Kunth) and the Eucalyptus (*Eucalyptus globulus* Labill) stand out, registered 9 times. As reported by the Ministry of Environment and Sustainable Development (2017), Alder is traditionally used for medicinal purposes and also as an ornamental species, while Eucalyptus, in addition to its medicinal uses, is used in the timber industry.

Another species with a high frequency of 8 records is the Orange Tree (*Zanthoxylum fagaroides* Kunth), which is used both for fruit production and to provide shade according to Gentry, A & Vasquez, R. (1996) cited by Haber, W. (2014). On the other hand, the Aromo or Black Guayacán (*Acacia melanoxylon* R.Br.) and the White Guayacán (*Guaicum leucoxylum* (Ortega) McVaugh), with frequencies of 6 and 5 respectively, are appreciated for their wood and ornamental potential.

In contrast, some species such as the Colombian Pine (*Pinus patula* Schiede ex Schltdl. & Cham.) and the Andean Myrtle (*Myrcianthes peruviana* Kunth) presented lower frequencies, of only 4 records each. This could indicate that these species are under threat, possibly due to factors such as deforestation and land use change, as noted by Rodríguez et al. (2014) in their study on forest loss trends in Colombian regions.

On the other hand, species with potential for food and medicinal uses were identified, such as the Stick Bean (*Canavalia guianensis* (Aubl.) Kuntze) and the tree tomato (*Solanum betaceum* Cav.), with frequencies of 3 and 2 respectively. This opens up opportunities for the development of new products and the diversification of the uses of these natural resources, as demonstrated by Acosta-Quezada et al. (2015) in their exhaustive research on the genetic diversity and nutritional potential of these Andean species.

Table 6. Frequency of identified species and their use in Busbanzá

Species	Common name	Frequency	Use
<i>globulus</i> Labill.	Eucalyptus	11	Medicinal, wood
<i>Schiede patula</i> ex Schltdl. & Cham.	Colombian Pine	10	Wood, reforestation
<i>Melanoxylon</i> auct. non-R.Br.	Aromo, Black Guayacán	8	Wood, ornamental
<i>spinosa</i> (Molina) Kuntze	Hawthorn or Hawthorn	8	Medicinal, ornamental
<i>acuminata</i> Kunth	Alder	7	Medicinal, ornamental
<i>Humboldtiana</i> Willd.	Willow	6	Erosion control, forage
<i>chinensis</i> Roxb.	Urapan	5	Food, medicinal
<i>buxifolium</i> Kunth	Olive tree	4	Wood, ornamental
<i>Carica</i> L.	Papaya	2	Fruity, medicinal
<i>ovalifolia</i> Deless. ex DC.	Higuillo	2	Forage, medicinal
<i>Sellowiana</i> (O. Berg) Burret	Feijoa	2	Fruity, ornamental
<i>Americana</i> Mill.	Avocado	1	Fruit, oil in cosmetics
<i>leucoxyla</i> (Ortega) McVaugh	White Guaiacan	1	Wood, ornamental
<i>limonia</i> Osbeck	Mandarin lemon	1	Fruity, medicinal
<i>nigra</i> L.	Walnut	1	Wood, medicinal
<i>persica</i> (L.) Batsch	Peach	1	Fruity, ornamental

Source: Authors

The analysis of the floristic composition reveals a complex ecological structure characterized by a heterogeneous distribution of native species. *Alnus acuminata* emerges as the predominant taxon, with seven records (n=7), suggesting a remarkable representativeness and potential adaptability in the ecosystem studied (Armenteras et al., 2019). In contrast, species such as *Juglans nigra* and *Citharexylum leucoxylon*, represented by a single record each (n=1), show significant population fragility that could indicate fragmentation processes or ecosystem pressure (Pauchard et al., 2006).

The low representativeness of *Juglans nigra* and *Citharexylum leucoxylon* raises critical questions about conservation mechanisms and natural regeneration dynamics. Recent studies indicate that the population reduction of native species can be an early indicator of ecosystem transformations, which demands immediate strategies for ecological preservation and restoration (Aide et al., 2013).

The study reveals a significant multifunctionality in the species recorded: medicinal use (41% of the species), timber use (35%), ornamental use (47%) and fruit use (35%)

This diversification of uses, as Pérez-Llorente et al. (2023) argue, represents an important source of socioeconomic resilience for local communities. The observed distribution and frequency patterns suggest the need to implement more effective conservation strategies. As Peyre et al. (2020) point out, the preservation of native species is essential to maintain the ecosystem integrity of the Colombian Andes. The dominant presence of introduced species, although economically important, poses challenges for the conservation of native biodiversity.

The floristic inventory for C3mbita (Table 7) reveals a remarkable diversity of species, where *Alnus acuminata* (Alder) emerges as the dominant species with 11 records. This dominance pattern is particularly significant considering that, as Murcia and Ochoa-Reyes (2008) point out, alder plays a fundamental role in water regulation and the restoration of Andean soils.

Table 7. Frequency of identified species and their use in C3mbita

Species	Common name	Frequency	Use
acuminata Kunth	Alder	11	Medicinal, ornamental
globulus Labill.	Eucalyptus	9	Medicinal, wood
Schiede patula ex Schltld. & Cham.	Colombian Pine	8	Wood, reforestation
Popayanensis Hieron.	Myrtle	8	Wood, reforestation
Humboldtiana Willd.	Willow	7	Erosion control, forage
melanoxylon auct. non R.Br.	Aromo, Black Guayac3n	7	Wood, ornamental
eriocarpus Liebm.	Blackberry of Castile	6	Feeding, forage
goudotiana (Decne.) Killip	Morti3o	5	Wood, medicinal
squamulosa Triana	Tuno	5	Ornamental, medicinal
Lusitanica Mill.	Portuguese Cypress	4	Ornamental, wood
mollis Kunth	Spiked Weld	3	Ornamental, medicinal
Peruvian Kunth	Andean myrtle	3	Medicinal, ornamental
pubescens A.DC.	Papayuela	3	Ornamental, medicinal
buxifolium Kunth	Uvito	2	Wood, erosion control, ornamental
communis L.	Higuerilla	2	Seasoning, medicinal
humboldtii Bonpl.	Andean Oak	2	Ornamental, traditional medicine
persica (L.) Batsch	Peach	2	Fruity, ornamental

<i>pubescens</i> Humb. (Humb. & Bonpl. ex Willd.) Wilbur	Seven Hides	3	Ornamental, reforestation
<i>quadrijuga</i> Bitter	Coffee walnut	2	Wood, medicinal
<i>rubrinervia</i> Kunth	Pig	2	Erosion control, riverbank restoration
<i>spinosa</i> (Molina) Kuntze	Guarango	2	Live fencing, medicinal, erosion control
<i>betaceum</i> Cav.	Tree tomato	1	Fruit
<i>Candida</i> Pers	Drunk	1	Medicinal, ornamental
<i>discolor</i> (Kunth) Pruski	Ashen	1	Medicinal, reforestation
<i>nigrum</i> L.	Black nightshade	1	Seasoning, medicinal
<i>paniculatum</i> Gaertn.	Cherry	1	Ornamental
<i>Pulcherrima</i> Willd. Ex Klotzsch	Poinsettia	1	Ornamental
(Ruiz & Pav.) D.Don	Red floripondium	1	Ornamental, reforestation
<i>stipularis</i> L.f.	Raque	1	Ornamental, medicinal
<i>viscose</i> (L.) Jacq.	Candle	1	Medicinal

Source: Authors

The significant presence of introduced species such as *Eucalyptus globulus* (n=9) and *Pinus patula* (n=8) reflects the historical transformation of the landscape. According to León et al. (2009), this configuration is characteristic of high Andean ecosystems modified by anthropogenic activities.

The research reveals a remarkable diversification in the use of floristic resources: 43.3% of the species recorded have medicinal properties, highlighting the importance of ethnomedicine in the region. As documented by Fonnegra and Jiménez (2017) cited by Salmerón-Manzano, E. et al (2020), many of these species maintain an active role in traditional health practices. The predominance of species with ornamental value (53.3%) suggests a strong relationship between the local flora and the cultural identity of the territory.

The identified species provide multiple ecosystem services, from erosion control to ecological restoration. According to Rodríguez-Eraso et al. (2010), this multifunctionality is crucial for the socio-ecological resilience of the territory.

Conclusions

This research offers a comprehensive overview of the complexity and dynamics of the high Andean ecosystems studied. The findings highlight the importance of biodiversity indices, species interactions, and the socio-ecological implications of local uses, providing a solid foundation for future conservation and sustainable management strategies.

The biodiversity indices reflect a marked heterogeneity among the municipalities evaluated, evidenced by the Shannon values, which range between 1.60 and 2.05. This range indicates variations in ecosystem complexity, which are significantly influenced by factors such as altitude and prevailing agricultural practices. Consequently, these differences underscore the need to adapt environmental management strategies to the specific characteristics of each locality.

The community structure, determined through Simpson's indices (0.14-0.26), suggests a relatively balanced distribution of species. This balance reflects efficient mechanisms of coexistence, even in ecosystems subject to anthropogenic transformations, which highlights the inherent resilience of these systems to alterations.

The predominance of species such as *Alnus acuminata* and *Eucalyptus globulus*, together with the outstanding representation of families such as Myrtaceae, Fabaceae and Betulaceae, indicates a complex dynamic between native and introduced species. This interaction defines the current configuration of the landscape, raising questions about the long-term effects of these relationships on biodiversity and ecosystem services.

The identification of multiple uses of the species, such as medicinal, timber and ornamental purposes, highlights the high value of the natural capital available in these territories. This not only contributes to socio-ecological resilience, but also highlights the interdependence between human communities and local ecosystems.

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