Bulletin of the *Transilvania* University of Braşov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 10 (59) No.2 - 2017

DIVERSITY, COMPOSITION AND STRUCTURE OF ANDEAN HIGH FOREST IN ECUADOR, SOUTH AMERICA

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Abstract: *Andean highland ecosystems are important for human well-being by presenting unique plant formations in the world which are valued for their floristic composition and for their evolutionary peculiarities that have resulted in high levels of endemism and biological diversity. They contribute to the sustenance of life of the planet by ecological functions and by providing essential goods and services for human development. This study was carried out in the Polylepis relict forest from the Reserva de Producción de Fauna Chimborazo. 8 transects and 54 plots were established in a study area corresponding to 0.5 ha, in order to determine the diversity, composition and structure of the forest. A total of 18 species and 6252 individuals, belonging to 11 families were identified. The most abundant species were Polylepis reticulata Hieron (2396), Bomarea glaucescens (768) and Hypochaeris sessiliflora (557). Margalef's, Shannon's, Simpson's, Fisher's alpha and Pielou's indexes were calculated. While all the component species were evaluated, the number of individuals of Polylepis reticulata Hieron with a height greater than 1 m (1190) was determined in each plot. The analyzed structural parameters were the height, diameter at the breast height and basal area of the individuals of the Polylepis sp., in relation to the plots. In addition, the physical and chemical properties of the soil as well as a microbiological analysis were taken into study. The results characterize the complexity of the forest and they can be used for the formulation of strategies for the biodiversity conservation.*

Key words: *diversity, composition, structure, richness, species, Andean forest*

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1. Introduction

Ecuador is considered to be one of the richest countries in species diversity and ecosystems worldwide, despite being the smallest of the 17 megadiverse countries [4]. Its geographical location and the presence of the Andes Mountains determine the existence of a huge variety of microclimates, from the wetlands of the Amazon and north-west, to the dry ecosystems of the south and from the warm beaches of the Pacific to the eternal snows of the volcanoes [30]. For instance, in the western mountain range rises the snow-capped Chimborazo with a height of 6268 m.s.n.m [29]. A group of scientists from the Research Institute for Development (IRD-France) and the Military Geographic Institute (IGM) [14] have determined by GPS measurements that Chimborazo is the highest point from the center of the earth [20].

In 1986, in order to protect the wildlife, the Reserva de Producción de Fauna Chimborazo was created in Ecuador with a total area of 58,560 hectares and an altitudinal range of 3,200 - 6,310 meters [21]. The climatic and altitudinal conditions are determinants of the existing vegetation that is formed by species of herbaceous type, with sporadic presence of small shrubs, grouped in four zones of life: Páramo Herbáceo, Páramo Seco, Gelidofitia and the Evergreen Forest Montano Alto which is dominated by *Polylepis* [22].

The *Polylepis* Forest (*Polylepis reticulata* Hieron 1896) is located in the northeastern part of the Reserve, on a large rocky wall. The United Nations Food and Agriculture Organization (FAO) defines the forests as those tree associations covering more than 0.5 hectares that are characterized by trees over 5 meters in height and a canopy cover of more than 10 percent, or trees capable of reaching this height in situ [28]. Given that the *Polylepis* Forest has an area of 0.35 hectares, the denomination of this space was redesigned into the so-called "Relicto de bosque". That's because around this area are present small remnants of *Polylepis reticulata* Hieron 1896, a fact which indicates the fragmentation and decrease in size of the original forest. Studies show that the current distribution of *Polylepis sp.* is mainly the result of thousands of years of human activity in the high Andes [18].

Anthropogenic practices such as hunting, fires and improved agricultural yields have reduced the forest cover [19]. Nevertheless, the erosion of these ecosystems can be attributed also to their location at high elevations in the Andes, where they are subject to temperature fluctuations, generally with a difference of 20-30 °C between day and night and frequent freezing periods. These fluctuations result in a significant stress for plants [12].

The relict forests located on the western slopes of the Andes in northern Peru and southern Ecuador are habitats with high plant diversity and a very high rate of endemism [42]. 49 species belonging to the *Polylepis* genus have been registered, and in Ecuador it is possible to find 14% of them, which corresponds to 7 species, two of them endemic (*Polylepis lanuginosa* and *Polylepis reticulata* Hieron) [25].

The IUCN Red List of Threatened Species evaluated the species and included them in the Vulnerable category [34]. Moreover, the presence of a reduced niche for the *Polylepis* sp. as an effect of global warming and modern conditions is in line with those predictions according to which the high Andean forests could be particularly vulnerable to the anticipated future climate change [2], [23].

The structural characteristics of a natural forest are crucial in the attempt of knowing its dynamics and especially in defining its structure and composition with the aim to design a management plan depending on the results obtained [11].

The characterization of an ecosystem allows identifying the complexity of the species of flora and fauna that inhabit it as well as how they respond to the anthropic perturbations [24]. As the biodiversity constitutes a crucial condition for a supply source of goods and services, that benefit the society [6], the floristic composition and vegetation, which identifies the species that make up a geographical area, as well as its distribution and physiognomy [25] are important components that should be carefully evaluated. The same is true for the structure that allows to interpret the distribution of individuals and species within the forest and their relation with the behavior of the floristic diversity and its dynamics [36].

The aim of this study was to determine the structure and composition of the *Polylepis* relict forest. The specific objectives of the study were to describe diversity parameters, floristic composition, and structure of the forest including a physical-chemical and microbiological analysis of the soil associated to the forest.

2. Materials and Methods

2.1. Study Area

The study was carried out in the *Polylepis* relict forest (Fig. 1) located inside the Reserva de Producción de Fauna Chimborazo – a Protected Area of Ecuador (Fig. 2), at an altitude of 4300 m.a.s.l. The Reserva de Producción de Fauna Chimborazo is one of the 51 protected areas of Ecuador, and it was established with the aim to conserve and properly manage the ecosystems and susceptible species [22]. Geologically, the forest relict is located in an area characterized by steep slopes and irregularities, on a large rocky wall of non-volcanic material. The soil is arid with little presence of rainfall [15].

2.2. Experimental Design and Field Data Collection

The experimental design for field data collection supposed the implementation of a specific inventory methodology for data collection [10]. The field phase was carried out in the period January – August 2017. Flora was collected during 7 field trips and transferred to the herbarium of Escuela Superior Politécnica (ESPOCH) where the identification was done at species level. The results were crosschecked and validated using the information available on the www.tropicos.org website.

To systematize the analysis of the forest, the area was divided into 54 smaller plots of approximately 10×10 m^2 each (Fig. 2).

The individuals were recorded by a coding procedure consisting of a character from A to H and a numerical series of 2 digits from 01 to 07 to identify the plot.

All individuals of *Polylepis reticulata* Hieron were registered using 3 parameters: height (h), DBH (Diameter at Breast Height) and BA (Basal Area).

The DBH values considered all individuals that presented a height greater than 1 m and was calculated by dividing the CBH (Circumference at Breast Height measured at 1.3 m) by constant π (π = 3.1416) [3]; in the case of trees with multiple stems, the measure was not registered. Then, the basal area of each individual was calculated using the formula $BA = \pi (DBH^2/4)$ [10], [31].

Subsequently the mean per plot and the mean of the total area of study were determined.

Soil samples were collected from 3 points characterizing the high, medium and low zones of the forest. The samples were taken to the ESPOCH Soil Laboratory, where the physical and chemical properties were determined: texture, structure, structural stability, apparent and actual density, as well as the contents of Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Iron [12], Zinc (Zn) and Manganese (Mn). Finally, a microbiological analysis of the collected soil samples was carried out, in which the CFUs (Colony Forming Units) of bacteria, fungi and actinomycetes were considered.

Isolation of the principal groups of microorganisms was carried out using two basic culture media - agar nutrient (NA) and agar potato dextrose (PDA). The three soil samples were homogenized, then by using the method of serial dilution (100 µl of dilutions 10^{-1} to 10^{-6}) they were inoculated in the Nutrient Agar medium (NA) to quantify the bacterial population and in the Potato Dextrose Agar (PDA) to quantify fungi and actinomycetes [8]; the Petri dishes were incubated for 72 h at 25ºC; after the incubation time, the number of colonies was quantified and the colony forming units per gram of soil of bacteria, fungi and actinomycetes were calculated for each sample [27].

The nematode quantification was done using the Baermann funnel method [41], to determine the number of individuals per gram of soil sample.

The evaluation of microorganisms was carried out at the ESPOCH laboratory of Biological Sciences.

Fig. 1. *A snapshot of the Polylepis relict forest*

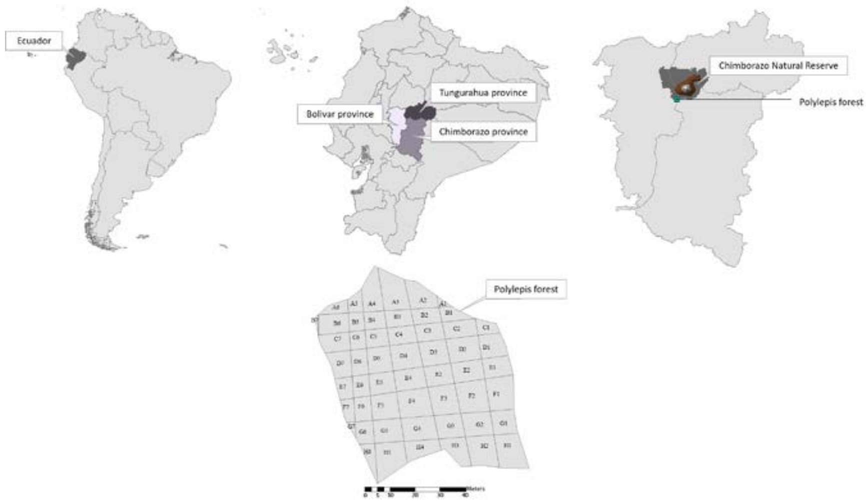

Fig. 2. *Map of the geographic location of the "Polylepis" forest in the Reserva de Producción de Fauna Chimborazo*

2.3. Data Analysis

Data analysis consisted of several steps. A first step aimed to calculate the descriptive community parameters [26]: richness (S), Margalef's index of species richness d = (S-1)/Log(N), Shannon's diversity H' = -SUM(Pi*Log$_e$(Pi)), Simpson's index of species 1-λ' = 1-SUM(Ni*(Ni-1)/(N*(N-1)), Fisher's alpha diversity and Pielou's evenness index J' = H/log(S).

The specimens of *Polylepis reticulata* Hieron were identified and selected for further studies as this species had the largest number of individuals in the territory. Individuals of *Polylepis reticulata* Hieron were identified in the plots, and the plots with the largest and smallest number of individuals were determined.

Height, basal area and DBH of the individuals, including the total and average values were calculated for each plot. In all the cases, only individuals having a height over 1 meter were taken into consideration.

Physical, chemical and micro biological analysis were done under the methodology of "Red de laboratorios de suelos del Ecuador" [32].

3. Results and Discussion
3.1. Diversity

In the botanical inventory, the order *Asterales* was the most common, grouping six species belonging to the family *Asteraceae*: *Aetheolaena lingulata* (Schltdl.) B. Nord., *Conyza cardaminifolia Kunth, Hypochaeris radicata* L., *Hypochaeris sessiliflora Kunth, Laciocephalus ovatus, Chuquiraga jussieui.*

The family *Rosaceae* grouped three species: *Polylepis reticulata* Hieron, *Lachemilla orbiculata* and *Lachemila afanoidea*. *Polylepis reticulata* Hieron was the most abundant species with 2396 individuals. *Bomarea glaucescens* (Kunth) Baker (768 individuals) and *Hypochaeris sessiliflora Kunth* (557) showed a higher relative abundance compared with the other species. *Polystichum orbiculatum* (30 individuals), *Hypochaeris radicata* (32), *Monnina aestuans* (35) and *Dalea coerulea* (39) were the species less frequent (Fig. 3 and 4). Regarding diversity indices, Margalef's index of species richness showed a value of 1.944, Shannon's diversity index presented a value of 2.188, Simpson's index of species diversity indicated a value of 0.813, Fisher's alpha diversity had a value of 2.272 and Pielou's evenness index had a value of 0.757 (Table 2).

Andean high forests are characterized by a biodiversity having a high level of endemism [43], and are considered as priority conservation areas [7]. This study shows that the *Polylepis* relict forest presents special biodiversity characteristics, partly due to its isolation, which are comparable only with those of populations located in Peru [25] and Bolivia [9].

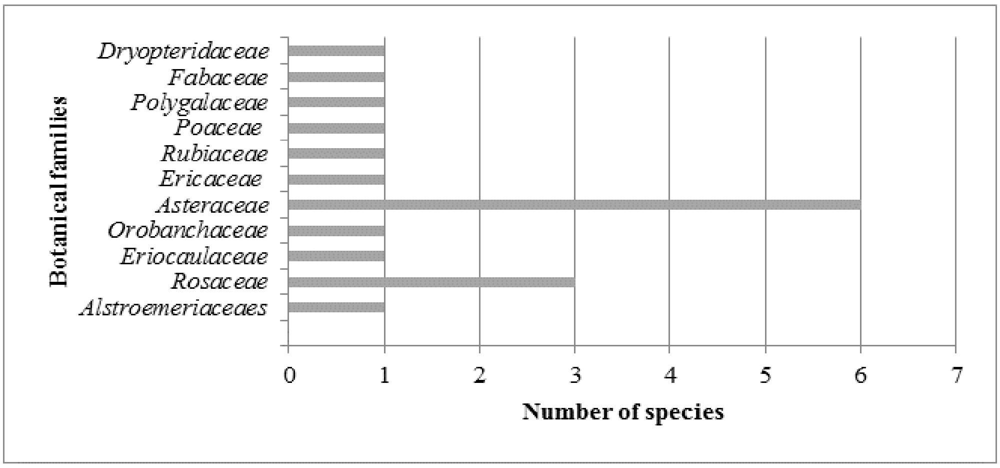

Fig. 3. *Botanical families and their abundance in the study area: number of species*

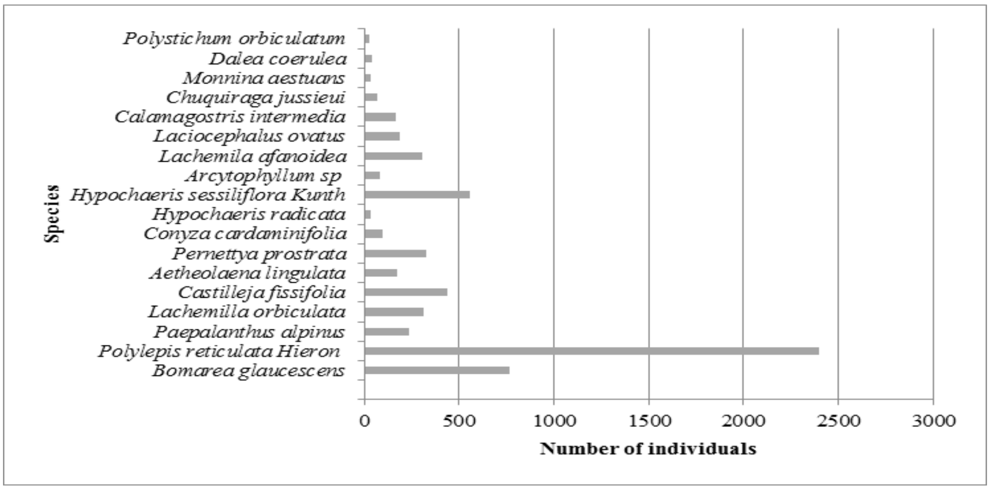

Fig. 4. *Botanical families and their abundance in the study area: number of individuals*

Hybridization in *Polylepis* genus is considered to be quite common [9], and it is possible to find hybrid populations in Bolivia and Ecuador [17], [33], [37], [38].

For all these reasons we recommend the development of a genetic diversity study of the *Polylepis* relict forest, since hybridization leads in many cases to speciation [35].

Specific index of richness and diversity Table 1

Index	DMg	H'	λ	αF	J’
Polylepis relict forest	1.944	2.188	0.813	2.272	0.757

Note: DMg - Richness Margalef’s index, H' - Shannon’s index, λ = Simpson’s index, αF = Fisher's alpha index, J’ = Pielou’s index.

Table 2

Summary of floristic diversity and number of individuals by species in the Polylepis relict forest of the Reserva de Producción de Fauna Chimborazo

Order	Family	Species	No. of individuals	Share %
Liliales	*Alstroemeriaceae*	*Bomarea glaucescen* Kunth, Baker (1882).	768	12.28
Rosales	*Rosaceae*	*Polylepis reticulata* Hieron Hieronymus, Georg Hans Emmo (1896).	2396	38.32
Poales	*Eriocaulaceae*	*Paepalanthus alpinus* Friedrich August (1863).	233	3.73
Rosales	*Rosaceae*	*Lachemilla orbiculata* Rydberg, Per Axel (1903).	316	5.05
Scrophulariales	*Orobanchaceae*	*Castilleja fissifolia* Martín Mociño, José Mariano (1787-1803).	438	7.01
Asterales	*Asteraceae*	*Aetheolaena lingulata* Nordenstam, Rune Bertil (1978).	173	2.77
Ericales	*Ericaceae*	*Pernettya prostrata* Sleumer, Hermann Otto (1935).	328	5.25
Asterales	*Asteraceae*	*Conyza cardaminifolia* Kunth, Karl (Carl) Sigismund (1820).	100	1.60
Asterales	*Asteraceae*	*Hypochaeris radiata* Linnaeus, Carl von (1753).	32	0.51
Asterales	*Asteraceae*	*Hypochaeris sessiliflora kunth* Karl (Carl) Sigismund (1820)	557	8.91
Gentianales	*Rubiaceae*	*Arcytophyllum sp* Willdenow, Carl Ludwig von (1827).	80	1.28
Rosales	*Rosaceae*	*Lachemila afanoidea* Rydberg, Per Axel (1908).	305	4.88
Asterales	*Asteraceae*	*Laciocephalus ovatus* Schlechtendal, Diederich Franz Leonhard von (1814).	185	2.96
Poales	*Poaceae*	*Calamagostris intermedia* Steudel, Ernst Gottlieb von (1840).	165	2.64
Asterales	*Asteraceae*	*Chuquiraga jussieui* Gmelin, Johann Friedrich (1792).	72	1.15

Fabales	*Polygalaceae*	*Monnina aestuans* Candolle, Augustin Pyramus (1824).	35	0.56
Fabales	*Fabaceae*	*Dalea coerulea.* Barneby Rupert Charles (1977).	39	0.62
Polypodiales	*Dryopteridaceae*	*Polystichum orbiculatum* Rémy, Ezechiel Jules Fée, Antoine Laurent Apollinaire (1854).	30	0.48

3.2. Botanical Composition

In the study area, a total of 6252 individuals (Table 3) were found belonging to 11 families. *Polylepis reticulata* Hieron and *Bomarea glaucescens* were the dominant species, accounting for 38.32% and 12.28% of total abundance, respectively. *Polylepis reticulata* Hieron was the most abundant species in this study and it was identified at an altitude much higher than 4000 m. Previous studies such as those carried out in the Peruvian Andean forests, founded 18 species of this genus, located however in the altitudinal range from 3000 to 4000 meters [25]. At family level, the predominant groups were *Rosaceae* (48.3%) and *Asteraceae* (17.9%) (Table 4). Of 2396 individuals of *Polylepis* species recorded, 50.33% (representing 1206 individuals) had less than 1 meter in height, while 49.67% (1190 individuals) were over 1 meter in height. The plots E07, F07 and G07 did not show any *Polylepis* individuals, but they presented individuals of other species.

The transect with the largest number of individuals was G (568) while the least number of individuals was found on transect D (163). In relation to the plots, the greatest number of individuals were found in G01 (262), G02 (185) and C01 (183) respectively (Table 4).

Number of individuals per species in the Polylepis relict forest Table 3

Species	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Total**
Paepalanthus alpinus	44	21	3	2	19	39	50	55	233
Lachemilla orbiculata	20	100	61	30	0	52	22	31	316
Castilleja fissifolia	24	36	23	61	156	52	39	47	438
Aetheolaena lingulata	8	23	37	5	37	18	14	31	173
Pernettya prostrata	16	78	34	26	46	47	38	43	328
Conyza cardaminifolia	3	5	0	2	29	6	32	23	100
Hypochaeris radiata	14	9	0	3	0	0	3	3	32
Hypochaeris sessiliflora kunth	4	76	69	113	160	47	50	38	557
Arcytophyllum sp	10	11	16	4	21	0	9	9	80
Lachemila afanoidea	1	29	8	16	185	0	35	31	305
Laciocephalus ovatus	57	14	18	4	41	28	11	12	185
Calamagostris intermedia	0	29	28	3	72	0	16	17	165
Chuquiraga jussieui	0	0	0	1	29	0	17	25	72
Monnina aestuans	0	1	0	0	0	0	12	22	35
Dalea coerulea	0	4	1	0	0	10	10	14	39
Polystichum orbiculatum	1	20	0	0	0	0	3	6	30
Total									6252

Summary of the Polylepis individuals Table 4

T	I	T	I	T	I	T	I	T	I	T	I	T	I	T	I
A01	36	B01	50**	C01	183**	D01	65**	E01	72**	F01	87**	G01	262**	H01	96**
A02	58	B02	29	C02	104	D02	23	E02	35	F02	46	G02	185	H02	89
A03	59	B03	17	C03	42	D03	15	E03	10*	F03	22	G03	25	H03	46
A04	50	B04	13*	C04	97	D04	25	E04	50	F04	23	G04	45	H04	36
A05	66**	B05	29	C05	21	D05	14	E05	20	F05	25	G05	37	H05	18
A06	3*	B06	30	C06	25	D06	19	E06	33	F06	7*	G06	14*	H06	13*
A07	NP	B07	24	C07	1*	D07	2*	E07	NI	F07	NI	G07	NI	H07	NP
$\bar{x}$ P	272	$\bar{x}$ P	192	$\bar{x}$ P	473	$\bar{x}$ P	163	$\bar{x}$ P	220	$\bar{x}$ P	210	$\bar{x}$ P	568	$\bar{x}$ P	298

Note: T = Transects, I = Individuals, NP = No. plot, NI = No. of individuals, $\bar{x}$ P = mean of the plot (calculations per plot did not included NP, NI and S‹1m)

3.3. Structure

Contrary to Mendoza and Cano [25], Bitter [16] considered that in Ecuador there are only two endemic species [25]. Besides *Polylepis reticulata*, other endemic species of this genus in Ecuador are *Polylepis lanuginosa* Kunth and *Polylepis microphylla* (Wedd.).

The *Polylepis reticulata* species represent a large part of the natural and endemic vegetation of the Andes [18]. It belongs to the *Rosaceae* family and in the studied area it has the highest number of individuals. The average value of height was 2.79 m and the mean DBH was of 8.58 cm. The average BA was of 97.56 cm^2 (Table 5).

In the plot A06, only individuals smaller than 1 meter were found. The average height calculated for each plot is given in Table 6. Additionally, the summary of the DBH averages per plot is given in Table 7. According to the means calculated per plot, the basal area shows the highest values in A04 (124.49 cm^2), B04 (177.24 cm^2), C03 (268.14 cm^2), D03 (404.78 cm^2), E03 (339.88 cm^2), F04 (98.72 cm^2), G04 (163.33 cm^2) and H05 (51.01 cm^2). A summary of the calculated averages is shown in Table 8.

Average h, DBH and BA Table 5

Name	H	DBH	BA
]*Polylepis reticulata* Hieron	2.79 m	8.58 cm	97.56 cm^2

Note: m = meters, cm = centimeters, cm^2 = square centimeters

Height per transects and plots Table 6

Height															
A		B		C		D		E		F		G		H	
T	A. H.	T	A. H.	T	A. H.	T	A. H.	T	A. H.	T	A. H.	T	A. H.	T	A. H.
A01	1.55	B01	3.51	C01	2.09	D01	2.55	E01	3.00	F01	1.97	G01	1.63	H01	1.24*
A02	2.40	B02	6.65**	C02	3.76	D02	3.69	E02	4.16	F02	2.77**	G02	2.29	H02	1.48
A03	4.04 **	B03	3.47	C03	8.17**	D03	3.61	E03	3.95	F03	1.38*	G03	2.57**	H03	1.50
A04	2.50	B04	4.13	C04	6.05	D04	1.98	E04	4.59**	F04	1.97	G04	3.11	H04	2.12**
A05	1.30*	B05	3.93	C05	0.96	D05	8.32**	E05	3.31	F05	1.87	G05	1.40*	H05	1.80
A06	S‹1m	B06	3.77	C06	0.58*	D06	2.71	E06	1.68*	F06	1.50	G06	1.40*	H06	1.63
A07	NP	B07	3.00*	C07	3.25	D07	1.03*	E07	NI	F07	NI	G07	NI	H07	NP
$\bar{x}$ P	2.35	$\bar{x}$ P	4.06	$\bar{x}$ P	3.55	$\bar{x}$ P	3.4	$\bar{x}$ P	3.44	$\bar{x}$ P	1.91	$\bar{x}$ P	2.06	$\bar{x}$ P	1.62

Note: T = Transect, AH = Average height, **max, *min, NP = No plot, S‹1m = species less than 1 meter, NI = No individuals, $\bar{x}$ P = mean of the plot (calculation per plot did not included NP, NI and S‹1m)

Diameter at breast height per transects and plots Table 7

DBH															
A		B		C		D		E		F		G		H	
T	DBH. $\bar{x}$	T	DBH. $\bar{x}$	T	DBH. $\bar{x}$	T	DBH. $\bar{x}$	T	DBH. $\bar{x}$	T	DBH. $\bar{x}$	T	DBH. $\bar{x}$	T	DBH. $\bar{x}$
A01	2.53*	B01	3.34*	C01	4.41*	D01	9.72*	E01	9.19*	F01	5.12	G01	1.89*	H01	TBB
A02	6.47	B02	9.50	C02	10.43	D02	15.32	E02	11.85	F02	9.34	G02	7.15	H02	3.05
A03	9.27	B03	13.28	C03	14.72**	D03	21.92**	E03	16.90**	F03	6.60	G03	7.38	H03	2.08*
A04	11.50**	B04	13.44	C04	4.69	D04	10.65	E04	15.58	F04	10.61**	G04	12.3**	H04	4.75
A05	7.44	B05	13.79**	C05	14.43	D05	15.27	E05	13.69	F05	6.31	G05	3.77	H05	5.32
A06	S‹1m	B06	10.59	C06	13.13	D06	11.25	E06	10.77	F06	3.59*	G06	TBB	H06	5.59**
A07	NP	B07	7.37	C07	9.54	D07	1.00	E07	NI	F07	NI	G07	NI	H07	NP
$\bar{x}$ P	7.44	$\bar{x}$ P	10.18	$\bar{x}$ P	10.19	$\bar{x}$ P	12.16	$\bar{x}$ P	12.9	$\bar{x}$ P	6.92	$\bar{x}$ P	5.41	$\bar{x}$ P	3.46

Note: T = Transect, DBH. $\bar{x}$ = mean diameter at breast height, **max, *min, NP = No plot, S‹1m = species less than 1 meter, NI = No individuals, TBB = trees with basal branch, $\bar{x}$ P = mean of the plot (calculation per plot did not included NP, NI and S‹1m)

Basal area per transects and plots Table 8

Basal area															
A		B		C		D		E		F		G		H	
T	BA. $\bar{x}$	T	BA. $\bar{x}$	T	BA. $\bar{x}$	T	BA. $\bar{x}$	T	BA. $\bar{x}$	T	BA. $\bar{x}$	T	BA. $\bar{x}$	T	BA. $\bar{x}$
A01	10.89	B01	23.92	C01	30.08*	D01	86.80*	E01	42.15*	F01	15.60*	G01	3.70*	H01	TBB
A02	46.27	B02	95.69	C02	136.74	D02	232.90	E02	122.13	F02	91.51	G02	57.84	H02	13.32
A03	107.88	B03	174.42	C03	268.14**	D03	404.78**	E03	339.88**	F03	50.75	G03	48.05	H03	8.48*
A04	124.49**	B04	177.24**	C04	40.97	D04	116.76	E04	224.77	F04	98.72**	G04	163.33**	H04	25.79
A05	52.80*	B05	170.07	C05	179.54	D05	212.10	E05	163.59	F05	37.48	G05	23.10	H05	51.01**
A06	S‹1m	B06	93.43	C06	155.03	D06	119.69	E06	116.46	F06	15.13	G06	TBB	H06	44.93
A07	NP	B07	41.00*	C07	71.62	D07	S‹1m	E07	NI	F07	NI	G07	NI	H07	NP
$\bar{x}$ P	68.47	$\bar{x}$ P	110.82	$\bar{x}$ P	126.02	$\bar{x}$ P	176.58	$\bar{x}$ P	168.17	$\bar{x}$ P	51.53	$\bar{x}$ P	59.2	$\bar{x}$ P	28.71

Note: T = Transect, BA $\bar{x}$ = mean of the basal area, **max, *min, NP = No plot, S‹1m = species less than 1 meter, NI = No individuals, TBB = trees with basal branch, $\bar{x}$ P = mean of the plot (calculation per plot did not included NP, NI and S‹1m)

3.4. Soil

The physical and chemical analysis of the soil have shown that the pH fluctuates between 5.7 and 6.1 corresponding to slightly acid soils according to the Cortés-Castelán & Islebe scale [5]. The content of organic matter varied between 1.1% (low zone) and 2.0% (high zone). However, the soil was evaluated as having a low level of organic matter; with respect to macronutrients (N, P, and K), all samples were characterized by a low content. It was quite the same for the content of micronutrients such as Ca, Mg, Zn and Mn, where the three samples had a low content, but not for Fe (Table 11), whose results indicated high contents in the samples, a fact that could be attributed to the immobility of this element, commonly observed at ground level.

The texture and structure of the soil corresponded to a loose sand, in the case of all three samples. In most soils, inorganic phosphorus is characterized by fairly low concentrations in the solution whilst a large proportion of it is more or less strongly held by diverse soil minerals. Phosphate ions can indeed be adsorbed onto positively charged minerals such as Fe and Al oxides. Phosphate (P) ions can also form a range of minerals in combination with metals such as Ca, Fe and Al [13]. Result of microbiological analysis showed a predominance of bacteria in the soil sample.

The fungal population was low in the samples collected from the high and low zones while in the sample collected from the medium zone it was absent. Actinomycetes were totally absent in the high and medium zone samples and had a very low concentration in the low zone sample (Table 10). Microbial population and the relative abundance of various microbial types suggest that the biochemical environment of untilled soils is less oxidative than that under conventional tillage [39].

The quality diminishes, with the presence of phytopathogenic nematodes (Table 9), particularly those forming gills (*Meloidogyne*, *Paratylenchus* and *Tylenchulus*), that may constitute a high risk for the development of *Polylepis* and other nearby species. Also, as a group of important natural enemies of nematode pests, nematophagous bacteria exhibit diverse modes of action: parasitizing, production of toxins, production of antibiotics or enzymes, competing for nutrients, inducing systemic resistance of plants and promoting plant health [1], [40].

Nematodes quantification Table 9

Zone	Nematodes/100 g of soil
High	106
Medium	96
Low	72

Note:High: Predominance of the genus *Meloidogyne* and *Paratylenchus*. Medium: Predominance of the genera *Tylenchulus* and *Paratylenchus*. Low: Predominance of the genus *Pratylenchus* and *Rotylenchus*.

Microorganism UFC/g of soil Table 10

Zone	**UFC/g soil bacteria**	**UFC/g soil fungi**	**Observa-tions**
High	1.8×10^5	2.0×10^3	Absence of actinomy-cetes
Medium	1.5×10^5	---------	Absence of actinomy-cetes
Low	3.9×10^5	1.0×10^4	2 colonies of similar actinos

Fig. 5. *Nematodes*

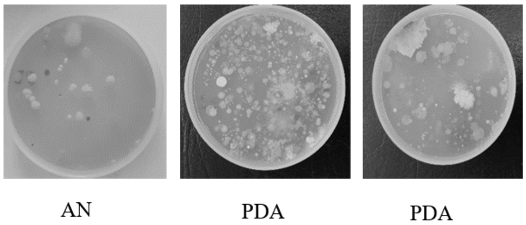

Fig. 6. *Bacteria, fungi and basic culture media*

Soil physical - chemical analysis Table 11

			mg/L			Meq/100g			ppm		(us/cm)			gr/cc		
Zone	pH	% M.O	NH4	P	K	Ca	Mg	Fe	Zn	Mn	C. E.	Texture	Structure	DA	DR	Structural Stability
High	5.9 SA	2.0 L	11.3 L	6.6 L	0.6 L	3.2 L	4.2 M	355.8 H	2.39 L	4.8 L	93.9 Not saline	Loose sand	Loose	1.4	2.5	Low
Medium	5.7 SA	1.8 L	9.9 L	5.8 L	0.11 L	3.5 L	3.6 M	348.8 H	1.63 L	3.3 L	88.9 Not saline	Loose sand	Loose	1.5	2.5	Low
Low	6.1 SA	1.1 L	9.1L	6.9 L	0.05 L	4.0 L	3.1 M	224.4 H	1.42 L	2.0 L	82.6 Not saline	Loose sand	Loose	1.6	2.6	Low

Note: pH = alkalinity or acidity, NH4 = ammonium, P = Phosphor, K = Potassium, Ca = Calcium, Mg = Magnesium, Fe = Iron, Mn = Manganese, N = Neutral, SA = Slightly alkaline, H = High, M = Medium, L = Low.

4. Conclusions

This study aimed to contribute to a better understanding of the structure and composition of the Andean high forests. In our knowledge, it is among the first studies addressing the *Polylepis* relict forest.

Although the diversity indexes calculated did not show high values, we found 18 species belonging to 11 families. Based on the number of individuals, the dominant species was *Polylepis reticulata* Hieron which is native for the Ecuadorian Andes. It represents an evidence of an important level of adaptation to the vegetation conditions from high Andes, where the altitude ranges between 4200 - 4600 m and the temperature averages 4ºC.

Our results could characterize a low biological activity and reflect the poor microbiological quality of the soil on which the *Polylepis* forest is located. However, there are few beneficial nematodes representing a great advantage for the elimination of insect pests that could cause diseases for the *Polylepis* and other species that are close to the study area.

We believe that the data reported in this study could be useful to further research about the dynamics of Andean highlands.

5. Acknowledgements

This study is a part of a doctoral thesis supported by Transilvania University of Braşov. The authors would like also to thank to Escuela Superior Politécnica de Chimborazo for their technical and financial support, especially to all the research team of Polylepis project, also to

Ana Cunachi and Franklin Arcos (Biological Sciences and Soils FRN laboratories). Finally, the authors would like to thank to the Environmental Ministry of Ecuador for permit to do this research.

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