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ORIGINAL RESEARCH ARTICLE

Time of tree diversity recomposition along plant succession in the forests of the Chanchamayo Valley, Junín, Peru

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ABSTRACT

A topic of current interest in forestry science concerns the regeneration of degraded forests and areas. Within this topic, an important aspect refers to the time that different forests take to recover their original levels of diversity and other characteristics that are key to resume their functioning as ecosystems. The present work focuses on the premontane rainforests of the central Peruvian rainforest, in the Chanchamayo valley, Junín, between 1,000 and 1,500 masl. A total of 19 Gentry Transects of 2 × 500 m, including all woody plants ≥2.5 cm diameter at breast height were established in areas of mature forests, and forests of different ages after clear-cutting without burning. Five forest ages were considered, 5–10, 20, 30, 40 and ≥50 years. The alpha-diversity and composition of the tree flora under each of these conditions was compared and analyzed. It was observed that, from 40 years of age, Fisher's alpha-diversity index becomes quite similar to that characterizing mature forests; from 30 years of age, the taxonomic composition by species reached a similarity of 69–73%, like those occurring in mature forests. The characteristic botanical families, genera and species at each of the ages were compared, specifying that as the age of the forest increases, there are fewer shared species with a high number of individuals. Early forests, up to 20 years of age, are characterized by the presence of Piperaceae; after 30 years of age, they are characterized by the Moraceae family.

Keywords: Premontane Forests; Secondary Forests; Forest Dynamics; Tree diversity; Gentry Transects

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1. Introduction

In recent years, work has been carried out to better understand the floristic composition of the central Peruvian rainforest and how it characterizes the different forest types existing in the area[1-3]. Currently, the initiative of establishing permanent plots under standard methodologies in tropical forest areas has opened the door to successive remeasurements over time, facilitating a vision of forest dynamics. Research teams such as the Amazonian Forest Inventory Network (RAINFOR) are currently leading works that cover geographically wide areas, allowing a better understanding of flora composition, taxa distribution patterns and forest dynamics.

In the Department of Junín, most of the floristic studies have been carried out in the Chanchamayo Province[4-9], but despite these efforts, this is still one of the Amazonian departments with the lowest levels of botanical collections and knowledge[10]. In addition, in Chanchamayo and surrounding areas, more than 80% of the territory has been deforested[11], a scenario generated by the conversion of protected land use and forest use to agriculture or cattle ranching.

Following RAINFOR methodologies[12], it has been possible to generate relevant information on the composition of the different forest types existing in the Chanchamayo valley, through the installation of Permanent Monitoring Plots that include the marking of trees with more than 10 cm diameter at breast height (DBH)[4,6,8,13]. These studies have allowed us to better understand the floristic structure and composition of montane and premontane forests as a function of their successional stage.

To date, studies conducted in the pre-montane rainforests of the Chanchamayo valley reveal that pioneer forests established from a burn are characterized by presenting in their initial stage woody species such as *Vernonanthura patens* (Kunth) H. Rob. Rob. (Asteraceae) and *Acalypha* spp. (Euphorbiaceae) among the most important; after 25 years, the composition tends to be dominated by species such as *Piper aduncum* L. and *Allophylus foribundus* (Poepp.) Radlk. (Sapindaceae)[14]. On the other hand, the late secondary forests present species such as *Trophis caucana* (Pittier) C.C. Berg (Moraceae), *Cupania cinerea* Poepp. (Sapindaceae), *Inga edulis* Mart. (Fabaceae) and *Mauria heterophylla* Kunth (Anacardiaceae)[15]. In primary forests, the most representative species with DBH <40 cm are *Batocarpus costaricensis* Standl. & L.O. Williams (Moraceae), *Inga cinnamomea* Spruce ex Benth. (Fabaceae) and *Trophis caucana* (Pittier) C.C. Berg (Moraceae), and with DBH >40 cm, *Clarisia racemosa* Ruiz & Pav. (Moraceae) and *Pseudolmedia laevis* (Ruiz & Pav.) J.F. Macbr. (Moraceae)[15].

Currently, in the Chanchamayo valley, most of the remaining primary forests, or those where anthropic intervention has been minimal, are located in areas with steep slopes and, therefore, difficult to access; while secondary forests, from areas previously dedicated to coffee and citrus cultivation, present a great variety of ages and cover a large part of the valley. Although the aforementioned studies are allowing us to understand the composition and structure of these forests, there are still many gaps in knowledge to be studied. Proof of this is that, in the last 30 years, other works with a taxonomic focus have generated the discovery of new endemic tree species for the central rainforest[17-19]. Likewise, very few studies have focused on knowing the diversity of woody plants smaller than 10 cm DBH[20,21], and even fewer, those that have analyzed the times of forest recomposition generated from anthropogenic disturbances[14].

There is a clear need for further research to provide more information on the stages of floristic recovery and tree diversity associated with different forest ages. Therefore, in this research the following objectives were proposed: (i) to document the floristic composition and tree diversity at different forest ages, (ii) to analyze the floristic similarities between the different forest ages, and (iii) to determine the recovery time of the premontane rainforests in the study area.

2. Materials and Methods

2.1 Scope of study

The study area is the premontane forest, between 1,000–1,500 masl, in the Chanchamayo valley, district of San Ramón, Junín, Peru; there are tropical rainforest areas of different ages where the sample units were established. The study area and the ecological classification by Holdridge life zones are shown in **Figure 1**. The central sampling area is located in the Instituto Regional de Desarrollo (IRD), Fundo La Génova, of the Universidad Nacional Agraria La Molina, which has areas of intact forest in its innermost parts, and a mosaic of forests of different ages in the outermost parts, towards the Chanchamayo River. It covers an area of 300 hm^2, of which approximately 40% is covered by premontane tropical rainforest and the rest by tropical crops, mainly citrus and pineapple.

2.2 Survey of sample units in forests of different ages.

The sample units used are the so-called Gentry Transects (TG), consisting of a 2 × 500 m evaluation grid along which all plants ≥2.5 cm DBH were recorded and collected. The TG were randomly established in humid forest areas of different ages within the Fundo Santa Rosa and the IRD Fundo La

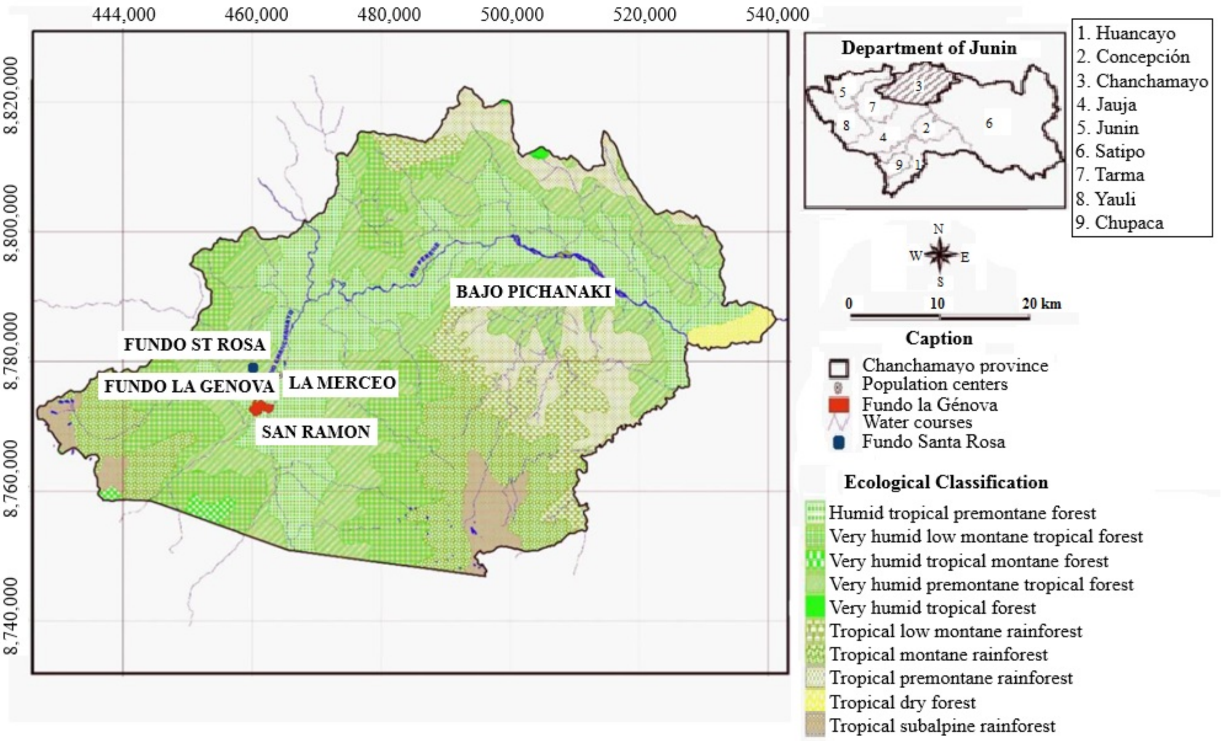

Figure 1. Stratification of the study area based on the Holdridge ecological classification system by life zones.

Table 1. Location of 0.1 ha Gentry Transects established at different approximate forest ages

Approximate ages	Transects	Coordinates			Altitude (masl)	Location
		Zone	East	South		
<10 years	T1	18 L	461463	8776420	1,150	Santa Rosa
	T2	18 L	461529	8776525	1,150	Santa Rosa
	T3	18 L	461419	8776802	1,150	Santa Rosa
	T4	18 L	461479	8776781	1,150	Santa Rosa
20 years	T5	18 L	460753	8773466	1,190	IRD La Génova
	T6	18 L	460870	8773519	1,170	IRD La Génova
	T7	18 L	460986	8773493	1,130	IRD La Génova
30 years	T8	18 L	460284	8773083	1,280	IRD La Génova
	T9	18 L	460367	8773166	1,240	IRD La Génova
	T10	18 L	460492	8773232	1,230	IRD La Génova
40 years	T11	18 L	460437	8773458	1,260	IRD La Génova
	T12	18 L	460465	8773384	1,230	IRD La Génova
	T13	18 L	460613	8773484	1,290	IRD La Génova
>50 years	T14	18 L	460823	8772416	1,116	IRD La Génova
	T15	18 L	460841	8772586	1,152	IRD La Génova
	T16	18 L	460881	8772617	1,136	IRD La Génova

Génova UNALM. The main source of information on the age of the forest areas studied was the reference of workers of the farms, several of whom have lived in the interior of the farm since their childhood. Mature forests were considered to be those areas that have not suffered human intervention in the last 50 years; and their state of maturity was also reflected in their flora assemblage. For forest areas of different ages along the plant succession, only those resulting from anthropogenic intervention without burning were considered (plant succession in forests generated from burning can be consulted in Echía *et al.*[14]). All plants included were collected, properly preserved and conditioned to be deposited in the Herbarium and identified by taxonomists. At least three TGs were collected for each approximate age of the forests in the field, for a total of 16 TGs. The codes of the collected TG, with indication of their position and corresponding ages, are shown in **Table 1**. The botanical specimens collected were deposited in the Herbarium of the Faculty of Forestry Sciences of the UNALM (collection of woody plants of the MOL Herbarium), where they were botanically determined by C. Reynel and R. Fernandez-Hilario.

Table 2. Diametric and altimetric classes established for the analysis of Alpha Diversity in the Gentry Transects

Classes		Intervals (cm)
Diametric	1	2.5–4.99
	2	5–9.99
	3	10–14.99
	4	15–19.99
	5	20–24.99
	6	25–29.99
	7	30–34.99
	8	35–39.99
	9	>40
Altimetric	1	1–4.99
	2	5–9.99
	3	10–14.99
	4	15–19.99
	5	20–24.99
	6	25–29.99
	7	>30

2.3 Analysis performed

2.3.1 Alpha diversity

Diameter classes of 5 cm were established to analyze the number of species (alpha diversity) recorded in each class. Likewise, for the altitudinal classes, 5 m classes were established (**Table 2**). The transects were analyzed as a whole for each of the ages studied.

2.3.2 Recomposition of alpha diversity (Dα) in forests of different ages

In the comparison of alpha diversity (number of species per unit area) between sample units of different ages, the absolute values of diversity in each case were taken into account, as well as the values obtained with Fisher's Alpha index, which corrects for the differences caused by different numbers of individuals in each Gentry Transect[22]. In tree diversity studies, this index shows a high stability with respect to sample size, since it depends on the number of individuals sampled[23,24]. Likewise, this index takes into account the positive effect that abundance has on diversity, allowing it to estimate the diversity of large geographic areas using samples from small areas and to compare sampling units[24,25]. Fisher's alpha index was calculated using Formula 1.

$$S = \alpha \ln[1 + {}^{N}/_{\alpha}]$$

Where:

α = Fisher's alpha index;

S = number of species in the sample;

N = number of individuals in the sample.

Fisher's alpha index was calculated with the PAST program, version 1.91[26].

2.3.3 Comparison of floristic composition in forests of different ages

The comparison was made by means of a similarity analysis using the Dice Index[27] and a cluster analysis. For both cases, the PAST program version 1.91 was used[26].

3. Results

3.1 Alpha diversity recomposition (Dα)

Regarding the recomposition of the Dα in forests of different ages (**Table 3**), it can be seen that the values of this parameter are very modest between the ages of <10 years, becoming considerably higher from the age range 20 years onwards. When the number of individuals recorded using Fisher's alpha diversity index is taken into consideration, it is also observed that from 40 years onwards there is a substantial recovery of the diversity of tree species present.

Observation of the data from the TGs collected shows that, in all cases, the first three diameter classes, 2.5–14.99 cm in diameter, register the highest abundances (**Table 4**). The values found suggest that, at the level of species and individuals, there is a great difference between pioneer forests (less than 10 years old) and forests older than 20 years. Also, in **Figure 2** it can be seen (except for the forest <10 years old) that the curves reflect an "inverted J" distribution where the largest number of individuals are found in the lower diameter classes. This indicates a clear tendency towards forest replenishment. With respect to the results obtained for the altitudinal classes (**Table 5**), we can see that both the greatest number of species and individuals are found in the second class (5–9.99 m), and although we would expect a "normal curve" trend in the altitudinal classes (**Figure 3**), this tends to the left, with the greatest number of individuals grouped in the first three classes.

Regarding the composition by families at different ages (**Table 6**), some interesting trends can be observed. It is only after the age of 40 that the Piperaceae family ceases to be a markedly abundant component in the forest. Similarly, after20 years of age, the Moraceae family begins to present a greater number of individuals, until it becomes the most important in mature forests (>50 years). With respect to diversity, in all forest ages the Fabaceae and Lauraceae families, in a fairly stable manner, present the greatest number of species, although the species are not necessarily the same at all ages. We also observed that in mature forests (>50 years), additional families appear that had not been recorded at previous ages (Connaraceae, Nyctagynaceae), and Annonaceae emerges as one of the most diverse families.

3.2 Fisher's alpha index

Although the highest number of individuals and species is recorded at the oldest forest ages (40 and >50 years), these do not necessarily represent the highest Fisher's alpha values. The maximum value is recorded for 40 years old forests. It is important to highlight that forests <10 years old present a high Fisher's alpha variability (5.78–14.66) and at least two of the corresponding transects show the lowest diversity of the entire evaluation (**Table 3**).

Table 3. Values of species, families and individuals in the different forest ages evaluated. Fisher's alpha is the average value found for the transects of each age

Approximate ages	Transects	Species		Families	Individuals		Fisher's Alpha	
<10 years	T1	11	48	19	33	188	5.78	10.2
	T2	16			29		14.66	
	T3	18			62		8.51	
	T4	22			64		11.85	
20 years	T5	58	95	32	491	1378	17.1	17.9
	T6	55			471		16.14	
	T7	63			416		20.64	
30 years	T8	56	87	28	601	1841	15.1	15.4
	T9	55			600		14.74	
	T10	60			640		16.21	
40 years	T11	80	108	33	683	1897	23.51	18.7
	T12	63			578		18	
	T13	56			636		14.8	
>50 years	T14	63	97	33	709	2002	16.7	18.4
	T15	75			684		21.48	
	T16	61			609		16.88	

Table 4. Number of species and individuals (in parentheses) by diameter class in the evaluated forest ages

Diameter class	<10 years	20 years	30 years	40 years	>50 years
1	24 (45)	63 (520)	68 (793)	82 (905)	71 (906)
2	31 (82)	68 (434)	59 (576)	71 (518)	59 (497)
3	14 (32)	39 (178)	46 (204)	48 (182)	39 (252)
4	9 (15)	34 (92)	27 (90)	33 (94)	42 (151)
5	3 (3)	19 (47)	21 (60)	30 (74)	26 (61)
6	4 (4)	12 (36)	15 (40)	17 (51)	25 (47)
7	2 (2)	10 (21)	16 (34)	12 (25)	20 (33)
8	2 (2)	4 (21)	4 (6)	7 (13)	14 (20)
9	3 (3)	5 (29)	11 (38)	15 (35)	10 (35)

Table 5. Number of species and individuals (in parentheses) by altitudinal class in the evaluated forest ages

Height class	<10 years	20 years	30 years	40 years	>50 years
1	16 (32)	50 (225)	51 (329)	55 (292)	46 (264)
2	35 (114)	77 (849)	72 (1 040)	85 (1 075)	71 (1 017)
3	13 (25)	37 (107)	51 (198)	48 (203)	39 (232)
4	7 (11)	29 (114)	33 (124)	47 (158)	37 (189)
5	4 (5)	13 (49)	13 (29)	25 (61)	33 (103)
6	1 (1)	5 (26)	15 (60)	23 (66)	30 (82)
7	0 (0)	1 (8)	12 (61)	13 (42)	29 (115)

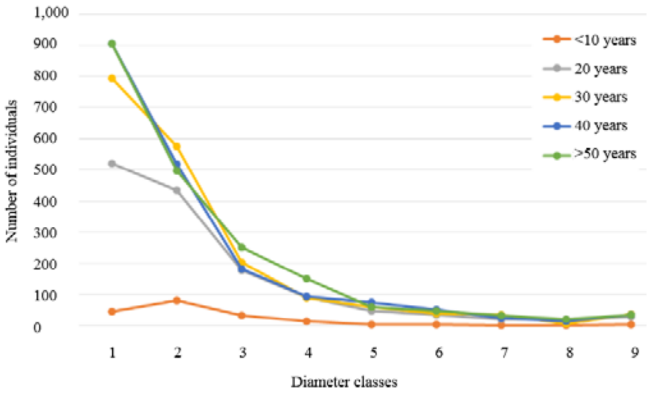

Figure 2. Diameter classes in the five forest ages evaluated.

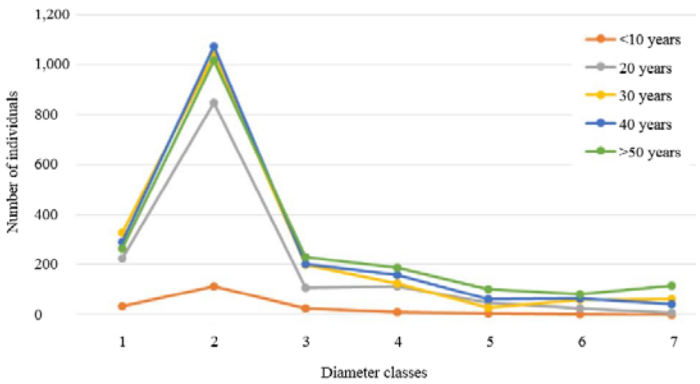

Figure 3. Altimetric classes in the five forest classes evaluated.

Table 6. The ten most diverse and abundant families for each forest age evaluated

N°	<10 years Family	Esp.	Family	Ind.	20 years Family	Esp.	Family	Ind.
1	Fabaceae	9	Fabaceae	31	Fabaceae	12	Piperaceae	303
2	Lauraceae	5	Lauraceae	25	Lauraceae	9	Urticaceae	230
3	Euphorbiaceae	4	Piperaceae	25	Melastomataceae	8	Moraceae	167
4	Solanaceae	4	Juglandaceae	24	Rubiaceae	7	Fabaceae	106
5	Malvaceae	3	Euphorbiaceae	20	Urticaceae	7	Euphorbiaceae	84
6	Piperaceae	3	Malvaceae	12	Euphorbiaceae	6	Melastomataceae	78
7	Urticaceae	3	Urticaceae	11	Moraceae	5	Arecaceae	69
8	Anacardiaceae	2	Rutaceae	8	Piperaceae	5	Rubiaceae	64
9	Melastomataceae	2	Myrtaceae	6	Malvaceae	4	Lauraceae	53
10	Moraceae	2	Anacardiaceae	5	Anacardiaceae	3	Malvaceae	53
N°	**30 years Family**	**Esp.**	**Family**	**Ind.**	**40 years Family**	**Esp.**	**Family**	**Ind.**
1	Fabaceae	11	Moraceae	360	Lauraceae	14	Moraceae	236
2	Lauraceae	10	Urticaceae	282	Fabaceae	11	Urticaceae	222
3	Urticaceae	9	Piperaceae	281	Piperaceae	9	Lauraceae	161
4	Moraceae	6	Fabaceae	275	Melastomataceae	8	Arecaceae	158
5	Malvaceae	5	Meliaceae	115	Urticaceae	8	Meliaceae	149
6	Melastomataceae	4	Lauraceae	106	Moraceae	7	Fabaceae	121
7	Meliaceae	4	Malvaceae	84	Malvaceae	5	Piperaceae	120
8	Myrtaceae	4	Myrtaceae	64	Arecaceae	4	Ochnaceae	101
9	Rutaceae	4	Arecaceae	55	Meliaceae	4	Rubiaceae	89
10	Arecaceae	3	Solanaceae	31	Rubiaceae	4	Myrtaceae	65
N°	**>50 years Family**	**Esp.**	**Family**	**Ind.**				
1	Lauraceae	12	Moraceae	633				
2	Fabaceae	9	Lauraceae	316				
3	Moraceae	8	Meliaceae	170				
4	Piperaceae	8	Nyctaginaceae	135				
5	Melastomataceae	7	Rubiaceae	87				
6	Urticaceae	6	Fabaceae	76				
7	Malvaceae	4	Urticaceae	64				
8	Annonaceae	3	Connaraceae	63				
9	Arecaceae	3	Piperaceae	60				
10	Euphorbiaceae	3	Myrtaceae	58				

(Esp. = Number of species; Ind. = Number of individuals).

3.3 Re-composition of the species assemblage (floristic composition)

The similarity analysis (Dice index; **Table 7**) reveals that the floristic composition of early ages (<10 years) is not very compatible with that of forests older than 20 years, with a similarity of less than 24%. The similarity of the species assemblages is noticeable in forests from 20 years and older, and very noticeable in forests 30 years and older, at which age 69–74% of the forest species are the same as at older ages. Forests between 30 and 40 years of age are quite similar to each other in that sense; and forests older than 50 years have a slightly different species assemblage.

The clustering analysis (**Figure 4**) shows that the <10 years old forest forms a solitary group, with only 20% similarity with the rest of the ages. on the other hand, the 30, 40 and >50 years old forests present a similarity of approximately 70%. Likewise, the two ages with the highest similarity (about 70%) are the 30 and 40-year-old forests. This suggests that, in the first stage, when the forest is a pioneer, there are very few species shared with mature forests, and only after 20 years of age do the species that characterize mature forests begin to proliferate.

Along the diagonal (from left to right and from top to bottom) is the number of species by forest age. Below the diagonal is the number of species in common among forest ages, and above is the Dice index. The minimum and maximum values recorded are highlighted in orange and green, respectively.

Table 7. Similarity between age groups according to the Dice Index.

Approximate ages	<10 years	20 years	30 years	40 years	>50 years
<10 years	48	0.238	0.222	0.192	0.152
20 years	17	95	0.659	0.640	0.594
30 years	15	60	87	0.738	0.685
40 years	15	65	72	108	0.693
>50 years	11	57	63	71	97

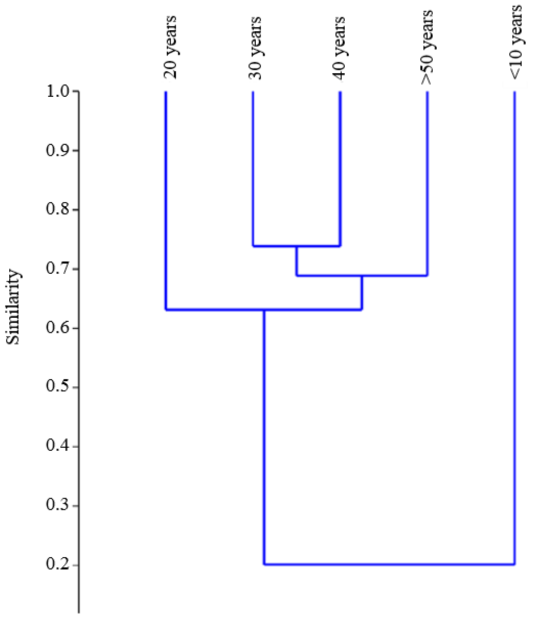

Figure 4. Dendrogram of similarity using the Dice Index for the forest ages evaluated.

Finally, we observed that few of the species shared between different ages show high abundance (**Table 8**). Most of the shared species present few individuals, the extreme case being the species in common between forests <10 years old and >50 years old, where only one presents more than 10 individuals at both ages. As the age of the forests increases, there are fewer shared species with a high number of individuals. Seven species with more than 50 individuals are shared in forests of 40 years and >50 years. From 20 years on, the species *Trophis caucana* is an abundant component in common with mature forests (>50 years).

4. Discussion

The premontane rainforests of the Amazon are one of the natural formations with the greatest anthropogenic impact and alteration in Peruvian territory. Productivity in montane forests is lower than in lowlands, consequently, recovery rates are relatively slower, in an environment marked by heterogeneity, where local factors such as landslides are common, and where species with divergent evolutionary histories interact[28]. An influential factor in the recomposition of tropical Andean forests is the edge effect of the surrounding vegetation[29].

Table 8. Species in common between mature forest (>50 years) and the other forest ages evaluated and based on a minimum number of individuals recorded

Approximate age of forest	**>50 years Species in common**				
	In total	**With >10 individuals at both ages**	**With >20 individuals at both ages**	**With >30 individuals at both ages**	**With >50 individuals at both ages**
<10 years	11	1	-	-	-
20 years	57	10	3	2	1 (*Trophis caucana*)
30 years	63	20	10	5	3 (*Myrcia splendens*; *Guarea guidonia*; *Trophis caucana*)
40 years	71	23	13	8	7 (*Prunus debilis*; *Ruagea glabra*; *Myrcia splendens*; *Ocotea cernua*; *Clarisia racemosa*; *Guarea guidonia*; *Trophis caucana*)

It has been postulated that a disturbed area embedded in a surrounding forest matrix with an intact structure and composition has significantly better chances of recovery than one surrounded by highly degraded forests[30]. To understand the recovery process of these forests, it is important to clarify the time it takes for them to recompose, from the point of view of their diversity and also of the species assemblages that characterize them. Based on such information it would be possible, for example, to find technical alternatives to shorten these times.

The data obtained show that, for secondary forests that have not been subjected to burning, the early stages of vegetation, also known as pioneers (up to 10 years of age), are very different in species abundance and diversity compared to the corresponding mature forests, containing considerably less diversity. In contrast to lowland Amazon forests, where at 20 years there is a recovery of 80% of species richness[31], the most important moments in the recomposition of these forests are shown above all from 30 years of age, time in which a similarity close to 70% with mature forests is reached. An open question for future research is what properties are achieved at these ages that allow the rapid recovery of diversity and species assemblage characteristic of mature forest formations. The rate of recovery could be limited by soil fertility and soil type[30]; in this sense, speculatively, it could be assumed that important properties related to soil fertility and carrying capacity, as well as the increase of biotic interveners such as seed dispersers, and the microclimate produced in the forest, could show substantial changes from these times onwards.

On the other hand, in the case of the premontane rainforest studied, the presence of some taxa could be interpreted as an indicator of the age and state of recovery of the forest; Piperaceae is a family characteristically present at early ages, remaining abundant until 30–40 years old, represented mainly by the species *Piper aduncum*; *Moraceae*, represented by the species *Trophis caucana*, is perceived as a family indicator of the mature condition of the forest in the studied forest. This coincides with the observations of Gentry & Ortiz[32]. If we compare these data with those obtained in forests regenerating after burning[14], we observe that in the latter the recovery is apparently slower. Considering the age range between 25–30 years, in the latter 57% of the diversity is recovered in that period, vs. 69–74% in forests that have not been subjected to burning, analyzed in the present study.

5. Conclusions

The floristic composition at different ages in the premontane moist forests studied is recognizable; additionally, the presence and abundance of some taxa can be interpreted as an indicator of the age and state of recovery of the forest; for example, early secondary forests, up to 20 years old, are characterized by the abundance of the Piperaceae family, with *Piper aduncum* as the most abundant species, while mature forests, after 30 years of age, are characterized by the Moraceae family, with the species *Trophis caucana*.

From the point of view of their diversity and flora assemblage, early forests, less than 20 years old, are significantly less diverse and differentiated in their floristic composition with forests older than 30 years (less than 24% similarity); after this age, species diversity increases significantly.

In the humid premontane forests of the study area, the most important moments in the recomposition of diversity and species assemblage occur after 20 years of age, and especially after 30 years of age, at which time a similarity of nearly 70% is reached with the composition of the flora of mature forests.

Conflict of interest

The authors declare that they have no conflict of interest

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