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Translated from the original in spanish **Original article**

Evaluation of passive restoration in three successional stages in an area of the El Cristal Natural Reserve, Loja, Ecuador

Evaluación de la restauración pasiva en tres estados sucesionales en un área de la Reserva Natural El Cristal, Loja, Ecuador

Avaliação da restauração passiva em três estados sucessionais em uma área da Reserva Natural El Cristal, Loja, Equador

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ABSTRACT

The study aimed to evaluate the differences in structure, floristic composition and diversity in three stages of forest succession in the El Cristal Natural Reserve, as essential elements of passive restoration. Three successional stages of 10-20, 20-30 and 30-40 years of abandonment and a reference ecosystem were studied. In each successional stage, three plots of 20x20 m were established for trees; within these, 5 subplots of 5x5 m for latizas and

5 subplots of 1x1 m for saplings were nested. Floristic diversity and composition were determined, structural parameters and diversity indices were calculated; and, the succession stages were compared using the Sorensen index. The floristic composition was 14 species in stage one, 15 for stage two; 20 for three and 26 species for the reference ecosystem. Stage one has a Shannon index of 0.74, stages two and three have values of 1.73 and 1.96 respectively, and the reference ecosystem 2.80. The three stages under study show floristic dissimilarity, with similarity index values below 0.69. The recovery of vegetation through natural succession processes is an important *in situ* restoration strategy, since Andean Forest species are gradually becoming established, which facilitate the formation of ecosystems similar to the reference systems.

Keywords: stage, natural succession, diversity, similarity, natural regeneration category.

RESUMEN

El estudio tuvo como objetivo evaluar las diferencias en estructura, composición florística y diversidad en tres estados de sucesión del bosque en la Reserva Natural El Cristal, como elementos esenciales de la restauración pasiva. Se estudiaron tres estados sucesionales de 10-20, 20-30 y 30-40 años de abandono y, un ecosistema de referencia. En cada etapa sucesional se establecieron tres parcelas de 20x20 m para fustales; dentro de estas se anidaron 5 subparcelas de 5x5 m para latizales y, 5 subparcelas de 1x1 m para brinzales. Se determinó la diversidad y composición florística, se calculó los parámetros estructurales e índices de diversidad; y, se comparó los estados de sucesión usando el índice de Sorensen. La composición florística fue de 14 especies en el estado uno, 15 para el dos; 20 para el tres y, 26 especies para el ecosistema de referencia. El estado uno tiene índice de Shannon de 0,74, el estado dos y tres tienen valores de 1,73 y 1,96 respectivamente, y el ecosistema de referencia 2,80. Los tres estados en estudio muestran disimilitud florística, con valores de índice de similitud bajo 0,69. La recuperación de la vegetación mediante procesos de sucesión natural es una importante estrategia *in situ* de restauración, ya que paulatinamente van estableciéndose las especies de bosque andino, que facilitan la formación de ecosistemas parecidos a los sistemas de referencia.

Palabras clave: estado, sucesión natural, diversidad, similitud, categoría de regeneración natural.

RESUMO

O estudo teve como objetivo avaliar as diferenças de estrutura, composição florística e diversidade em três estágios de sucessão florestal na Reserva Natural El Cristal, como elementos essenciais da restauração passiva. Foram estudados três estágios sucessionais de 10-20, 20-30 e 30-40 anos de abandono e um ecossistema de referência. Em cada estágio sucessional foram estabelecidas três parcelas de 20x20 m para árvores; Dentro destas, foram aninhadas 5 subparcelas de 5x5 m para latizas e 5 subparcelas de 1x1 m para mudas. Foram determinadas a diversidade e composição florística, calculados parâmetros estruturais e índices de diversidade; e, os estados de sucessão foram comparados através do índice de Sorensen. A composição florística foi de 14 espécies no estado um, 15 no estado dois; 20 para três e 26 espécies para o ecossistema de referência. O estado um possui índice de Shannon de 0,74, os estados dois e três possuem valores de 1,73 e 1,96 respectivamente, e o ecossistema de referência 2,80. Os três estados em estudo apresentam dissimilaridade florística, com valores de índice de similaridade abaixo de 0,69. A recuperação da vegetação por meio de processos de sucessão natural é uma importante estratégia de restauração in situ, uma vez que gradativamente se estabelecem espécies florestais andinas, o que facilita a formação de ecossistemas semelhantes aos sistemas de referência.

Palavras-chave: estado, sucessão natural, diversidade, similaridade, categoria regeneração natural.

INTRODUCTION

In Ecuador there are areas that have been affected by the overexploitation of natural resources, mostly caused by anthropogenic factors, causing a number of ecological impacts. However, to stop these impacts, forest conservation and restoration strategies have been proposed, such as the National Forest Restoration Plan (Ministry of the Environment of

Ecuador [MAE], 2019), whose objective is the recovery of vegetation cover through techniques of active and passive restoration, this plan responds to a policy of the government of Ecuador by forming part of organizations and agreements for the protection of the environment and in line with the restoration decade 2020-2030 (Domínguez *et al.*, 2019).

The restoration of forest ecosystems is a method for the conservation of forests and for the recovery of areas degraded by anthropogenic or natural action. This plays an indispensable role for the connection, stability and functional balance of the biotic and abiotic components of ecosystems, promoting biological diversity and ecosystem services (Ipinza *et al.*, 2021). Restoration can be achieved in two fundamental ways: passive or assisted (active) restoration. In passive restoration, the natural regeneration of the forest acts on its own, without any human intervention; while active restoration entails human intervention to facilitate natural regeneration and guarantee the development of ecosystem recovery processes (Vargas, 2011).

Moreover, the ability to restore an ecosystem depends on prior information about the magnitude of the change in the structure, composition and functioning of the ecosystem, availability of native biota, regeneration patterns, or recovery status of the species (*ie* , reproductive strategies, dispersal mechanisms, growth rates, functional role and other attributes of these) and possible trajectories of the system as a result of self-organizing processes after the occurrence of disturbances (Vargas, 2011; Salmeron -López and Geada-Lopez 2023).

The El Cristal Natural Reserve is located in the Ecuadorian mountains; it currently has abandoned areas in different periods of time that in the past were spaces intended for agriculture and livestock. This determines that there are areas with different recovery stages, which makes them a suitable scenario to carry out studies of vegetation dynamics and the effectiveness of passive restoration.

Under this background, the present study had the objective of evaluating the differences in structure, floristic composition and diversity in the three successional stages of passive restoration in the El Cristal Natural Reserve. This will allow us to understand the behavior of the vegetation in three successional stages of the El Cristal Natural Reserve, as well as the time in which they stabilize, for decision-making in assisted restoration processes.

MATERIALS AND METHODS

Study area

The El Cristal Natural Reserve (RNEC) is located 15 km from the city of Loja, it belongs to the San Sebastián parish, canton and province of Loja (Figure 1). It has an area of 602.51 ha, located in the buffer zone of the Podocarpus National Park with an altitudinal range of 1,950 to 3,250 m asl., precipitation ranges between 1,500 - 2,000 mm; The temperature between 6 22! (Samaniego, 2020).

The RNEC is made up of several plant formations: the lower part made up of the arboretum, agroforestry and silvopastoral systems and eucalyptus and pine forest plantations; the middle part where the study was carried out made up of: scrubland, natural regeneration forest and native forest; and the upper area made up of shrubby and herbaceous moorland.

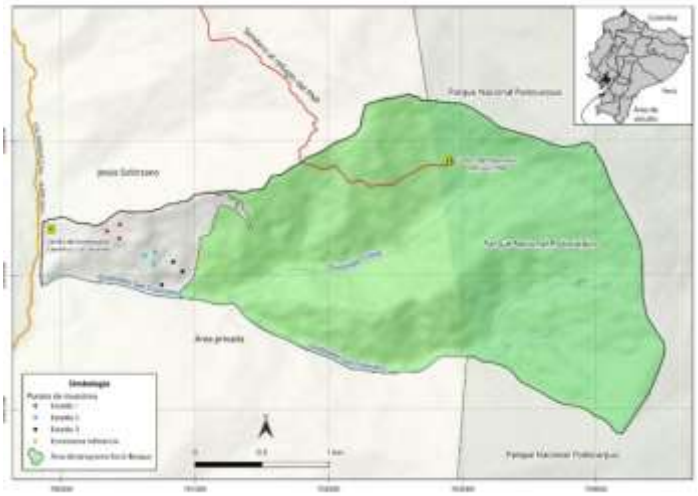

***Figure** 1. - Location of the sampling sites in the El Cristal Natural Reserve*

For the identification and selection of sampling areas, we had the support of key actors familiar with the history of land use of the El Cristal property, who provided the required information to identify three stages of succession in relation to the time of abandonment: E1- 10-20, E2- 20-30 and E3 30-40 years of abandonment, within the high Andean ecosystem; In addition, the reference ecosystem (ER) was selected.

In each area corresponding to a succession stage, three plots of 20 x 20 m (400 m^2) were randomly established with a distance of 100 m between them. Within each plot, five subplots of 5 x 5 m (25 m^2) were nested. At the same time, within these, a plot of 1 x 1 m (1 m^2) was established according to Aguirre (2019).

In each plot the following variables were recorded: in the 20 x 20 m plots, the height and diameter of the individuals with DBH equal to or greater than 5 cm (trunk category), which were numbered; In the 5 x 5 m plots, individuals greater than 1.50 m in height and less than or equal to 5 cm DAP were counted (latizal category) and in the 1 x 1 m subplots (Figure 2), regeneration individuals were counted up to 1.5 m high (sapling category) (Sáenz and Finegan, 2000).

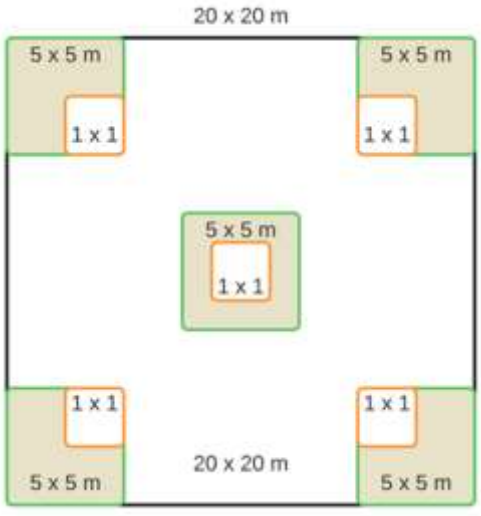

Figure 2. *- Model of the sampling units implemented in the El Cristal Natural Reserve*

Structure and composition

Table 1 presents the structural parameters and diversity indices used for the information analysis.

Table 1. *- Formulas for calculating structural parameters and diversity indices*

Parameter	Formula
Absolute abundance (A) # ind m^{-2}	$(A) = \frac{N°.\,total\ \ individuals\ per\ specie}{Total\ area\ sampled}$
Relative Abundance (RA) %	$(AR) = \frac{N°.\,of\ individuals\ per\ specie}{Total\ number\ of\ individuals} x\ 100$
Relative Frequency (Fr) %	$(Fr) = \frac{N°\ of\ plots\ where\ is\ the\ specie}{\sum\ of\ the\ frequencies\ of\ all\ the\ species}$
Relative Dominance (DmR) %	$(DmR) = \frac{Basal\ area\ of\ the\ specie}{Basal\ area\ of\ all\ species}\ x\ 100$
Importance Value Index (IVI) %	$(IVI)\% = \frac{DR+DmR+FR}{3}$
Shannon diversity index (H)	$H = \sum_{i-1}^{S}(Pi)(\log_n Pi)$
Pielou equity index (E)	$H = \frac{H'}{H\ max}$

Source: *Aguirre (2019)*

The values of the diversity indices were classified following the criteria of Aguirre (2019). For the Shannon Index: 0-1.35 low diversity; 1.36-3.5 average diversity; > 3.5 high diversity.

Pielou evenness index: 00.33 heterogeneous in abundance and low diversity; 0.340.66 slightly heterogeneous in abundance and average diversity; > 0.67 homogeneous in abundance and high diversity.

Comparison of the structure, floristic composition and diversity in three successional stages of vegetation in the El Cristal Natural Reserve

To determine the similarity between successional stages, the Sorensen index was calculated, which provides a quantitative measure of the similarity between the sampling sites in terms of diversity and floristic composition. A value of 1 indicates perfect similarity, meaning that

the sites share exactly the same species, while a value of 0 indicates complete dissimilarity, meaning that they do not share any species. To graph the similarity between stages, a dendrogram was made through the InfoStat software, which allowed the successional stages to be compared. Finally, to calculate the Sorensen similarity index, the following formula adapted by Aguirre (2019) was applied (Equation 1).

$$Ks = \frac{2c}{a+b} x\ 100 (1)$$

Where:

Ks Sorensen similarity index

a = Number of species in sample 1

b = Number of species in sample 2

c = Number of species in common

RESULTS

Floristic composition of the vegetation in the El Cristal Natural Reserve (RNEC)

The floristic composition of the tree component (Figure 3), in 4 800 m² was 26 families, 27 genera and 30 species, with 655 individuals. In the latizal category, an area of 1,500 m² was sampled where 23 botanical families, 25 genera and 27 species were recorded with 170 individuals reported; while in the sapling category (60 m²) 7 families, 7 genera and 8 species were recorded, with 45 individuals.

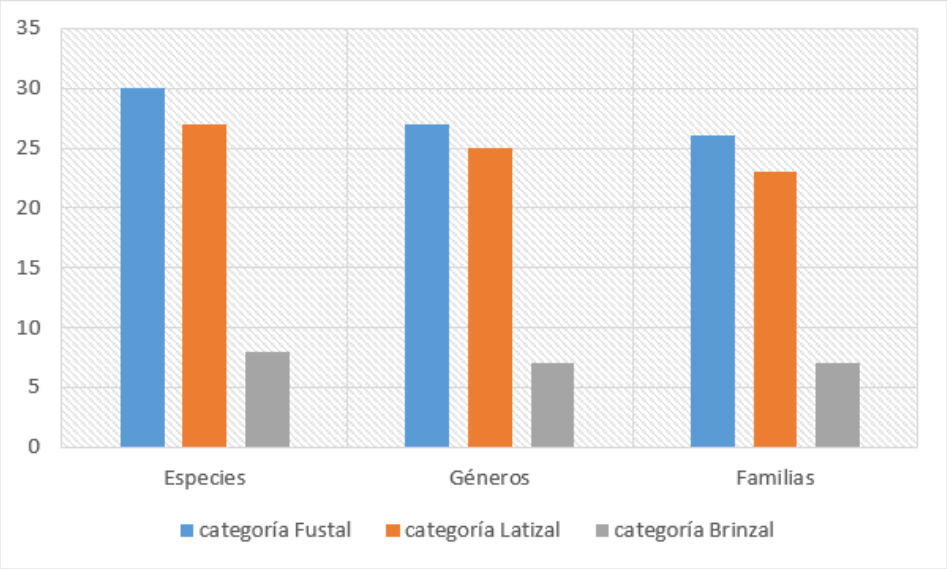

Figure 3. *- Floristic composition of the RNEC by regeneration category*

Table 2 details the floristic composition by successional stage in the RNEC, in the three recovery stages and in the reference ecosystem, where it is evident that the composition increases as the abandonment period increases.

Table 2. *- Floristic composition by successional stage in the RNEC*

	E1	**E2**	**E3**	**ER**
Species	14	15	20	26
Genus	12	14	19	24
Families	12	14	18	23
Individuals	162	149	298	261

Structural parameters of vegetation by successional stage in the El Cristal Natural Reserve

Stage 1: abandonment between 10 to 20 years

Table 3 shows the species with the highest IVI that are characteristic of the Andean Forest, therefore, they are abundant and frequent, and have established themselves in these

recovery spaces, becoming species of high ecological value to maintain. the internal balance of the forest.

Table 3. *- Index Value Importance of the species registered in stage one*

Species	**Relative abundance**	**Relative frequency**	**IVI $_{100}$**
Alnus acuminata Kunth	62.96	10.00	36.48
Frangula granulosa (Ruíz & Pav)	7.41	10.00	8.70
Heliocarpus americanus L.	7.41	10.00	8.70
Siparuna muricata (Ruiz & Pav .) A. DC.	4.94	10.00	7.47
Myrsine sodiroana (Mez) Pipoly	3.70	10.00	6.85
Oreopanax ecuadorensis Seem.	1.85	10.00	5.93
Verbesine cf. *arborea* Kunth	4.32	5.00	4.66
Verbesine arborea Kunth	1.85	5.00	3.43
Boehmeria caudata (Poir .) Bonpl .	1.23	5.00	3.12
Andean Myrsine (Mez) Pipoly	1.23	5.00	3.12
Viburnum triphyllum Benth.	1.23	5.00	3.12
Cinchona officinalis L.	0.62	5.00	2.81
Hedyosmum racemosum (Ruiz & Pav.) G. Don	0.62	5.00	2.81
Vismia baccifera (L.) Triana & Planch .	0.62	5.00	2.81
Total	**100**	**100**	**100**

Stage 2: abandonment between 20 and 30 years

The three species that presented the highest IVI in stage two were: *Myrsine sodiroana* , *Alnus acuminata* and *Viburnum triphyllum*, which are typical of successional ecosystems, were therefore recorded in the three regeneration categories and in the four sampling sites, while *Clusia latipes* , *Myrcianthes fragans* and *Verbesina* cf. *arborea* presented the lowest IVI, due to the low abundance and frequency recorded (Table 4).

Table 4. - *Importance Value Index (IVI) of the species registered in stage two*

Species	Relative abundance	Relative frequency	IVI $_{100}$
Myrsine sodiroana (Mez) Pipoly	28.19	12.00	20.09
Alnus Kunth *acuminata*	24.16	4.00	14.08
Viburnum triphyllum Benth.	13.42	12.00	12.71
Siparuna muricata (Ruiz & Pav) A. DC.	5.37	12.00	8.68
Frangula granulosa (Ruíz & Pav .)	7.38	8.00	7.69
Euphorbia laurifolia Juss. former Lam.	9.40	4.00	6.70
Boehmeria caudata (Poir) Bonpl.	2.68	8.00	5.34
Cupania cinerea Poepp.	2.01	8.00	5.01
Vismia baccifera (L.) Triana & Planch.	1.34	8.00	4.67
Aiouea dubia (Kunth) Mez	1.34	4.00	2.67
Andean Myrsine (Mez) Pipoly	1.34	4.00	2.67
Oreopanax rosei Harms	1.34	4.00	2.67
Clusia latipes Iron. & Triana	0.67	4.00	2.34
Myrcianthes fragrans (Sw.) McVaugh	0.67	4.00	2.34
Verbesina cf. Kunth *arborea*	0.67	4.00	2.34
Total	**100**	**100**	**100**

Stage 3: abandonment between 30 and 40 years-

In Table 5, the IVI of the species registered in stage 3 is presented, where 20 species were reported among the three regeneration categories, with 91 individuals registered and present in the three regeneration categories, *Myrsine sodiroana* presented the highest IVI, unlike the species *Boehmeria caudata, Casearia sylvestris, Cedrela montana , Cinchona officinalis, Clethra revoluta* and *Podocarpus oleifolius* that presented the lowest IVI, with only one individual registered.

Table 5. *- Importance Value Index of the species registered in stage three*

Species	**Relative abundance**	**Relative frequency**	**IVI $_{100}$**
Myrsine sodiroana (Mez) Pipoly	30.54	9.09	19.81
Siparuna muricata (Ruiz & Pav .) A. DC.	19.46	6.06	12.76
Myrcianthes fragrans (Sw .) McVaugh	11.07	6.06	8.57
Cupania cinerea Poepp .	6.71	9.09	7.90
Alnus Kunth *acuminata*	10.74	3.03	6.88
Frangula granulosa (Ruíz & Pav .)	4.03	9.09	6.56
Meliosma sp	6.38	6.06	6.22
Oreopanax ecuadorensis Seem.	2.01	6.06	4.04
Saurauia bullosa Wawra	1.34	6.06	3.70
Palicourea amethystina (Ruiz & Pav.) DC.	1.01	6.06	3.53
Clusia latipes Iron. & Triana	0.67	6.06	3.37
Andean Myrsine (Mez) Pipoly	2.68	3.03	2.86
Viburnum triphyllum Benth.	0.67	3.03	1.85
Weinmannia Kunth *phagaroids*	0.67	3.03	1.85
Boehmeria caudata (Poir .) Bonpl .	0.34	3.03	1.68
Casearia sylvestris Sw .	0.34	3.03	1.68
Cedrela montana Moritz ex Turcz .	0.34	3.03	1.68
Cinchona officinalis L.	0.34	3.03	1.68
Clethra revoluta (Ruiz & Pav.) Spreng .	0.34	3.03	1.68
Podocarpus oleifolius D. Don	0.34	3.03	1.68
Total	**100**	**100**	**100**

Reference ecosystem: forest in nearby area

Table 6 presents the IVI of the species registered in the reference ecosystem, which is part of the socio-forest conservation program. With 37 individuals registered in the three regeneration categories, *Myrsine sodiroana* was the species with the highest IVI followed by *Cupania cinerea* present in three categories with 23 individuals. The species with the lowest IVI were *Brunellia* sp., *Hedyosmum racemosum* and *Schfflera acuminata,* these species are generally found in recovered forests, being indicators of good ecological health.

Table 6. *- Index Value Importance of the species recorded in the reference ecosystem*

Species	**Relative abundance %**	**Relative frequency %**	**IVI $_{100}$**
Myrsine sodiroana (Mez) Pipoly	14,18	6.25	10.21
Cupania cinerea Poepp .	8.81	6.25	7.53
Frangula granulosa (Ruíz & Pav .)	7.28	6.25	6.76
Cinchona officinalis L.	6.13	6.25	6.19
Siparuna muricata (Ruiz & Pav .) A. DC.	5.75	6.25	6.00
Clusia latipes Iron . & Triana	6.51	4.17	5.34
Alnus acuminata Kunth	8.43	2.08	5.26
Oreopanax ecuadorensis Seem.	4.21	6.25	5.23
Myrcianthes fragrans (Sw) McVaugh	5.75	4.17	4.96
Andean Myrsine (Mez) Pipoly	5.75	4.17	4.96
Casearia sylvestris Sw .	5.36	4.17	4.77
Meliosma sp	4.21	4.17	4.19
Mauria heterophylla Kunth	3.07	4.17	3.62
Cedrela montana Moritz ex Turcz .	2.30	4.17	3.23
Clethra revoluta (Ruiz & Pav.) Spreng .	2.30	4.17	3.23
Saurauia bullosa Wawra	1.53	4.17	2.85
Viburnum triphyllum Benth .	1.15	4.17	2.66
Oreopanax rosei Harms	1.53	2.08	1.81
Heliocarpus americanus L.	1.15	2.08	1.62
Weinmannia glabra Lf	1.15	2.08	1.62

Inga sp	0.77	2.08	1.42
Miconia calvescens DC.	0.77	2.08	1.42
Nectandra sp	0.77	2.08	1.42
Brunellia sp	0.38	2.08	1.23
Hedyosmum racemosum (Ruiz & Pav.) G. Don	0.38	2.08	1.23
Schfflera acuminata (Pav .) Harms	0.38	2.08	1.23
Total	**100**	**100**	**100**

Diversity by successional stage of vegetation in the El Cristal Natural Reserve

The Shannon diversity index was 2.40 for individuals greater than 5 cm DBH in the four successional stages, classified as medium diversity. Regarding Pielou's evenness index in the four successional stages, it was 0.85, which means that the distribution of the species in the sampling is homogeneous in abundance (Table 7).

Table 7. - Shannon and *Pielou diversity indices by successional stage*

	E1	**E2**	**E3**	**E.R.**
Shannon	0.74	1.73	1.96	2.80
Pielou	0.33	0.77	0.81	0.92

Composition and floristic diversity of vegetation in three successional stages in the El Cristal Natural Reserve

The similarity analysis verifies that stage three is the most similar to the reference ecosystem, with a similarity value of 0.69 and 16 shared species. On the other hand, stage one presented less similarity with a value of 0.50. The results in Figure 4 show two floristically similar groups, where stage three resembles the reference ecosystem, this suggests that stage three shares a greater proportion of species and floristic characteristics with the reference ecosystem compared to stage one. These differences are probably due to the difference in the recovery time of these areas.

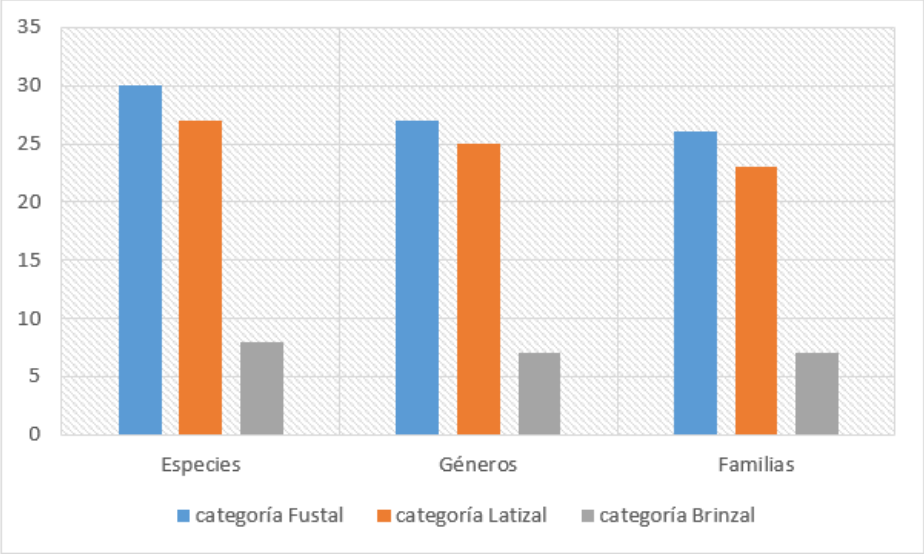

Figure 4 *- Dendrogram of similarity between successional stages studied in the El Cristal Natural Reserve.*

Composition and floristic diversity of the natural regeneration categories of the successional stages

Fustal category

Successional stages three and four, which corresponds to the ecosystem greater than 30 years of abandonment and the reference ecosystem, with a value of 0.63. And there is greater dissimilarity between stages one and three, which corresponds to the stage of 10 to 20 years of abandonment and stage three with a period of abandonment greater than 30 years (Table 8).

Natural regeneration in the forest category is mainly characterized by the presence of pioneer species, which tend to increase their density and frequency to establish themselves as a forest, in the initial stages of 10 to 20 years and 20 to 30 years (E1- E2).

Table 8. - *Sorensen similarity index in the stem category*

Stages	E1	E2	E3	ER
E1	-	0,50	0,27	0,29
E2	4	-	0,54	0,38
E3	3	7	-	0,63
ER	4	6	12	-

Note: *Above the diagonal the Sorensen index, below the number of species in common*

latizal category

Sorensen similarity indices of the latizal category (Table 9) show that there is greater similarity between stages three and four with 13 species in common, and stage one and three; two and four are the stages that present the greatest dissimilarity.

Table 9. - *Sorensen similarity index in the latizal category*

Stages	E1	E2	E3	ER
E1	-	0,55	0,40	0,50
E2	7	-	0,43	0,40
E3	6	6	-	0,73
ER	9	6	13	-

Sapling category

Table 10 shows the Sorensen similarity indices for the sapling category, which reflects greater similarity between stages three and four with a value of 0.80 (4 species in common), while there is greater difference between the stages one and two with 0.29 similarity. These differences are probably due to the low regeneration, but with the same behavior in the stem and latizal categories. In general, as time passes its diversity increases.

Table 10. *- Similarity index of the sapling category*

Stages	E1	E2	E3	ER
E1	-	0,29	0,67	0,50
E2	1	-	0,44	0,55
E3	2	2	-	0,80
ER	2	3	4	-

DISCUSSION

Floristic composition of the vegetation in the El Cristal Natural Reserve (RNEC)

The floristic composition of trees with DBH equal to or greater than 5 cm by successional stage in the El Cristal Natural Reserve was different from the results reported by Aguirre *et al.* (2022) who, in a study about the growth dynamics of forest species in the Andean forest of the "Francisco Vivar Castro" University Park, recorded 44 species, 38 genera and 29 botanical families ; Similar results were reported by Aguirre *et al.* (2023) who in a study in the Andean forest recorded 17 species in the sapling category and 21 in latizal. But these results differ from those reported by Ramírez (2023), who in a study of the structure and successional dynamics of the natural regeneration of the piedmont evergreen forest in Zamora-Chinchipe reported 125 species, 88 genera and 41 botanical families. This difference in the strata could be related to land use, since the RNEC ecosystem is an ecosystem in recovery, while the study of the "Francisco Vivar Castro" University Park was carried out under the canopy of forest plantations and Andean Forest.

Structural parameters of vegetation by successional stage in the RNEC

Stage 1: abandonment between 10 to 20 years

In stage 1, the *Alnus species predominated acuminata,* which was recorded in all sampling sites, this predominance is attributed to its capacity to adapt to the soil and climatic conditions of

the site, as well as the capacity for dispersal and competition for resources (Pacheco-Agudo and Quisbert-Guarachi, 2016).

Stage 2: abandonment between 20 and 30 years

In this ecosystem the species that stood out were: *Myrsine sodiroana* with 20.09%, *Alnus acuminata* with 14.08 % and *Viburnum triphyllum* with 12.71 %, which are species that reached the highest IVI in this ecosystem. In the case of *Myrsine sodiroana,* the high value of the IVI is probably attributed to its capacity for reproduction and seed production, which is twice a year (Aponte and Sanmartín, 2011).

Stage 3: abandonment between 30 and 40 years

The highest IVI in this successional phase is due to the dominance and frequency of the recorded species; this abundance is probably attributed to the ability of the species to adapt and reproduce in high Andean ecosystems (Aponte and Sanmartín, 2011); unlike species such as: *Boehmeria caudata, Casearia sylvestris, Cedrela montana*, *Cinchona officinalis, Clethra revoluta* and *Podocarpus oleifolius* that presented the lowest IVI, due to the low density and frequency recorded. The few records of these species are probably attributed to their phenological characteristics, since they are typical species of mature forests; Furthermore, they are species of high commercial value and that were probably exploited selectively (Yaguana *et al.*, 2010).

Reference ecosystem: forest in nearby area

The reference area, being a national conservation area, remains in a better stage of ecological health, where greater diversity was evident and species absent in the other stages under analysis were recorded. Meneses (2018) mentions that in general the reference ecosystems tend to be spaces without major anthropic intervention, where it is about maintaining the ecosystems in a natural or pristine stage.

Diversity by successional stage of vegetation in the El Cristal Natural Reserve

The data reflect a medium diversity for Shannon and for Pielou, it is a homogeneous ecosystem in abundance and with high diversity. These results differ from those reported by Aguirre *et al.* (2023), who reported Shannon index values of 3.99 (highly diverse) and 1.95 for Pielou , classifying it as a system homogeneous in abundance and with high diversity according to Aguirre (2019).

The information obtained shows the recovery of ecosystems over time. That is, the longer the period of abandonment, the diversity and floristic composition increases in each of the evaluated stages. This information is corroborated with the studies of Aguirre *et al.* (2019) and Aguirre *et al.* (2023), on natural succession under *Pinus radiata* and *Eucalyptus plantations globulus*, developed in Hoya de Loja, they affirm that the older the plantations or areas in recovery, the greater the diversity, as well as the abundance of some species.

Composition and floristic diversity of vegetation in three successional stages in the El Cristal Natural Reserve.

The results of similarity between successional stages in the RNEC express that, as the ecosystem progresses in its succession, the species composition tends to stabilize and converge towards a more heterogeneous stage characterized by the presence of a set of species adapted to the conditions of the established environment. These results differ from those reported by Ramírez (2023), who in his study of the structure and successional dynamics of the natural regeneration of the piedmont evergreen forest of Zamora-Chinchipe, staged that the floristic composition of the species of the total natural regeneration did not form floristically distinct groups.

Composition and floristic diversity of natural regeneration categories in successional stages

In general, the results regarding the floristic composition by category of natural regeneration show two groups: stage 1 and stage 2 form a group similar to each other, while stages 3 and 4 correspond to the ecosystem with a period of abandonment of between 30 to 40 years and to the reference ecosystem respectively, form the second similarity group. This

information is similar to the results presented by Ramírez (2023), who stages that with the passage of time the structure of the forest recovers. Similar results are presented by Armenteras and Vargas (2016) and Vargas (2011), who stage that an ecosystem recovers when there are no anthropogenic activities that affect the successional dynamics of the species.

On the other hand, stages 3 and 4 present dissimilarity, while stage 2 is dissimilar to the reference ecosystem (RE). This pattern is evident in each regeneration category. It is likely that this dissimilarity is due to the influence of environmental factors or the presence of anthropic disturbances, since the vegetation of a given area is due to the interaction of environmental factors, biological and phenological processes of a set of species that cohabit in a certain ecosystem (Fortanelli *et al.*, 2014).

The recovery of vegetation through natural succession processes is an important *in situ* restoration strategy, since the establishment of typical species and characteristics of these Andean ecosystems is observed, as the time of abandonment and recovery progresses. Thus, stage three shows a similarity of 0.69 with the reference ecosystem, sharing 16 species. This reflects the importance of time in the recovery process of a degraded ecosystem, evidencing the progressive convergence towards a more stable and diverse stage.

The results suggest that in the future ecosystems could be dominated by native trees, which would lead to the formation of forests with characteristics similar to those of the original native forests.

CONCLUSIONS

The stem category of stage three registers the highest number of individuals in natural regeneration (248 individuals of 16 species). These allow us to predict that in the future these ecosystems will be dominated by trees forming secondary forests.

There is a difference in the diversity, structure and floristic composition of the vegetation by successional stage, the early stages that correspond to areas with a recovery period of up to 20 years show a low diversity with dominance of *Alnus acuminata,* at all established sampling sites; while successional stages with abandonment periods of more than 30 years show an increase in diversity and floristic composition.

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Cristian Contento Yunga: preparation of the database, statistical analysis, financing of funds, preparation of tables and figures, writing of the original

Zhofre Huberto Aguirre Mendoza: conception of the idea, director of the research work, general advice, review and final version of the authorship.