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Original article

Succession of woody plant species under the *Eucalyptus globulus* Labill plantation, on Loja valley, Ecuador

Sucesión de especies vegetales leñosas bajo una plantación de *Eucalyptus globulus* Labill., en la hoya de Loja, Ecuador

Sucessão de espécies de plantas lenhosas sob uma plantação de *Eucalyptus globulus* Labill., na Hoya de Loja, Equador

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ABSTRACT

Ecosystem dynamics is based on successional processes that occur after anthropic and natural disturbances. The succession of native woody plant species was studied under a plantation of *Eucalyptus globulus* in Loja, Ecuador; with the objective of determining the floristic composition and monitoring natural regeneration. Five permanent plots of 20 m x 20 m were established to investigate latizales, five subplots of 5 m x 5 m were nested for saplings and five subplots of 1 m x 1 m for seedlings. Height and basal diameter were



measured at the beginning of the experiment and at 12 months. Floristic composition and structural parameters were determined at the first sampling time; with the data from the second measurement, survival and growth were evaluated. The influence of the environmental variables: soil depth, slope and luminosity on the floristic diversity and abundance of natural regeneration were analyzed. Twenty-eight species within 24 genera and 21 families were recorded. The abundant species with the highest IVI are: *Solanum aphyodendron* (seedlings), *Miconia obscura* (sapling) and *Viburnum triphyllum* (latizal). Seedlings have a higher survival rate (100 %) and saplings have a lower survival rate (88.55 %). *Viburnum triphyllum* (seedlings), *Verbesina arborea* (saplings) and *Inga acreana* (grassland) showed the highest growth in height. Basal diameter is dominated by *Solanum aphyodendron* (seedlings), *Alnus acuminata* (saplings) and *Critoniopsis pycnantha* (latizal). The floristic diversity present in the latizales correlates with the environmental variables, in the seedlings and saplings there is no significant relationship.

Keywords: Successional dynamics; Natural regeneration; Floristic diversity; Environmental variables; Forest plantation.

RESUMEN

La dinámica de los ecosistemas se basa en los procesos sucesionales que se dan luego de alteraciones antrópicas y naturales. Se estudió la sucesión de especies vegetales leñosas nativas bajo una plantación de *Eucalyptus globulus* en Loja, Ecuador; con el objetivo de determinar la composición florística y monitorear la regeneración natural. Se establecieron cinco parcelas permanentes de 20 m x 20 m para investigar latizales, se anidaron cinco subparcelas de 5 m x 5 m para brinzales y cinco subparcelas de 1 m x 1 m para plántulas. Se midió altura y diámetro basal al inicio del experimento y a los 12 meses. Se determinó la composición florística y parámetros estructurales en el primer momento de muestreo; con los datos de la segunda medición se evaluó la sobrevivencia y crecimiento. Se analizó la influencia de las variables ambientales: profundidad del suelo, pendiente y luminosidad sobre la diversidad florística y abundancia de la regeneración natural. Se registraron 28 especies dentro de 24 géneros y 21 familias. Las especies abundantes y con mayor IVI son: *Solanum aphyodendron* (plántulas), *Miconia obscura* (brinzal) y *Viburnum triphyllum* (latizal). Las plántulas tienen mayor sobrevivencia (100 %) y los brinzales menor sobrevivencia (88,55 %). El mayor crecimiento en altura presenta *Viburnum triphyllum* (plántulas), *Verbesina arborea* (brinzal) e *Inga acreana* (latizal). En diámetro basal domina *Solanum aphyodendron* (plántulas), *Alnus acuminata* (brinzal) y *Critoniopsis pycnantha* (latizal). La diversidad florística presente en los latizales se correlaciona con las variables ambientales, en las plántulas y brinzales no se evidencia relación significativa.

Palabras clave: Dinámica sucesional; Regeneración natural; Diversidad florística; Variables ambientales; Plantación forestal.

RESUMO

A dinâmica dos ecossistemas é baseada em processos sucessionais que ocorrem após distúrbios antropogênicos e naturais. Estudamos a sucessão de espécies de plantas lenhosas nativas sob uma plantação de *Eucalyptus globulus* em Loja, Equador, com o objetivo de determinar a composição florística e monitorar a regeneração natural. Cinco parcelas permanentes de 20 m x 20 m foram estabelecidas para investigar latizales, 5



subquadrantes de 5 m x 5 m foram aninhados para mudas e 5 subquadrantes de 1 m x 1 m para mudas. A altura e o diâmetro basal foram medidos no início da experiência e após 12 meses. A composição florística e os parâmetros estruturais foram determinados na primeira amostragem; com os dados da segunda medição, a sobrevivência e o crescimento foram avaliados. Foi analisada a influência das variáveis ambientais: profundidade do solo, inclinação e luminosidade na diversidade florística e abundância da regeneração natural. Vinte e oito espécies dentro de 24 gêneros e 21 famílias foram registradas. As espécies abundantes com a IVI mais alta são: *Solanum aphyodendron* (plântulas), *Miconia obscura* (brinjal) e *Viburnum triphyllum* (latizal). As mudas têm maior sobrevivência (100 %) e os brinzais têm menor sobrevivência (88,55 %). *Viburnum triphyllum* (plântulas), *Verbesina arborea* (brinjal) e *Inga acreana* (latizal) apresentaram o maior crescimento em altura. O diâmetro basal é dominado por *Solanum aphyodendron* (plântulas), *Alnus acuminata* (brinjal) e *Critoniopsis pycnantha* (latizal). A diversidade florística presente nos latizales se correlaciona com as variáveis ambientais, nas mudas e nas plântulas não há relação significativa.

Palavras-chave: Dinâmica sucessória; Regeneração natural; Diversidade florística; Variáveis ambientais; Plantação florestal.

INTRODUCTION

In the last 50 years, natural ecosystems have been transformed, which has caused strong pressures on the biological attributes that characterize these ecosystems, such as diversity, floristic composition, density and growth of forest stands. This destructive process is occurring in all of Ecuador's ecosystems, caused by land use conversion, deforestation, overexploitation of resources, forest fires, infrastructure works and mining (Aguirre and Weber 2008).

The Andean forest in Ecuador is considered one of the most diverse and complex biological systems in the biosphere; it is also of great value to humanity because it provides goods and services that meet the needs of the societies that live there, such as fruit, wood, firewood, fiber, medicines, climate regulation and water (Tobón 2009; Young 2006; Beck *et al.*, 2008).

The dynamics of Andean ecosystems are based on aspects such as species growth and survival, successional processes that occur after anthropogenic disturbances and their phenological response to exogenous factors (Aguirre *et al.*, 2014). Likewise, understanding the dynamics of a forest and its species involves knowledge of attributes including tree growth and population dynamics, which depend on both environmental factors and species characteristics. Evenly, tree growth rates vary across environmental gradients, which are critical to understanding the problem of species distribution and abundance (Smith and Smith 2007).

The study of successional dynamics is based on the description of the structure and composition of a given forest area and the analysis of the changes it undergoes over time (Aguirre *et al.*, 2014). In addition, it is the only method that allows direct knowledge of the recruitment and mortality rates of each species and the net changes in the structure and composition of a forest during the study period.



With respect to planted forests in the southern region of Ecuador, it has been shown that diverse native plant species are established under these ecosystems (Aguirre *et al.* 2016). However, little is known about the growth rates and survival rates of these understory species in these ecosystems. On the other hand, the scarce information available on such species is scattered and not very accessible as scientific knowledge (MAE and FAO 2014).

Given this scarcity of information, it is necessary to develop research on successional dynamics in areas that have been altered by the establishment of plantations with exotic species, intensive agriculture and those that have been abandoned after productive processes. This information would provide knowledge for the planning of projects with the use of appropriate species to ensure the sustainability of forest production.

Under this context and with the purpose of generating scientific information on the successional dynamics under *Eucalyptus* plantations in the Andes of Ecuador, especially in the southern region, this research was carried out; which allowed to identify and know aspects of the successional dynamics of native woody plant species of the understory of a plantation of *Eucalyptus globulus* established in the University Park "Francisco Vivar Castro" in the province of Loja, Ecuador. The objective of this study was to determine the floristic composition of the natural succession and the growth in diameter and height of the woody plant species under the plantation of *Eucalyptus globulus* Labill to generate bases for the management of these ecosystems.

MATERIALS AND METHODS

Study area

The research was carried out in a plantation of *Eucalyptus globulus* Labill (7.50 ha) located in the University Park "Francisco Vivar Castro" (PUFVC), property of the National University of Loja (Figure 1), located in the parish of San Sebastian, canton Loja, Loja province. Located in an altitudinal range of 2 130 - 2 520 m a.s.l., it has an area of 99.13 ha, between UTM coordinates: 700 592 - 9 554 223 N, 700 970 - 9 553 139 S, 701 309 - 9 553 171 E and 699 961 - 9 554 049 W (Aguirre *et al.*, 2016).

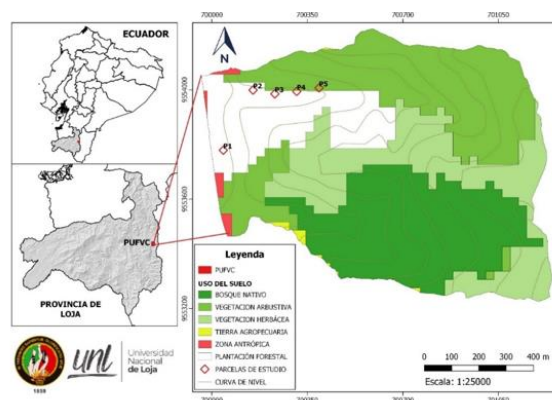


Figure 1. - Location of the study area within the University Park "Francisco Vivar Castro" in the province of Loja, Ecuador.



Sampling unit and recording of natural regeneration

Five permanent plots of 20 m x 20 m (400 m²) were installed under the *Eucalyptus globulus* plantation, systematically separated 100 meters from each other. For the study of natural regeneration, the categories proposed by Orozco and Brumer (2002) were used, which are: Seedlings: individuals ≤ 30 cm height; Saplings: individuals > to 30 cm and ≤ 1.50 m height; Latizal: individuals > to 1.50 m height and ≤ to 10 cm diameter.

The recording of latizales was done in permanent plots of 20 m x 20 m, in each of these plots five subplots of 5 m x 5 m (25 m²) were nested for saplings; and, within each subplot (25 m²) a subplot of 1 m² was nested to count seedlings (Figure 2). The height and basal diameter of each individual in the natural regeneration categories were measured at two sampling times: August 2019 and August 2020.

Each individual within each plot was labeled with a yellow plastic plate, in order to monitor the survival and growth of the species, following the methodology suggested by Aguirre (2019).

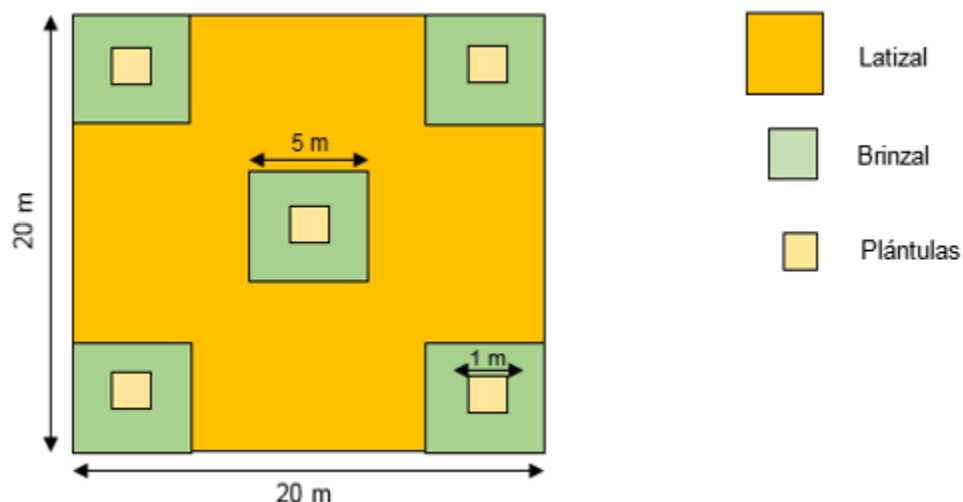


Figure 2. - Design of the permanent sampling plots and subplots for the study of natural regeneration under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

Data analysis

With the initial sampling data, floristic diversity and composition were determined for each category of natural regeneration and a t-test was performed to see differences in the floristic composition of the categories of natural regeneration. In addition, the structural parameters of the vegetation were calculated: relative density, relative frequency and importance value index. For the second moment, the survival of each of the species recorded at the end of the study period (nine months) was estimated. In addition, for each species, within each permanent plot, growth in height and growth in diameter were calculated. These analyses for each species were obtained for each



category of natural regeneration. For the calculations, the formulas suggested by Aguirre (2019) were applied (Table 1).

Table 1. - Formulas for obtaining the parameters for succession analysis under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

Parameter	Formula
Relative density (%)	$DR = \left(\frac{\text{Number of individuals per species}}{\text{Total Number of individuals}} \right) * 100$
Relative frequency (%)	$FR = \left(\frac{\text{Number of plots containing the species}}{\text{Add of the frequency of all species}} \right) * 100$
Value index of simplified importance (%)	$IVI = \frac{DR + FR}{2}$
Survival (%)	$Survival = \left(\frac{N^{\circ} \text{ of alive individuals at the end of the period}}{N^{\circ} \text{ of alive individuals at the beginning of the period}} \right) * 100$
Growth in height (m)	$CrH = Hf - Hi$
Growth in diameter (cm)	$Crd = df - di$

Influence of environmental variables on natural regeneration

Three environmental variables were recorded in the area under the *eucalyptus* plantation in order to evaluate their relationship with the abundance and floristic diversity of the natural regeneration in each of the categories. Brightness was measured using hemispheric photographs of the canopy to determine the percentage of light entering the understory of the *eucalyptus* plantation; a Canon SX 30 IS camera was used with the 180° fisheye mode, which helps to obtain a better enhancement of the photographs. The slope using a clinometer taking the measurement in percentage (%), the data were recorded for each permanent plot. And the soil depth (O horizon) was measured with a tape measure in each subplot, in order to calculate an average value for each permanent plot. With the collected data, Pearson correlation analysis and principal component analysis (PCA) were performed with the statistical program InfoStat and R, separately for each of the regeneration categories to see the influence of the variables on the floristic composition and abundance.

RESULTS

Floristic composition of the natural regeneration by category

Twenty-eight species were recorded within 24 genera and 21 families, of which 15 are trees and 13 are shrubs (Annex 1). From the sampling under the *Eucalyptus globulus* plantation, 434 individuals of natural regeneration were recorded. The grassland category has the largest number of individuals (294) belonging to 25 species, the sapling category has 131 individuals of 18 species and seedlings have 9 individuals within four



species. The representative species in the latizal category are *Viburnum triphyllum*, *Alnus acuminata* and *Miconia obscura*; in the saplings category are *Miconia obscura* and *Viburnum triphyllum*, while *Solanum aphyodendron* in the seedling category (Table 2). The t-student test determined that the three categories of natural regeneration are statistically equal; no significant differences were evident in terms of floristic composition (Table 3).

Table 2. - Number of individuals per species and category of natural regeneration that regenerate under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

Species	Family	Category of natural regeneration		
		Latizal	Saplings	Seedlings
<i>Alnus acuminata</i> Kunth	Betulaveae	27	8	0
<i>Clethra fimbriata</i> Kunth	Cletraceae	1	1	0
<i>Clusia latipes</i> Planch. & Triana	Clusiaceae	4	2	0
<i>Critoniopsis pycnantha</i> (Benth.) H. Rob.	Asteraceae	1	0	0
<i>Delostoma integrifolium</i> D. Don	Bignoniaceae	1	0	0
<i>Frangula granulosa</i> (Ruiz & Pav.) Grubov	Rhamnaceae	4	2	0
<i>Hesperomeles obtusifolia</i> (Pers.) Lindl.	Rosaceae	2	0	0
<i>Inga acreana</i> Harms	Fabaceae	3	0	0
<i>Mauria heterophylla</i> Kunth	Anacardiaceae	1	0	0
<i>Miconia lutescens</i> (Bonpl.) DC.	Melastomataceae	5	0	0
<i>Miconia obscura</i> (Bonpl.) Naudin	Melastomataceae	27	29	0
<i>Morus insignis</i> Bureau	Moraceae	2	0	0
<i>Myrsine andina</i> (Mez) Pipoly	Primulaceae	11	3	0
<i>Myrsine sodiroana</i> (Mez) Pipoly	Primulaceae	4	4	0
<i>Oreopanax rosei</i> Harms	Araliaceae	1	15	1
<i>Palicourea amethystina</i> (Ruiz & Pav.) DC.		0	1	0
<i>Palicourea</i> sp.	Rubiaceae	0	1	0
<i>Piper barbatum</i> Kunth	Piperaceae	26	16	2
<i>Prunus opaca</i> (Benth.) Walp.	Rosaceae	3	8	0
<i>Roupala monosperma</i> (Ruiz & Pav.) I.M. Johnst.	Proteaceae	2	0	0
<i>Saurauia bullosa</i> Wawra	Actinidaceae	0	2	0
<i>Siparuna muricata</i> (Ruiz & Pav.) A. DC.	Actinidaceae	2	2	0
<i>Solanum aphyodendron</i> S. Knapp	Solanaceae	16	10	4



<i>Solanum cutervanum</i> Zahlbr.	Solanaceae	8	1	0
<i>Tibouchina lepidota</i> (Bonpl.) Baill.	Melastomataceae	2	0	0
<i>Tournefortia fuliginosa</i> Kunth	Boraginaceae	2	0	0
<i>Verbesina arborea</i> Kunth	Asteraceae	23	6	0
<i>Viburnum triphyllum</i> Benth.	Adoxaceae	116	20	2
Total		294	131	9

Table 3. - Student's T-test for independent samples of the floristic composition of the natural regeneration under the plantation of *Eucalyptus globulus* of the University Park "Francisco Vivar Castro", Loja, Ecuador

Variable	Comparison(1) vs (2)		n (1)	n (2)	Media (1)	Media (2)	T	p	test
Floristic Composition	Sapling Latizal	vs	18	25	7,28	11,76	-0,89	0,3821	Bilateral
	Sapling Seedlings	vs	18	4	7,28	2,25	2,54	0,0195	Bilateral
	Latizal Seedlings	vs	25	4	11,76	2,25	2,01	0,0560	Bilateral

Structural parameters of natural regeneration

In the seedling category, the abundant species with the highest IVI is *Solanum aphyodendron*; the frequent species are *Solanum aphyodendron* and *Viburnum triphyllum* (Table 4).

Table 4. - Structural parameters of the seedling regeneration category under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

Species	Family	D Ind. ha ⁻¹	DR (%)	F	FR (%)	IVI (%)
<i>Solanum aphyodendron</i> S. Knapp	Solanaceae	20	44,44	2	33,33	38,89
<i>Viburnum triphyllum</i> Benth.	Adoxaceae	10	22,22	2	33,33	27,78
<i>Piper barbatum</i> Kunth	Piperaceae	10	22,22	1	16,67	19,44
<i>Oreopanax rosei</i> Harms	Araliaceae	5	11,11	1	16,67	13,89
Total		45	100,00	6	100,00	100,00

Density (D); Relative density (RD); Frequency (F); Relative frequency (FR); Importance value index (IVI).



Table 5 shows the structural parameters of the 10 main species of the sapling category under *Eucalyptus globulus* plantation, based on the highest importance value index (IVI). The species with the highest IVI are *Miconia obscura*, *Viburnum triphyllum* and *Oreopanax rosei* (Table 5).

Table 5. - Structural parameters of the sapling regeneration category under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

Species	Family	D Ind ha ⁻¹	DR (%)	F	FR (%)	IVI (%)
<i>Miconia obscura</i> (Bonpl.) Naudin	Melastomataceae	145	22,14	4	9,76	15,95
<i>Viburnum triphyllum</i> Benth.	Adoxaceae	100	15,27	4	9,76	12,51
<i>Oreopanax rosei</i> Harms	Araliaceae	75	11,45	5	12,20	11,82
<i>Piper barbatum</i> Kunth	Piperaceae	80	12,21	3	7,32	9,77
<i>Myrsine sodiroana</i> (Mez) Pipoly	Primulaceae	20	3,05	4	9,76	6,40
<i>Solanum aphyodendron</i> S. Knapp	Solanaceae	50	7,63	2	4,88	6,26
<i>Alnus acuminata</i> Kunth	Betulaceae	40	6,11	2	4,88	5,49
<i>Prunus opaca</i> (Benth.) Walp.	Rosaceae	40	6,11	2	4,88	5,49
<i>Myrsine andina</i> (Mez) Pipoly	Primulaceae	15	2,29	3	7,32	4,80
<i>Verbesina arborea</i> Kunth	Asteraceae	30	4,58	2	4,88	4,73

Density (D); Relative density (RD); Frequency (F); Relative frequency (FR); Importance value index (IVI).

Table 6 shows the structural parameters of the 10 main species of the latizal category under the *Eucalyptus globulus* plantation, based on the highest importance value index (IVI). The species with the highest IVI are: *Viburnum triphyllum*, *Piper barbatum* and *Verbesina arborea* (Table 6).

Table 6. - Structural parameters of the latizal regeneration category under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

Species	Family	D Ind. ha ⁻¹	DR (%)	F	FR (%)	IVI (%)
<i>Viburnum triphyllum</i> Benth.	Adoxaceae	580	39,46	5	8,62	24,04
<i>Piper barbatum</i> Kunth	Piperaceae	130	8,84	5	8,62	8,73
<i>Verbesina arborea</i> Kunth	Asteraceae	115	7,82	5	8,62	8,22
<i>Miconia obscura</i> (Bonpl.) Naudin	Melastomataceae	135	9,18	4	6,90	8,04
<i>Alnus acuminata</i> Kunth	Betulaceae	135	9,18	3	5,17	7,18
<i>Solanum aphyodendron</i> S. Knapp	Solanaceae	80	5,44	4	6,90	6,17



<i>Myrsine andina</i> (Mez) Pipoly	Primulaceae	55	3,74	4	6,90	5,32
<i>Frangula granulosa</i> (Ruiz & Pav.) Grubov	Rhamnaceae	20	1,36	3	5,17	3,27
<i>Solanum cutervanum</i> Zahlbr.	Solanaceae	40	2,72	2	3,45	3,08
<i>Miconia lutescens</i> (Bonpl.) DC.	Melastomataceae	25	1,70	2	3,45	2,57

Density (D); Relative density (RD); Frequency (F); Relative frequency (FR); Importance value index (IVI).

Survival of natural regeneration

Under the *Eucalyptus globulus* plantation, the overall survival of the natural regeneration was 91.94 %, corresponding to 399 individuals. In turn, the seedling category registered 100 % survival, followed by the sapling category with 93.20 %, and the sapling category with 88.55 % (Figure 3).

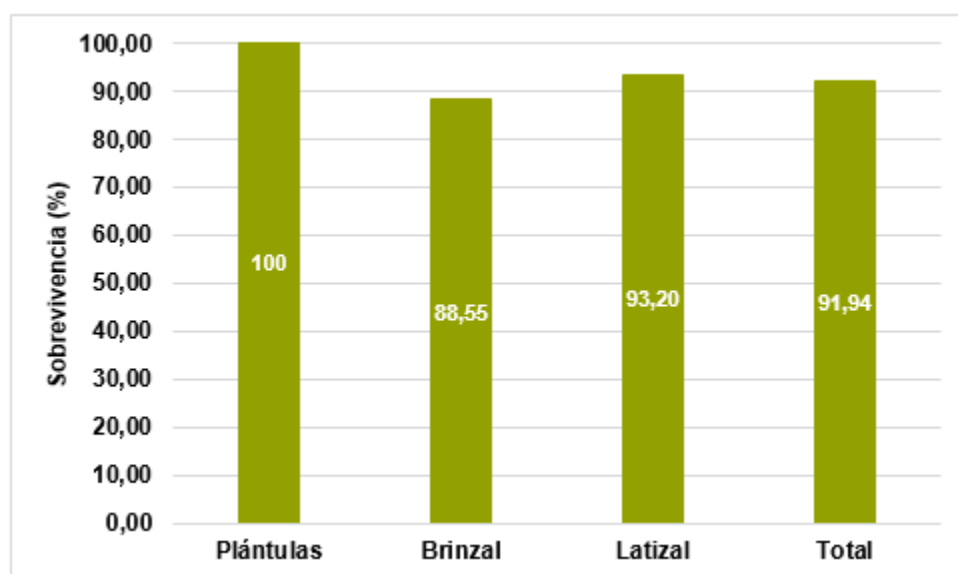


Figure 3. - Survival of natural regeneration under the *Eucalyptus globulus* plantation in the "Francisco Vivar Castro" University Park, Loja, Ecuador

Growth of natural regeneration

Figure 4 shows the average growth in height and diameter of the natural regeneration under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro" (Figure 4).



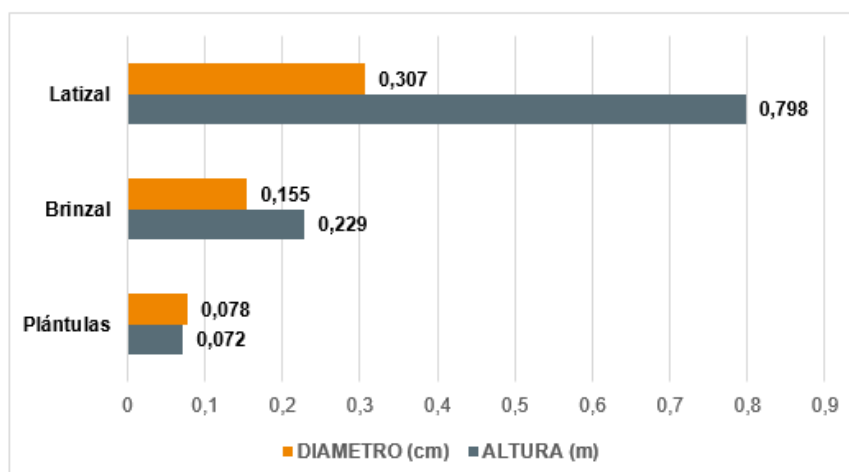


Figure 4. - Growth of the natural regeneration under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

The species with the highest average height growth are *Viburnum triphyllum* (seedlings), *Verbesina cf. arborea* and *Alnus acuminata* (sapling); *Inga acreana*, *Morus insignis* and *Critoniopsis pycnantha* (latizal); while the species with the highest average growth in diameter are *Solanum aphyodendron* (seedlings); *Alnus acuminata*, *Verbesina cf. arborea* and *Clethra fimbriata* (sapling); *Critoniopsis pycnantha*, *Tournefortia fuliginosa* and *Morus insignis* (latizal).

Influence of environmental variables

Regarding the correlation analysis ($\alpha = 0.05$) between environmental variables and natural regeneration, considering the number of individuals and species; in the seedling category, positive and negative trend relationships were determined (Table 7).

According to the principal component analysis, in the seedling category, a strong correlation was found between slope and lightness ($r = 0.68$, $P = 0,00017$), while soil depth had no relationship with lightness ($r = 0,0023$, $P = 0.99$). The soil depth variable grouped the majority of seedlings. The numbers of individuals and species are reflected to a greater degree in dimension 2 and have no significant relationship with environmental variables (Table 7 and Figure 5).



Table 7. - Pearson correlation matrix between environmental variables and natural regeneration in the seedling category under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

Variables	Number of individuals	Number of species	Depth	Slope	Lightness
	O horizon				
Number of individuals		< 0,001	0,37	0,72	0,31
Number of species	0,86		0,07	0,89	0,69
Depth	-0,19	-0,37		0,13	0,99
O horizon					
Slope	0,08	-0,03	0,31		< 0,001
Lightness	0,21	0,08	0,002	0,68	

*Values below the diagonal represent the correlation coefficient values above the diagonal indicate the P-value.
 Values in bold indicate a significant correlation.

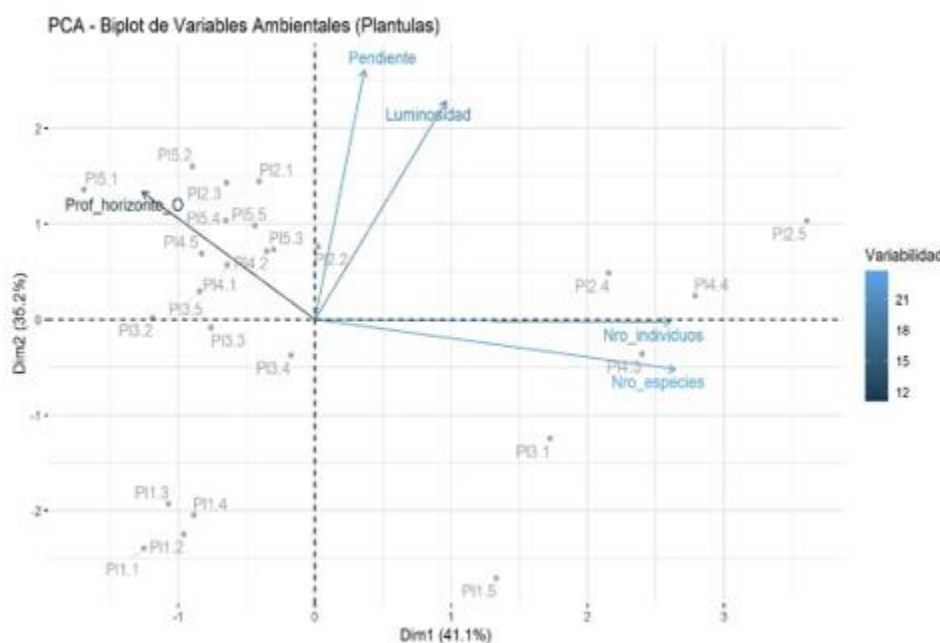


Figure 5. - Principal component analysis PCA (Biplot) of environmental variables on natural regeneration in the seedling category under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

In the sapling category, the correlation analysis ($\alpha = 0.05$) between variables showed positive and negative trend relationships. Luminosity showed a high correlation with slope ($r = 0.68$, $P = 0,00017$), while soil depth presented low correlation with slope ($r = 0.31$, $P = 0.13$) and no relationship with luminosity ($r = 0,0023$, $P = 0.99$). The variables of lightness, slope and soil depth separated the majority of saplings in plots 2,



3, 4, 5 from the saplings in plot 1. The number of species had a low correlation with slope ($r = 0.27$, $P = 0.19$) and luminosity ($r = 0.22$, $P = 0.29$), while the number of individuals had no relationship with the environmental variables; similarly a negative correlation was observed with soil depth ($r = -0.30$, $P = 0.15$). This is confirmed with the correlation matrix (Table 8) and the principal component analysis in Figure 6 (Figure 6).

Table 8. - Pearson correlation matrix between environmental variables and natural regeneration in the sapling category under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

Variables	Number of individuos	Number of species	Depth O horizon	Slope	Lightness
Number of individuos		0,00021	0,15	0,88	0,83
Number of species	0,68		0,42	0,19	0,29
Depth O horizon	-0,30	-0,17		0,13	0,99
Slope	-0,03	0,27	0,31		0,0017
Lightness	0,04	0,22	0,0023	0,68	

*Values below the diagonal represent the correlation coefficient, values above the diagonal indicate the P-value.
 Values in bold indicate a significant correlation.

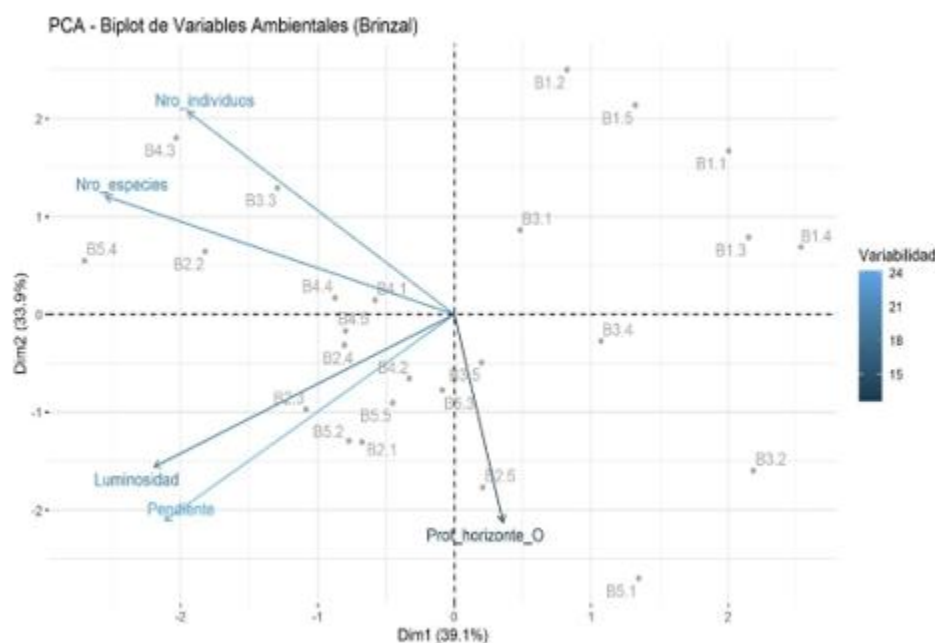


Figure 6. - Principal component analysis PCA (Biplot) of environmental variables on natural regeneration in the sapling category under *Eucalyptus globulus* plantation in Loja, Ecuador



Table 9 shows the correlation analysis ($\alpha = 0.05$) between environmental variables and natural regeneration in the latizal category, considering the number of individuals and species. In turn, the principal component analysis determined a strong correlation between environmental variables and the number of species ($r = 0.85$; $r = 0.79$; $r = 0.66$), while the number of individuals presented a strong negative correlation with environmental variables and the number of species. The variables of luminosity, slope and soil depth separated the latizales of plots 2, 3, 4, 5, from the latizales of plot 1. The slope variable showed a high correlation with luminosity ($r = 0.73$, $P = 0.16$) and soil depth ($r = 0.74$, $P = 0.15$); on the other hand, luminosity and soil depth had a low correlation ($r = 0.32$, $P = 0.60$) (Table 9 and Figure 7).

Table 9. - Pearson correlation matrix between environmental variables and natural regeneration in the latizal category under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

Variables	Number of individuals	Number of species	Depth O horizon
Number of individuals		0,04	0,17
Number of species	-0,89		0,22
Depth O horizon	-0,72	0,66	
Slope	-0,63	0,79	0,74
Lightness	-0,74	0,85	0,32

*Values below the diagonal represent the correlation coefficient, values above the diagonal indicate the P-value.
 Values in bold indicate a significant correlation.

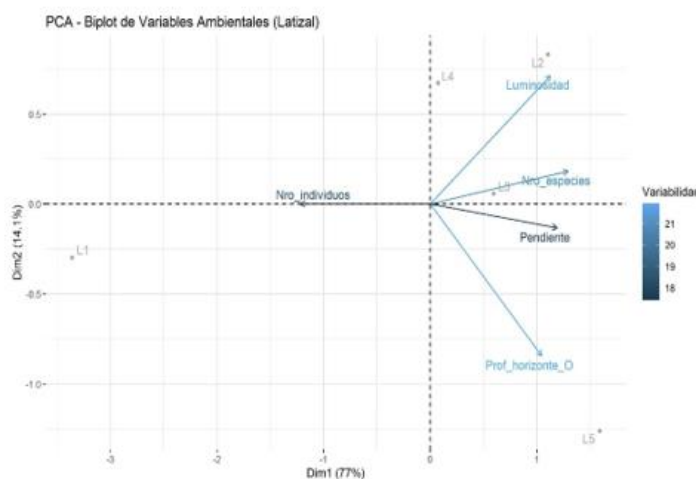


Figure 7. - Principal component analysis PCA (Biplot) of the environmental variables on natural regeneration in the latizal category under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador



DISCUSSION

Floristic composition and structural parameters

The floristic composition under the *Eucalyptus globulus* plantation of the PUFVC corroborates Real de Abreu *et al.*, (2011) who state that forest plantations can recover high native plant diversity. Furthermore, in agreement with this research, several authors such as Lima (1996), Ferreira *et al.* (2010), Fernández *et al.*, (2012) report in their studies references of plant diversity growing in stands of several eucalyptus species. In addition, it should be noted that the floristic composition of the understory of forest plantations is important to know the successional dynamics of the species present in these disturbed sites, and in turn, to know the resilience of these ecosystems (Ballester *et al.*, 1982).

Under the *Eucalyptus globulus* plantation in the PUFVC, 28 species were found, of these 15 are arboreal and 13 are shrubs, this represents a floristic diversity similar to that reported by Coraizaca and Yamasqui (2018) who report 30 species under the *Eucalyptus* plantation of the Llaviucuo Reserve within the Cajas National Park. On the other hand, Chávez (2016) recorded 50 species under an *E. globulus* plantation affected by forest fires in the northern highlands of Ecuador, which differs with this research. In this study, the latizal category is the most abundant with 294 individuals, which differs with Aguirre *et al.*, (2019), who in the Loja pit report 407 individuals in the seedling category.

The abundant species in the latizal, saplings and seedling category are *Viburnum triphyllum*, *Miconia obscura* and *Solanum aphyodendron*, this abundance is justified by the presence of these species in the floristic composition of the native forest of the PUFVC that is nearby (Aguirre *et al.*, 2017). On the other hand, these results are similar to those reported by Aguirre *et al.*, (2019), who mention *Viburnum triphyllum* as the abundant shrub species (145 ind ha⁻¹).

The most important species according to IVI are: *Solanum aphyodendron* in seedlings, *Miconia obscura* in saplings and *Viburnum triphyllum* in the latizal category, these species are different from those reported in Cajas National Park under eucalyptus plantations, where *Brugmansia sanguinea* and *Piper andreanum* stand out as species with the highest IVI according to Coraizaca and Yamasqui (2018).

Survival of natural regeneration

After monitoring the plots over a period of 12 months, the survival under *E. globulus* plantation reached 91.94 % corresponding to 399 living individuals at the end of the monitoring period; which evidently is a good survival percentage, suggesting a potential to become a secondary forest with an interesting floristic composition. On the other hand, the seedling category registered 100% survival, this data contrasts with that indicated by Delgado (2007), who mentions that seedlings are more sensitive to mortality due to competition with pioneer and invasive species. On the other hand, the high percentage of survival of the seedling category suggests that these species would adapt to areas with forest clearings, which is a characteristic of the study site, which is corroborated by Aguirre and Weber (2008) who showed that seedlings have better health in clearings in front of closed canopy.



In this study, survival in the latizal category (93.20 %) was higher than in saplings (88.55 %), which is corroborated by **Samper and Vallejo (2007)** who mention that mortality decreases in large individuals. In addition, the percentage of survival in these categories is acceptable, if it is considered that the individuals of these categories were more exposed than the individuals of the seedling category, due to the design of the plots that placed the seedlings in the center, which in a certain way favored them, but not the saplings and grasses.

Growth of natural regeneration

The growth of the natural regeneration showed a positive relationship between growth and the initial size of the individuals, with the greatest increase in the latizal category with 0.798 m in height and 0.307 cm in diameter; then, the saplings category reached an increase of 0.229 m in height and 0.155 cm in diameter; finally, the seedling category had the smallest increase in height and diameter with 0.072 m and 0.078 cm, respectively. For Jaramillo and **Muñoz (2009)**, seedling growth is related to the level of competition for light, water and mineral availability, photosynthetic capacity and levels of predation, which could explain to some extent the low growth of seedlings.

Another important aspect is the difference in growth rates between species, both in height and diameter. Thus, in height dominate: *Viburnum triphyllum* (seedlings); *Verbesina arborea* and *Alnus acuminata* (sapling); *Inga acreana*, *Morus insignis* and *Critoniopsis pycnantha* (latizal); and, in diameter dominate: *Solanum aphyodendron* (seedlings); *Alnus acuminata*, *Verbesina arborea* and *Clethra fimbriata* (sapling); *Critoniopsis pycnantha*, *Tournefortia fuliginosa* and *Morus insignis* (latizal); which could be due to physiological characteristics of the species and to the initial advantage (greater illumination) that some of these species presented in the different categories in relation to the others.

This suggests that some shade-tolerant species such as *Inga acreana* or *Morus insignis*, when under similar light conditions to other more light-demanding species such as *Alnus acuminata* and *Critoniopsis pycnantha*, achieve similar growth rates; this behavior is corroborated by **Manokaran and Kochummen (1987)** and **Sáenz et al., (1999)** who have found results that show that some shade-tolerant species have similar growth rates to pioneer species.

Influence of environmental variables on natural regeneration

The influence of environmental variables on natural regeneration was manifested in a differentiated manner, the slope had a strong correlation with the number of species in the latizal category, where it was observed that the greater the slope, the greater the number of species; this is due to the fact that the latizales of plots 2 and 5 have the greatest number of species and the greatest slope with 63.53 % and 69 %, respectively; on the contrary, the latizales of plot 1 have the least number of species and the least slope (36.10 %). This differs from **Laurance et al. (2010)** who report that, in natural Andean forests, the increase in slope decreases the abundance, richness and diversity of plant species, because the steeper areas have more adverse conditions for the establishment of vegetation. Similarly, soil depth correlates with the number of species in the latizal category, which is explained by the greater floristic diversity in the latizales of plots 2, 3, 4, 5, which have the highest soil depth values, compared to the latizales of plot 1.



Regarding luminosity, there is a correlation with the number of species in the latizal category, this would be explained by a higher number of species (14) in the latizales of plot 2, which has a higher luminosity (52 %), and a lower number of species (7) in the latizales of plot 1, which has a lower luminosity (27.60 %). The influence of light on natural regeneration is important, since light is considered one of the most important environmental variables in the regeneration processes in forest ecosystems (Melo and Vargas 2003). On the other hand, the percentage of light in this study was 27.60 % to 52 %, which represents a high percentage compared to what Jaramillo and Muñoz (2009) report in the San Francisco Scientific Station with low canopy openness values between 11.84 % and 17.11 %; this is due to the fact that canopies are more open in intervened areas such as forest plantations compared to native forests (Lamprecht 1990).

We could not find sufficient evidence in the category of seedlings and saplings to support that greater luminosity, greater slope or greater soil depth is the cause of greater abundance or greater floristic diversity; therefore, it can be assumed that there are more relevant factors in the development of natural regeneration. Pariona *et al.*, (2003) state that forest species are influenced by the availability of light, formation of clearings and competition with the pioneer species of the forest. However, in the latizal category, the influence of environmental variables on floristic diversity was observed, as previously mentioned. On the other hand, since environmental variables did not affect the abundance of natural regeneration under the *Eucalyptus* plantation, it is assumed that random processes could determine the number of individuals of woody plant species.

CONCLUSIONS

The floristic composition of the natural regeneration of native woody plant species under the *Eucalyptus globulus* plantation, represented by 28 species, demonstrates that the recovery of the natural vegetation is feasible. And because of the diversity and abundance of species in the different categories evaluated, a natural forest is projected for the future in the event of the elimination of the forest plantation.

As part of the floristic diversity of the natural regeneration, *Solanum aphyodendron* (seedlings), *Miconia obscura* (sapling) and *Viburnum triphyllum* (latizal), stand out in abundance; while in frequency they are: *Solanum aphyodendron* and *Viburnum triphyllum* in seedlings, *Oreopanax rosei* in saplings; and, in the latizal category *Viburnum triphyllum*, *Piper barbatum* and *Verbesina arborea*.

After one year of observation, the survival of natural regeneration is acceptable, seedlings survived 100 %, the latizales reached 93.20 %, and the saplings have the lowest survival.

The individuals of the latizal category had the highest average growth in height and diameter. The species with dominance in height growth are: *Viburnum triphyllum* (seedlings), *Verbesina arborea* (sapling), *Inga acreana* (latizal). And the species that grew more in diameter are: *Solanum aphyodendron* (seedlings), *Alnus acuminata* (saplings) and *Critoniopsis pycnantha* (latizal).



Environmental variables did not significantly influence the abundance and floristic diversity of natural regeneration in the seedling and sapling categories. However, in the latizal category, there is evidence of an influence of luminosity on floristic diversity.

ANNEXES

Annex 1. - Trees and shrubs of the natural regeneration under the *Eucalyptus globulus* plantation of the University Park "Francisco Vivar Castro", Loja, Ecuador

Habit of growth	Family	Species	Number of individuals
Tree	Betulaceae	<i>Alnus acuminata</i> Kunth	35
	Clethraceae	<i>Clethra fimbriata</i> Kunth	2
	Clusiaceae	<i>Clusia latipes</i> Planch. & Triana	6
	Rhamnaceae	<i>Frangula granulosa</i> (Ruiz & Pav.) Grubov	6
	Fabaceae	<i>Inga acreana</i> Harms	3
	Anacardiaceae	<i>Mauria heterophylla</i> Kunth	1
	Moraceae	<i>Morus insignis</i> Bureau	2
	Araliaceae	<i>Oreopanax rosei</i> Harms	17
	Rosaceae	<i>Prunus opaca</i> (Benth.) Walp.	11
	Proteaceae	<i>Roupala monosperma</i> (Ruiz & Pav.) I.M. Johnst.	2
	Actinidiaceae	<i>Saurauia bullosa</i> Wawra	2
	Siparunaceae	<i>Siparuna muricata</i> (Ruiz & Pav.) A. DC.	4
	Solanaceae	<i>Solanum aphyodendron</i> S. Knapp	30
	Boraginaceae	<i>Tournefortia fuliginosa</i> Kunth	2
	Asteraceae	<i>Verbesina cf. arborea</i> Kunth	29
Total		15 species	152 individuals
shrubs	Asteraceae	<i>Critoniopsis pycnantha</i> (Benth.) H. Rob.	1
	Bignoniaceae	<i>Delostoma integrifolium</i> D. Don	1
	Rosaceae	<i>Hesperomeles obtusifolia</i> (Pers.) Lindl.	2
	Melastomataceae	<i>Miconia lutescens</i> (Bonpl.) DC.	5
	Melastomataceae	<i>Miconia obscura</i> (Bonpl.) Naudin	56
	Primulaceae	<i>Myrsine andina</i> (Mez) Pipoly	14
	Primulaceae	<i>Myrsine sodiroana</i> (Mez) Pipoly	8
	Rubiaceae	<i>Palicourea amethystina</i> (Ruiz & Pav.) DC.	1
	Rubiaceae	<i>Palicourea</i> sp.	1
	Piperaceae	<i>Piper barbatum</i> Kunth	44
	Solanaceae	<i>Solanum cf. cutervanum</i> Zahlbr.	9
	Melastomataceae	<i>Tibouchina lepidota</i> (Bonpl.) Baill.	2
	Adoxaceae	<i>Viburnum triphyllum</i> Benth.	138
Total		13 species	282 individuals



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Conflict of interests:

The authors declare not to have any interest conflicts.

Authors' contribution:

Zhofre Huberto Aguirre Mendoza: Conception of the idea, literature search and review, instrument making, instrument application, compilation of information resulting from the instruments applied, statistic analysis, preparation of tables, graphs and images, general advice on the topic addressed, drafting of the original (first version), review and final version of the article, article correction, authorship coordinator, translation of terms or information obtained, review of the application of the applied bibliographic standard.



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