academicJournals

Vol. 9(16), pp. 703-715, 30 August, 2014
DOI: 10.5897/SRE2014.5993
Article Number: 919633047062
ISSN 1992-2248 © 2014

http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

Microclimatic gradients in transition zones of Andean forest: A case study of Purace National Park

Angélica María Mosquera[1], Juan Pablo Martínez[2]* and Apolinar Figueroa[2]

[1]Environmental Study Group, University of Cauca, Colombia.
[2]Environmental Study Group, Department of Biology, University of Cauca, Colombia.

Received 3 June, 2014; Accepted 20 August, 2014

This study investigated two transition zones (matrix-forest edge-interior gradient) associated to forest fragments with different degrees of intervention, in an Andean paramo ecosystem located in Puracé National Park (Colombia). The relationship between the structures of vegetation and the spatial dynamics associated with microclimatic variation in each patch of woodland was determined in order to establish the Depth of Edge Influence (DEI). In each fragment, the vegetation was evaluated using transects of 80 x 2 m perpendicular to the margin, corresponding to 30 m of the matrix and 50 m into the woodland. All woody plants were identified, the heights and dominance was the most relevant features to determining the structure of the forest edge. Microclimatic data (humidity, sunlight exposure, air and soil temperature) were measured in transects and mapped using interpolation for determining the spatial dynamics in each gradient and the behavior of the variables associated with the DEI. The results obtained indicate that the change of microclimatic variables was significant in the margin-forest edge-interior gradient when comparing the forest fragments. The differences are related to the degree of human intervention, since the pressure exerted on certain plant species determined the spatial arrangement of these plants in the gradient. On mapping the dynamics of the microclimatic variables and their relationship to the distance in the gradient, a depth of edge influence was identified of 10 m for the fragment with less intervention (Woodland 2) and 20 m for the one with most intervention (Woodland 1).

Key words: Paramo, ecotone, edge effect, gradient, microclimate.

INTRODUCTION

One of the main threats to paramo ecosystems in Colombia is fragmentation (Armenteras et al., 2003). Landscape ecology defines fragmentation as the breaking up of a habitat, ecosystem or land-use type into smaller patches (Llausàs and Nogué, 2012), isolated from each other in a matrix of different habitats (Haila, 2002; Di Giulio et al., 2009; Conceição and de Oliveira, 2010). Fragmentation involves changes in the biotic and abiotic factors of these patches of Andean forest (Sarmiento, 2002; Aubad et al., 2008), where microclimatic

*Corresponding author. E-mail: juanpabmartinez@gmail.com, Tel: 57 092 8361351 - 57 092 8209800, 57 3164015901, Ext. 2645. Fax: 57 092 8209860.

variations are found between the edge of the forest fragments and the matrix. This variation has been attributed to the increase of the transition zones, where the influence of the matrix on the fragment generates significant changes in humidity, air temperature, light exposure, evapotranspiration and wind speed from the edge inward, which lead to substantial changes in the ecological processes and biological communities (Davies-Colley et al., 2000; Fletcher, 2005; Harper et al., 2005; Porensky and Young, 2013).

The transition zones are frontier habitats whose ecological characteristics are different from the adjacent habitats (Ries et al., 2004), consisting of two or more adjacent edges separated by a border zone. Border is the outer edge of an element of the landscape where the atmosphere is significantly different from the inside, presenting various microclimatic, soil and biological characteristics (Hardt et al., 2013). A characteristic of these environments is the interaction between them, which means that they have a controlling influence on the flows of material and energy that occur among different components of the units that they make up (Didham and Ewers, 2012). Microclimatic gradients in the transition zones play an important role as they are closely related to the plant communities that they comprise and the structure shown by the dominant species (Hoffmann et al., 2004).

The generation of forest edges in the Andean páramo ecosystems of the Cauca Department in southwestern Colombia has increased as a result of human activities (disturbance regime) carried out in the area (logging, burning, tourism and agricultural frontier expansion) causing the degradation of these natural systems (Martínez et al., 2009). This situation, has created transition zones where the microclimatic changes are exerting a significant control on the distribution and availability of plant species that make up the woodland patches and on the depth of edge influence (Mosquera and Figueroa, 2009).

On the basis of the above review of literature and the problem of land cover change and fragmentation in paramo. The present study aims to evaluate the dynamic of microclimatic variables in the transition zones, establishing the depth of edge influence in forest fragments with two degrees of intervention in those ecosystem; this research will be useful for further planning and management of the selected conservation area and also will be effective to enhance the environmental management of high Andean national parks.

METHODS

Study area

The study area is located in the northeast of Puracé National Park (PNNP) in the municipality of Puracé (Cauca), between the maximum and minimum geographical coordinates of N: 2°22'54.99'' - W: 76°19'49.89'' and N: 2°21'21.61'' - W: 76°22'09.17''. It is named the *Laguna de San Rafael* sector with 3,300 and 3,450 masl. The average temperature ranges between 9 and 12°C. It has a unimodal-biseasonal rainfall with an average annual rainfall of 2,284.39 mm, classifying the San Rafael area as wet seasonal (Rangel, 2002). The vegetation cover forms a mosaic characterized by patches of Andean páramo woodland within an herbaceous matrix consisting mainly of a grassland-frailejón mixture (Figure 1).

Selection of the sampling sites (transition zone) was carried out. Two wooded areas (patches) were chosen with similar conditions of slope, sunlight exposure and aspect. The two areas featured different levels of intervention and were identified as woodland W1- with a high degree of human intervention and woodland W2, having less intervention. Nevertheless, both of the patches chosen have forest edges of the closed type which are characterized as an area covered with dense vegetation composed by similar species to those found before the disruption (Didham and Ewers, 2012).

Characterization of microclimatic variables in the transition zones

Six transects were established in two forest fragments (Patch) with different degrees of intervention, considering a presence-absence matrix analysis which included activities like logging, cattle grazing, burning, tourism and the expansion of agricultural frontier. For each patch, measurements were taken in the morning (08 h 00 – 10 h 00), in the middle of the day (12 h 00 – 13 h 00) and in the afternoon (15 h 00 and 16 h 00) for three consecutive days each month per four months, taking into account the direction of the transects (south-north, northeast and northwest) and the climate dynamics of the area (rainfall) (Figure 2a). Each transect was 80 m totally length, 50 m extended into the woodland and 30 m into the adjacent area (matrix). The border is considered the initial point from which these distances are established (Figure 2b).

Solar radiation, relative humidity, air and soil temperature were the microclimatic variables evaluated in the edges, considering the methodological references outlined by Williams-Linera et al. (1998). The first three parameters were measured at 1m height above ground level. To measure solar radiation, a heavy duty light meter model 407026 and datalogger module, model 3800340 (Extech), were used. The logger recorded five data every 15 s for a time of 3 s. The air temperature and relative humidity were recorded with a Thermo-hygrometer (CE). Soil temperature was measured at a depth of 5 cm using a soil thermometer (Brixco). Measurements were made every 10 m from the boundary into the forest fragment and every 5 m from the boundary towards the matrix.

Study of vegetation architecture in the matrix-edge-fragment gradient

In each transect (matrix-edge-fragment) defined for the study of microclimatic variables, nested plots were established to identify the structure of plant communities (abundance and height), determining the presence of species in three vegetation strata: Arboreal, shrub and herbaceous (Figure 3).

Spatial analysis of microclimatic gradients in the transition zones

To study the spatial distribution of the microclimatic variables in the defined gradients, an interpolation procedure was used, based on longitudinal registration at each of the points where the parameters of solar radiation, relative humidity, air and soil temperature were sampled. The ArcGIS 9.2 platform was used, running the Kriging interpolation technique that has been applied to similar analyses

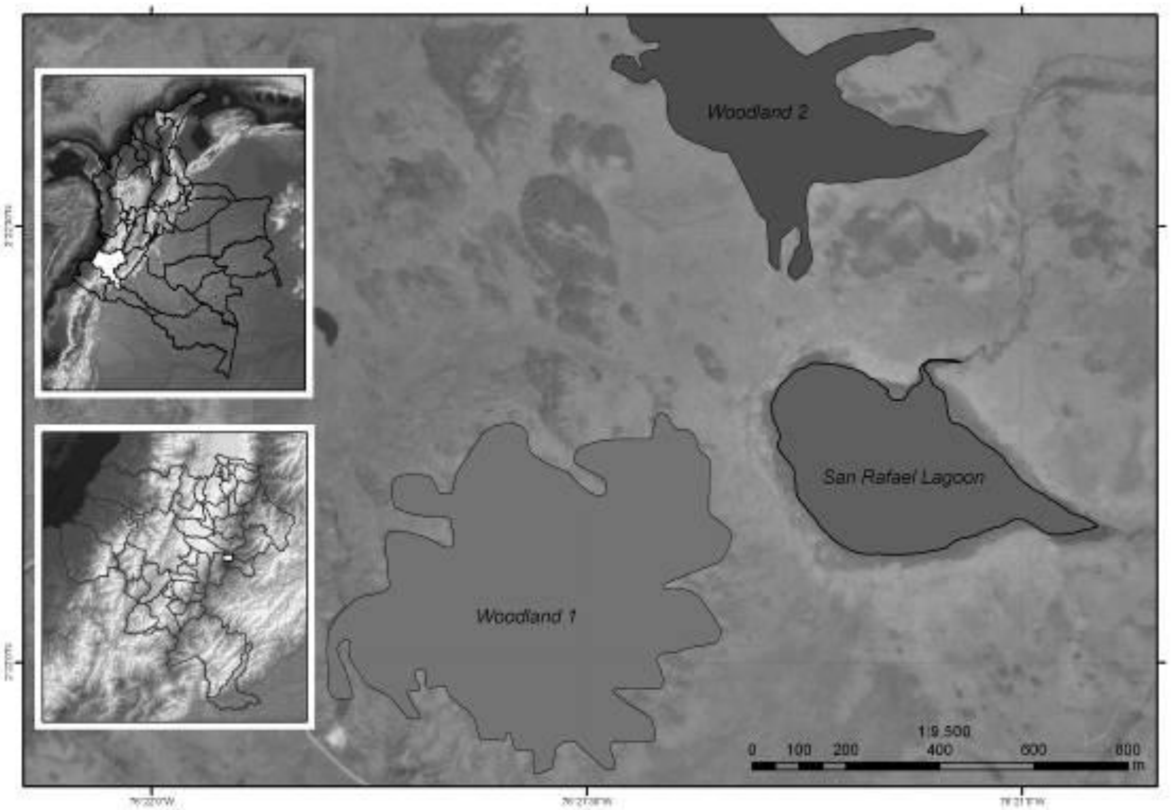

Figure 1. Map of study area.

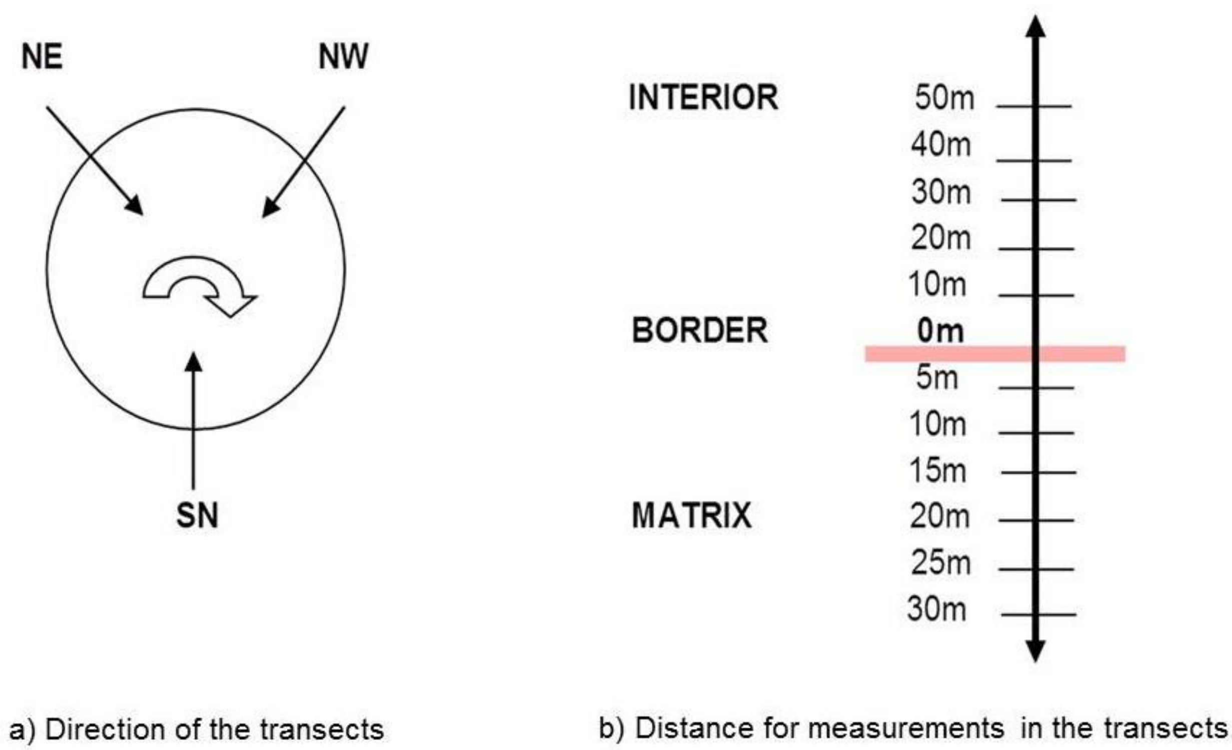

Figure 2. Microclimatic variables assessment; (a) Direction and (b) Distance for measurements in transects.

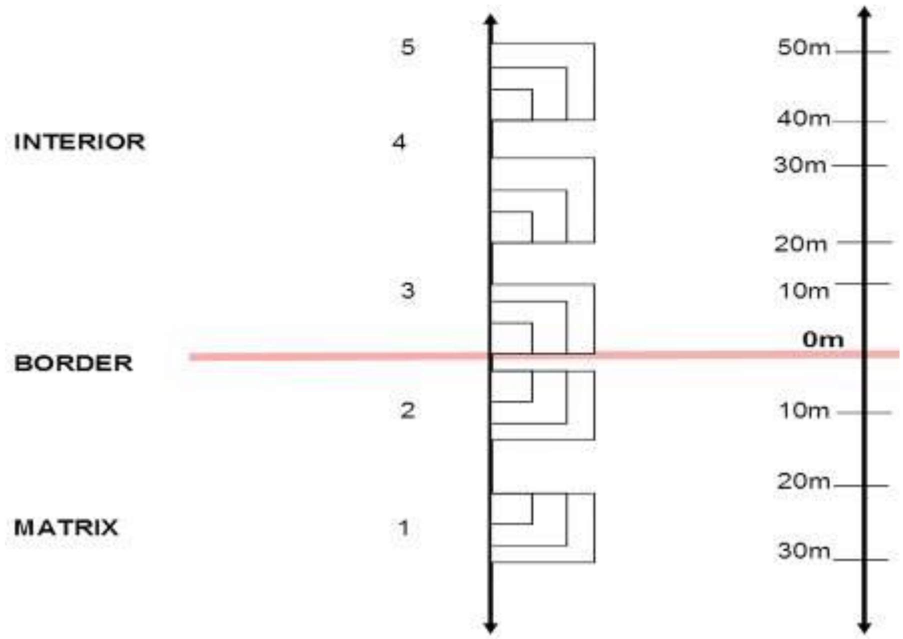

Figure 3. Nested plots established for the identification of plant species across the matrix-edge-fragment gradient.

(Liu et al., 2006; Mubiru et al., 2007). Essentially this geostatistical method allows the analysis of the spatial variation of the microclimatic variables (attribute Z in the series of points), considering a statistically homogeneous distribution along the gradient. The procedure was developed following these steps:

i) Generation of map points for each gradient: Based on geographical coordinates and the azimuth of each transects, each sampling points was mapped. The location of each point and its attribute (environmental variable) was saved in a Geo-database for ArcGis.
ii) Application of interpolation method: The Kriging method was used to generate a map with the distribution of microclimatic variables in each gradient for the two patches.
iii) Mapping the DEI in the woodland fragments: A map overlaying process integrating plant cover with the surface map of microclimatic variables was carried out to determine the depth of edge influence in each forest fragment. The obtained data were collated with the results of the statistical analysis to confirm the variations found.

Data analysis

The analysis done for the microclimatic variables along the gradient (matrix-edge-fragment) in the two transition zones was as follows:

(i) Parametric test, such as factorial ANOVA, complemented by multiple comparison tests for homogeneous variances (data for the sites satisfy homogeneity of variance: Levene: $p > 0.05$). This was done in order to analyze whether the hours the samples were taken (8 h 00-10 h 00, 12 h 00 -13 h 00, and 15 h 00 to 16 h 00) had any influence on the sites (forest W1, showing more human disturbance and W2 with less) and on the type of location (matrix-edge-fragment), or if instead they acted independently.
(ii) Similarly, a Pearson correlation test was performed to observe how distance affects each variable measured at the three different hours (measurement times). To get a better representation of the data obtained over the four months, the average of these data was used, taking account of the fact that the statistical analysis indicated no significant differences in the incidence of the months and the time of sampling in the variables measured.

The statistical tests were performed using the statistical program SPSS version 11.5. With regard to the plant species, a floristic similarity study (Jaccard quantitative index) was conducted for the two sampled forest fragments and a cluster analysis carried out in order to identify the distributed species along the matrix-edge-fragment gradient. This analysis was carried out using TWISPAN giving a measure of similarity or dissimilarity between groups of plots, so that a reliable classification could be performed.

The human impact degree was established by qualitative analysis, a presence-absence matrix was applied to determine the existence of human activities in selected fragments. To define the impact degree, the accumulation of activities in each unit (fragment) was estimated establishing a proportionality relationship in which the most number of interventions found was the higher human impact degree (Table 1). As seen in Table 1, the degree of human impact of W1 corresponds to a rate of 100% due to the many man-made activities, whereas for W2 the rate is 25%.

RESULTS

Species composition in transition zones

In terms of the species composition for the two forest types, it was found that the family with the highest number of individuals in the two patches is *Cunoniaceae*, with 53 individuals, equivalent to 13.25% of the total of individuals for woodland W1, followed by *Melastomataceae* family, with 11.5% (46 individuals),

Table 1. Human impact degree in the forest fragments studied.

Activities \ Fragment of woodland	Woodland 1 (W1)		Woodland 2 (W2)	
	Presence	**Absence**	**Presence**	**Absence**
Logging	X			X
Burning	X			X
Cattle grazing	X			X
Tourism	X		X	
Total	**4**	**0**	**1**	**3**
Proportion	**4:0**		**1:3**	
Degree	**Impact(100%)**		**Less impact (25%)**	

Asteraceae with 11% (44 individuals), *Chloranthaceae* and *Clusiaceae* families with 9.75% (each with 39 individuals). For woodland W2, it was found 60 individuals from *Cunoniaceae* family, 15.62%, *Melastomataceae* with 10.9% (42 individuals), *Asteraceae* with 10.4% (40 individuals), *Ericaceae* with 7.2% (28 individuals) and *Poaceae* with 6.25% (24 individuals). For both fragments, the *Weinmannia mariquitae* and *Hedyosmum cumbalense* species are those that show the highest density and relative frequency, being the top value for individual abundance species and a spatial distribution extending uniformly into the forest fragment. They are followed by *Clusia multiflora* for W1 and *Symplocos quitensis* for W2. Towards the matrix, the species that show the highest relative frequency, for both woodland fragments, are *Espeletia hartwegiana*, *Calamagrostis effusa* and *Cortaderia nitida*. The most representative species for the two forest types are:

(i) W1 (high human impact)
Interior: *W. mariquitae* and *C. multiflora*
Edge: *Diphostephium shultzii, Hesperomeles obtusifolia, Miconia salicifolia, Monina obtusifolia and Gaiadendron punctanum* (exclusive to the transition zone).
Matrix*: Hypericum valleanum, C. nítida* and *E. hartwegiana.*
(ii) W2 (low human impact)
Interior: *W. mariquitae, H. cumbalense* and *S. quitensis.*
Edge: *Diphostephium spinulosum, E. hartwegiana.* and *G. punctanum* (exclusive to the transition zone).
Matrix*: C. nítida, C. effusa* and *Blechum loxense*

In addition to these, in both patches several species were found distributed across the whole gradient, including *Pernettya prostrate*, *Diphostephium tricopus* and *Pentacalia floribundum*. Considering the individuals sampled in the two patches of forest, a total of 86 species were found, of which 19 were exclusive to W1, 22 to W2, and 45 shared (52.33%). The two regions shared 28 families out of a total of 42, six families appearing exclusively in W1 and eight only in W2. The Jaccard index (0.52) shows low similarity for the two forest fragments, because the W1 patch had more human activities (livestock, logging and burn), additional to the climatic factors acting differently upon the two woodlands.

In a similar way, the cluster analysis indicated that the three locations had specific vegetation which determines the arrangement of the matrix-edge-forest gradient for each patch (Table 2).

Microclimatic variables in transition zones

The microclimatic variables data for the four sampling months were averaged to determine the trend of the values along the gradient (matrix-edge-fragment); in the following Table 3, the values are compared for each type of forest. The data obtained from the statistical analysis for each environmental variable measured in the two forest types are presented below, to determining the incidence of these factors on the behavior of the variables. The numbers in bold represent the significant values with a confidence interval of 95%, the signs (+) and (-) in the correlation indicate the type of correlation given for the variables (Table 4).

Spatial dynamics associated with microclimatic variation in each forest fragment

For the spatial dynamics analysis, four maps were made in which the measured microclimatic variables (relative humidity, air temperature, soil temperature and light exposure) were compared in both forest types and the three established transects in order to determine the depth of edge influence (DEI) in the different woodland fragments. The interpolation map generated shows that there is differentiation between the woodland interior and the matrix, the relative humidity measured in both forest types is higher inside the forest than in the matrix. The top human impact woodland, W1, reveals a strip towards the forest edge area in which the matrix-edge-fragment gradient can be made out (darker colors to the inside that begin fading towards the edge and the matrix) and in a direct correlation with the relative humidity values

Table 2. Plant height in relation to the gradient established in the two forest types.

	Location	Gradient (distance)	Plant species with the highest top	Plant height - average (m)
Woodland 1 (high human impact)	Matrix	-30 m	*Cortaderia nitida*	1.0
		-25 m	*Hypericum valleanum*	1.2
		-20 m	*Espeletia hartwegiana*	1.5
		-15 m	*Pentacalia tricopus*	1.6
		-10 m	*Miconia salicifolia*	1.8
	Edge	- 5 m	*Diplostephium shultzii*	2.2
		0 m	*Herperomeles obtusifolia*	2.6
		10 m	*Gaiadendron punctanum*	4.0
	Interior	20 m	*Monina obtusifolia*	7.0
		30 m	*Weinmania mariquitae*	10.0
		40 m	*Clusia multiflora*	11.0
		50 m	*W. mariquitae*	12.0
Woodland 2 (low human impact)	Matrix	-30 m	*C. nitida*	0.5
		-25 m	*Calamagrostis effusa*	0.7
		-20 m	*Blechum loxense*	0.9
		-15 m	*C. nitida*	1.5
		-10 m	*E. hartwegiana*	1.4
	Edge	- 5 m	*Diplostephium spinulosum*	1.6
		0 m	*G. punctanum*	4.3
		10 m	*Hedyosmun cumbalense*	6.3
	Interior	20 m	*W. mariquitae*	8.0
		30 m	*Symplocos quitensis*	9.0
		40 m	*W. mariquitae*	12.0
		50 m	*W. mariquitae*	14.0

Table 3. Averages and standard deviation of microclimate variables measured in the matrix-edge-fragment gradient for the two forest types.

Woodland W1 (High human impact)

Variable \ Distance (m)	Matrix							Woodland fragment				
	30	25	20	15	10	5	0	10	20	30	40	50
Relative humidity (%)	55.0	59.0	60.5	61.1	62.6	64.2	65.5	66.1	71.7	76.6	80.1	82.6
SD	1.29	0.82	0.68	0.41	1.05	0.97	0.94	0.99	1.5	2.32	2.20	2.37
Air temperature (°C)	15.8	15.4	15.0	14.6	14.4	13.8	13.4	13.0	12.0	11.4	10.5	10.1
SD	0.72	0.10	0.38	0.42	0.44	0.15	0.15	0.29	0.39	0.44	0.28	0.33
Soil temperature (°C)	11.5	11.4	10.8	10.5	10.3	10.0	9.5	8.7	8.3	7.9	7.7	7.5
SD	0.12	0.15	0.41	0.30	0.42	0.29	0.34	0.11	0.08	0.35	0.24	0.25
Light exposure (lux)	34.6	31.6	29.7	28.1	26.7	24.8	22.8	9.5	4.5	2.8	2.3	1.8
SD	1.37	0.49	0.46	0.25	1.08	1.36	1.55	0.31	0.35	0.25	0.58	0.14

Woodland W2 (Low human impact)

Variable \ Distance (m)	Matrix							Woodland fragment				
	30	25	20	15	10	5	0	10	20	30	40	50
Relative humidity (%)	58.8	60.3	61.2	62.4	62.8	63.2	65.3	67.3	73.5	78.6	82.0	85.5
SD	0.79	0.41	0.27	0.71	0.61	0.32	0.85	0.53	1.34	2.47	2.08	1.38
Air temperature (°C)	15.0	14.7	14.4	14.2	14.0	13.5	13.0	12.5	11.6	10.8	10.1	9.6
SD	0.28	0.32	0.37	0.17	0.31	0.12	0.06	0.24	0.18	0.13	0.10	0.37
Soil temperature (°C)	11.1	10.7	10.6	10.2	10.0	9.6	9.2	8.4	8.0	7.7	7.5	7.0
SD	0.17	0.25	0.14	0.14	0.18	0.15	0.22	0.05	0.10	0.14	0.03	0.06
Light exposure (lux)	30.8	28.8	27.4	25.8	23.8	23.2	21.1	6.3	1.9	1.0	0.6	0.4
SD	2.60	2.05	1.82	1.86	0.39	1.29	1.91	0.11	0.05	0.13	0.03	0.04

Table 4. The p-values (significance) for the ANOVA test.

Factors	Relative humidity	Air temperature	Soil temperature	Light exposure
Sampling hour	0.18	0.82	0.17	**0.051**
Site (W1 - W2)	**0.00**	0.70	0.06	**0.042**
Location (matrix, fragment)	**0.00**	**0.00**	**0.00**	**0.00**
Distance	**0.00**	**0.00**	**0.03**	**0.00**
Sampling hour-Sites interaction	0.29	0.96	0.06	0.77
Sampling hour-Location interaction	0.45	0.72	0.36	0.07
Sampling hour-Distance interaction	0.72	0.69	0.99	0.89
Sites–Location interaction	0.19	0.25	0.67	0.20
Pearson correlation (Distance)	**0.00 (+)**	**0.00 (-)**	**0.00 (-)**	**0.00 (-)**

recorded. In forest W2 with less human impact, the edge-fragment gradient is not so clearly displayed due to the fact that the relative humidity in these forests is more homogeneous (the presence of higher values of relative humidity towards the forest edge can be attributed to the architecture of the plant species) (Figure 4).

The maps of air and soil temperature (Figures 4 and 5) indicate that the data are not significant because it is not so clear where the forest edge extends toward the matrix-edge-fragment gradient. This is consistent with the statistical significance analysis for the measurements of microclimatic variables (Table 3), in which it is specified that the air and soil temperature variables are not significant for this type of variable measured in the two forest types. However, the higher values were found towards the matrix and lower inside the forest. As relative humidity, the light exposure map reveals a darker strip towards the interior of the forest fragment (from 10 m onwards in W2 and 20 m in W1) and fading towards the matrix and forest edge, due to the availability of plant species (shrubs and grasses present in the matrix and forest edge) that configure the gradient (Figure 5).

ANALYSIS AND DISCUSSION

According to the results, the relative humidity showed a clear distinction between the matrix and the forest fragment. At the matrix, this variable has lower values ranging from 55 to 57% for both woodland types, but increase toward the forest interior to reach 87% in the low human impact forest (W2) and 85% for the higher impact fragment (W1)(Figure 6). Similarly, a homogeneous behavior is presented from the matrix up to 10 m in W2, from this point, the relative humidity increases toward the core of the forest; while in the W1 forest the variable increases since 20 m. The increase in relative humidity inside the forest W2, from 10 m, is favored by the vegetation architecture where the majority of species in the arboreal strata are *W. mariquitae* and *S. quitensis*, with heights between 9 and 14 m keeping the forest humidity. The significance and correlation tests, show that sampling hours (08 h 00 - 10 h 00, 12 h 00 - 13 h 00 and 15 h 00 - 16 h) do not influence the meaning of the data; however, the intervention degree, location and distance do significantly influence the variable, but there is no interaction between the factors (acting independently).

The air temperature for the two forest types ranged between 16 and 9°C, showing changes in function of distance and location type (matrix-interior) (Figure 6). The trend for this variable in the matrix-edge-fragment gradient showed higher values outside the forest, reaching 16 ºC for W1 and 15 °C for W2. Inside the forest, the values vary from 9 to 10 ºC respectively. There was a change in the variable (decrease) at 10 m inside the forest for W1 and 20 m for W2, due to vegetation cover and moisture conditions found in the two areas. The sunlight exposure, air and soil temperature, decline across the gradient inverse to relative humidity.

Soil temperature measured in the two patches showed a similar dynamic to air temperature, the sampling hour had no effect on the variable, although distance and location were significant (Figure 6). Along the gradient, the value for soil temperature declines steadily, with higher values in the matrix (9 and 12°C) and lowers inside the forest (8 and 7°C). In forest W1 this variable changes significantly at a depth of 10 m, while in the W2 forest this change occurs at 20 m. The human activities have reduced vegetation cover increasing the light penetration inside the patch, promoting the presence of low bushes such as *Diplostephium, Hypericum* and *Espeletia* toward the edge, creating the transition zone.

Considering the four variables, the light exposure was the only showing influence. In this study, this variable is the most susceptible to the edge effect found in the disturbed fragments (Figure 6). A clear distinction was seen between the interior of the fragment and the matrix for the light exposure, in the matrix was found higher values varies from 21 to 35 lux while data inside the forest ranges from 0.4 to 10 lux in the two patches. The graphical variation for this variable has a pronounced inflection point at 10 m inside the forest W1 and 20 m for W2, showing two independent data groups.

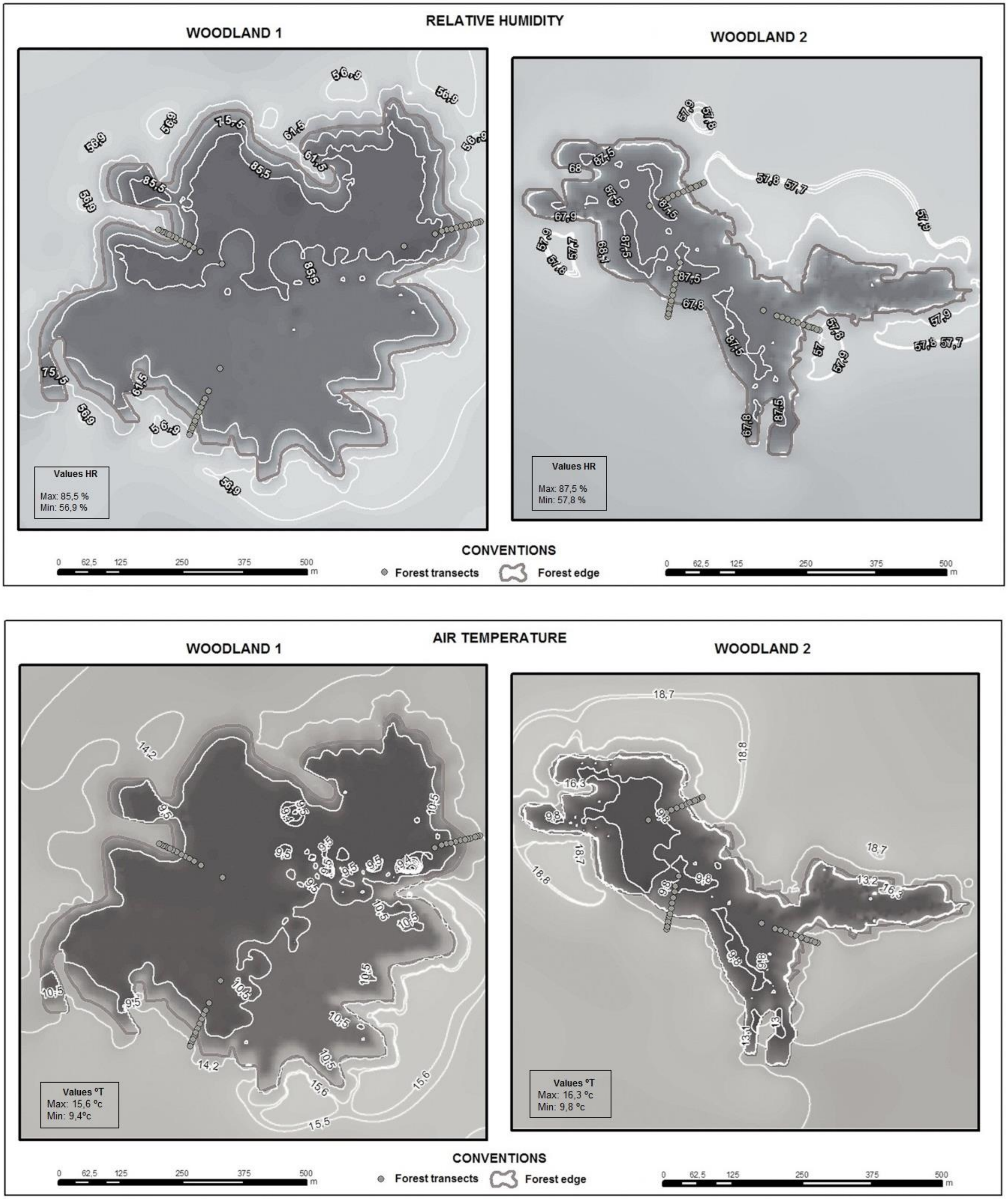

Figure 4. Data interpolation maps relative humidity and air temperature for the two types of forest.

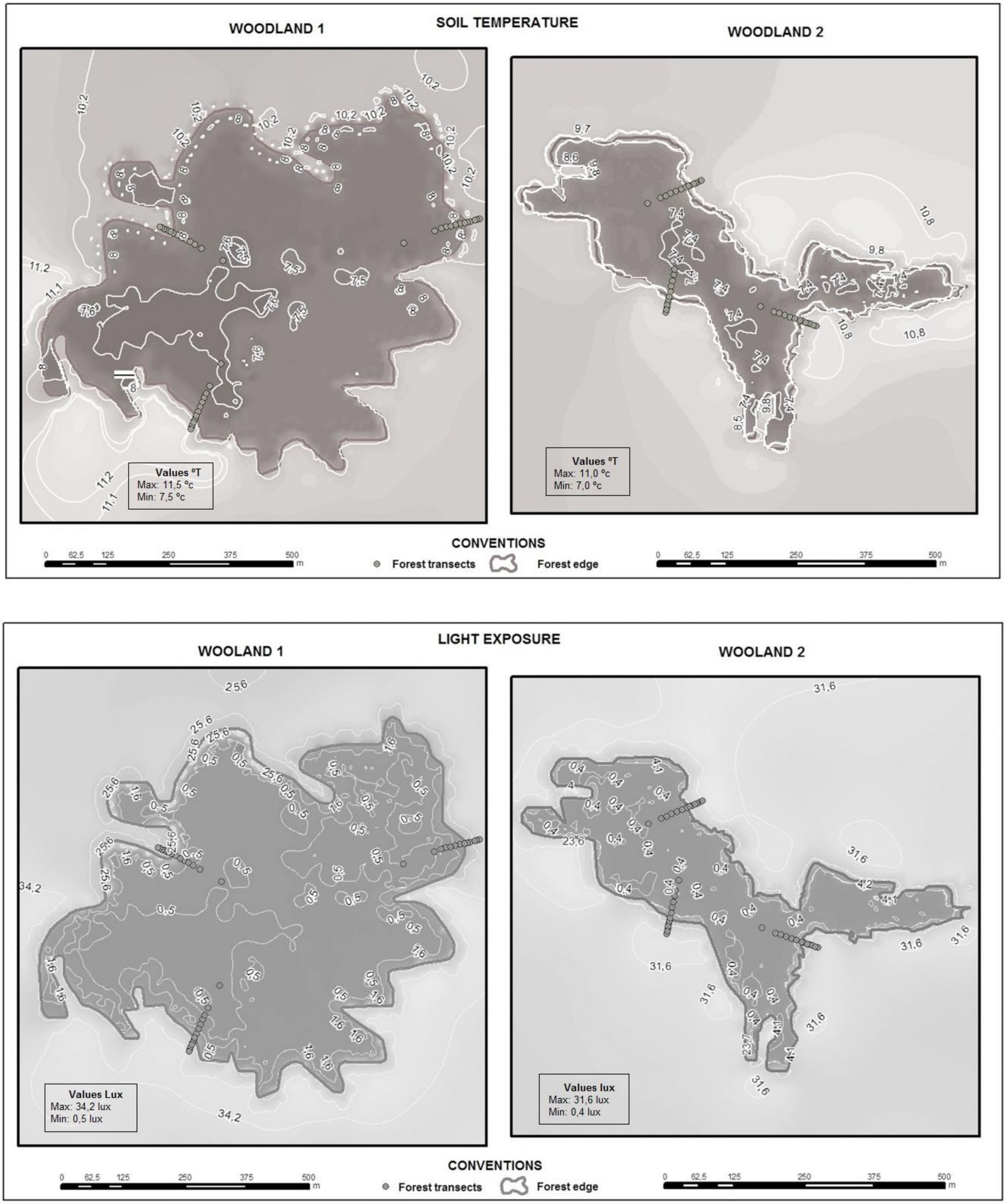

Figure 5. Data interpolation maps soil temperature and light exposure for the two forest types.

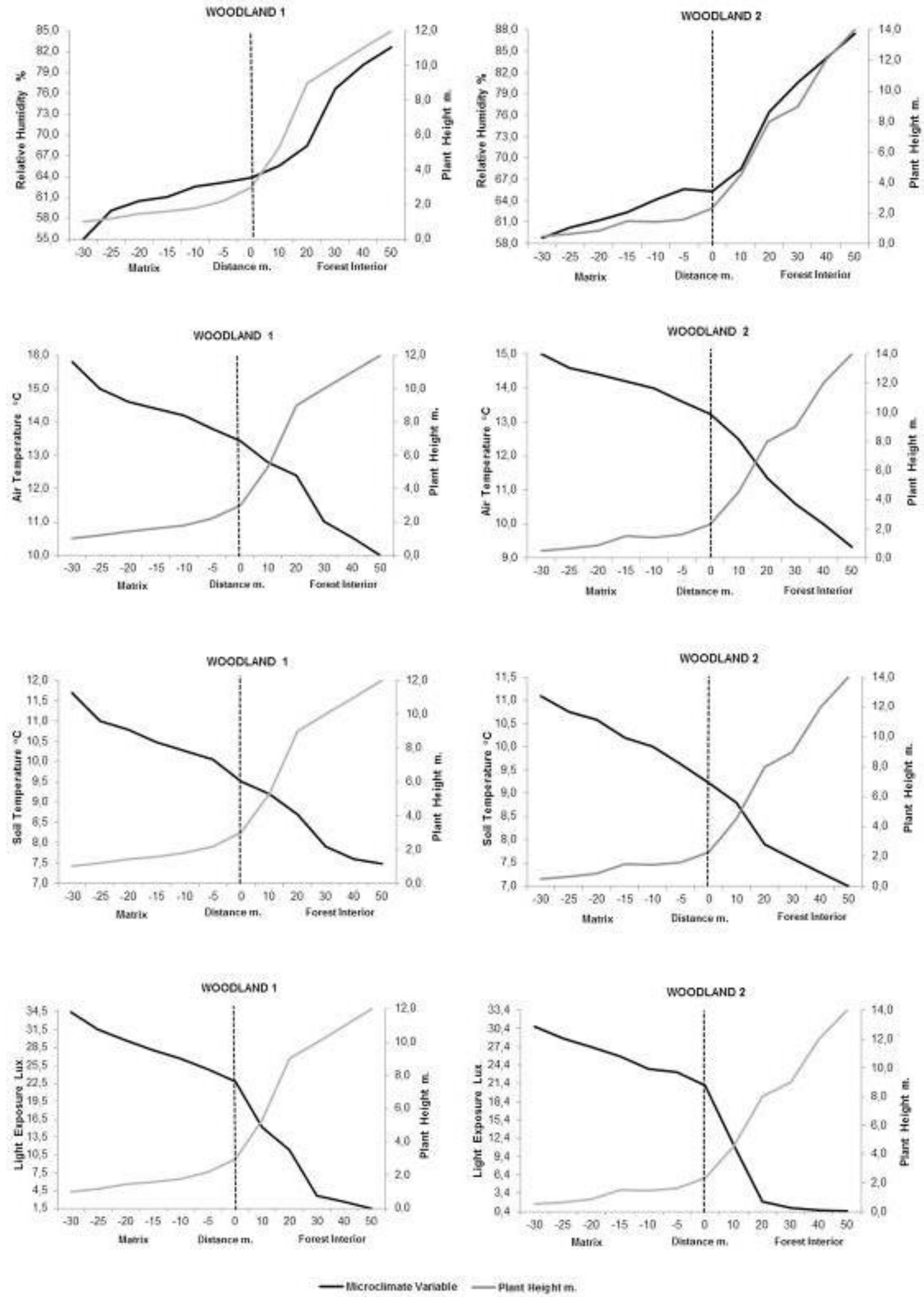

Figure 6. Microclimatic variable measurements (black solid line) vs. plant height (gray solid line), the names of the plant species are found in Table 4.

The change in the light exposure for the two patches is determined by mature tree structures and dense canopies toward the core of the fragments. The tree species present in W1 was *W. mariquitae*, *C. multiflora* and *M. obtusifolia* whit heights between 7 and 12 m, in W2 patch *W. mariquitae*, *S. quitensis* and *H. cumbalense,* with heights between 9 and 14 m. Correlations among distance and measured variables were significant mostly negative, then an increase in the distance toward the forest core reduce the value of light exposure, air and soil temperature. In contrast, the correlation for relative humidity was positive; so inside the forest is wet while the exterior (matrix) is drier.

Relative humidity and light exposure had a significant influence in both forest areas evaluated, reporting high values of light exposure in W1, with a lower relative humidity. In contrast, W2 was more humid, with less light due to the structure and composition of the vegetation cover. This is related to microclimatic parameters for forest edges usually depending on or correlating with the vegetation structure (Hennenberg et al., 2005; Mosquera et al., 2009).

Integrating the data of microclimatic variables and the distribution of vegetation in the two forest types, especially the relative humidity and light exposure, it was identified for W1 an edge influence (DEI) of a 20 m depth into the forest and a 10 m DEI for W2. The DEI found for W2 (10 m) relates to the type of surrounding matrix, with shrubs taller than those of W1 (*W. mariquitae, H. cumbalense*), and forest edge species (*D. spinulosum E. hartwegiana* and *G. punctatum*) that allow climate regulation in the forest interior, thereby reducing the microclimate effects of the matrix, lending it a self-regulatory capacity.

In contrast; the DEI reported for W1 (20 m) results from logging, cattle grazing, burning and tourism in the area, reducing the arboreal strata and leads to microclimatic changes, affecting the structure of vegetation and the environmental conditions beneath the canopy (Hennenberg et al., 2008; Montenegro and Vargas, 2008).

Different research considered the human intervention in forest fragments as determinant in woodland dynamics at local and regional scales, since the type and intensity of the disturbance can alter the structure and floristic composition of lowland and mountain forests (Fahrig, 2001; Ramírez-Marcial et al., 2001; Montenegro and Vargas, 2008). That explain the changes observed in the transition zone of W1 patch, where the microclimatic conditions and successional processes are altered, forming a type of edge habitat composed by low-height vegetation (Gascon et al., 1999; Rodríguez et al., 2007; Mosquera et al., 2009).

The results would allow classify the forest edge found as “closed” according to the reported studies of Williams-Linera et al. (1998) and Didham and Lawton (1999) for open and closed forest edge types, considering the closed edges have a lower affectation by abiotic factors, such as sunlight radiation and wind, than those with an open type edge (over 20 m).

In this study, several species (*P. prostrata, P. tricopus and D. floribundum*) were found to be distributed across the gradient for both forest types. These species become vital in the forest conservation and regeneration, as they could facilitate the vegetal succession, allowing in the future the establishment of arboreal strata typical of mature forest softening the influence of the paramo open matrix.

Finally it is proposed that plant species found in the boundary zone could be included in further studies, as they constitute important elements in the restoration of forest fragments, due to their tolerance of both habitats. These same species could promote the forest expansion and contribute to regulating environmental conditions, creating a stable and protected habitat. Thereby, success in the conservation of areas with degraded forest edge (transition) zones is necessary to consider the particular characteristics of the forest border, as these areas can either help facilitate the process or prevent it in cases where they only help to maintain degradative trends in the woodland patches, precluding the development of species from the forest into the matrix (Brotons et al., 2005; Armenteras et al., 2009; Riutta et al., 2012; Dupuch and Fortin, 2013).

Conclusions

The DEI for the forest fragments tested was determined in a range from 10 to 20 m, considering the dynamics of the environmental variables measured (relative humidity, air and soil temperature, and light intensity) and the presence of forest edge species in the gradients (matrix-edge-interior). This DEI range is proposed for forest fragments with similar conditions. Microclimatic differences were found in the two forests studied (W1 and W2), the forest W1 is more exposed to microclimatic changes resulting from perturbations such as cattle grazing and burning. Those conditions determine the availability of specific environments and the vegetation arrangement to configure the matrix-edge-interior gradient in each forest type. The results reveal the consequences of ecosystem fragmentation on Colombian high Andean landscapes and provide key information to focus future research on the edge effect in paramos. This information, enhance the understanding of microclimatic zones in andean forest patchs to improve the environmental management plans to conserve natural areas susceptible to fragmentation.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

To Natural National Parks Network (South-Andean office) and especially to Puracé National Park for logistical support and trust, to the Indigenous Council of Puracé (Cauca) and to the Environmental Study Group (GEA - University of Cauca) for their help and support in this work.

REFERENCES

Armenteras D, Gast F, Villareal H (2003). Andean forest fragmentation and the representativeness of protected natural areas in the eastern Andes, Colombia. Biol. Conservation 113(2):245-256. DOI: 10.1016/S0006-3207(02)00359-2.

Armenteras D, Rodríguez N, Retana J (2009). Are conservation strategies effective in avoiding the deforestation of the Colombian Guyana Shield? Biological Conservation 142(7):1411-1419. DOI: 10.1016/j.biocon.2009.02.002.

Aubad J, Aragón P, Olalla-Tárraga MÁ, Rodríguez MÁ (2008). Illegal logging, landscape structure and the variation of tree species richness across North Andean forest remnants. For. Ecol. Manage. 255(5-6):1892-1899. DOI: 10.1016/j.foreco.2007.12.011.

Brotons L, Wolff A, Paulus G, Martin JL (2005). Effect of adjacent agricultural habitat on the distribution of passerines in natural grasslands. Biol. Conservation 124(3):407-414. DOI: 10.1016/j.biocon.2005.01.046.

Conceição KS, de Oliveira VM (2010). Habitat fragmentation effects on biodiversity patterns. Physica A: Statistical Mechanics and its Applications 389(17):3496-3502. http://dx.doi.org/10.1016/j.physa.2010.04.036.

Davies-Colley R, Payne G, Van Elswijk M (2000). Microclimate gradients across a forest edge. New Zealand J. Ecol. 24(2):111-121.

Di Giulio M, Holderegger R, Tobias S (2009). Effects of habitat and landscape fragmentation on humans and biodiversity in densely populated landscapes. J. Environ. Manage. 90(10):2959-2968. http://dx.doi.org/10.1016/j.jenvman.2009.05.002.

Didham RK, Ewers RM (2012). Predicting the impacts of edge effects in fragmented habitats: Laurance and Yensen's core area model revisited. Biol. Conservation 155(0):104-110. http://dx.doi.org/10.1016/j.biocon.2012.06.019.

Didham RK, Lawton JH (1999). Edge Structure Determines the Magnitude of Changes in Microclimate and Vegetation Structure in Tropical Forest Fragments. Biotropica 31(1):17-30.

Dupuch A, Fortin D (2013). The extent of edge effects increases during post-harvesting forest succession. Biol. Conservation 162(0):9-16. http://dx.doi.org/10.1016/j.biocon.2013.03.023.

Fahrig L (2001). How much habitat is enough? Biological Conservation 100(1):65-74. DOI: 10.1016/S0006-3207(00)00208-1.

Fletcher RJ (2005). Multiple edge effects and their implications in fragmented landscapes. J. Animal Ecol. 74(2): 342-352. 10.2307/3505623.

Gascon C, Lovejoy TE, Bierregaard Jr RO, Malcolm JR, Stouffer PC, Vasconcelos HL, Laurance WF, Zimmerman B, Tocher M, Borges S (1999). Matrix habitat and species richness in tropical forest remnants. Biological Conservation 91(2-3):223-229. DOI: 10.1016/S0006-3207(99)00080-4.

Haila Y (2002). A conceptual genealogy of fragmentation research: from island biogeography to landscape ecology. Ecol. Appl. 12(2):321-334. http://dx.doi.org/10.1890/1051-0761(2002)012[0321:ACGOFR]2.0.CO;2.

Hardt E, Pereira-Silva EFL, Dos Santos RF, Tamashiro JY, Ragazzi S, Lins D B. d. S. (2013). The influence of natural and anthropogenic landscapes on edge effects. Landscape and Urban Planning 120(0):59-69. http://dx.doi.org/10.1016/j.landurbplan.2013.08.014.

Harper K, Macdonald E, Burton P, Chen J, Brosofske K, Saunders S, Euskirchen E, Roberts D, Malanding J, Per- Anders E (2005). Edge influence on forest structure and composition in fragmented landscape. Conservation Biol. 19:768-782. DOI: 10.1111/j.1523-1739.2005.00045.x.

Hennenberg K, Goetze D, Kouame L, Orthmann B, Porembski . (2005). Border and ecotone detection by means of vegetation composition along continuous forest savanna transects in north-eastern Ivory Coast. Vegetation Sci. 16:301-310.

Hennenberg K, Goetze D, Szarzynski J, Orthmann B, Reineking B, Steinke I, Porembski S (2008). Detection of seasonal variability in microclimatic borders and ecotones between forest and savanna. Basic Appl. Ecol. 9:275-285. DOI: 10.1016/j.baae.2007.02.004.

Hoffmann W, Orthen B, Franco A (2004). Constraints to seedling success of savanna and forest trees across the savanna-forest boundary. Oecologia 140:252-260. DOI: 10.1007/s00442-004-1595-2.

Liu T, Juang K, Lee D (2006). Interpolating soil properties using Kriging Combined with Categorical Information of Soil Maps. Soil Sci. Soc. Am. J. 70:1200-1209. 10.2136/sssaj2005.0126.

Llausàs A, Nogué J (2012). Indicators of landscape fragmentation: The case for combining ecological indices and the perceptive approach. Ecological Indicators 15(1):85-91. http://dx.doi.org/10.1016/j.ecolind.2011.08.016.

Martínez J, Figueroa A, Ramírez B (2009). Spatial analysis of land covers change and fragmentation in Puracé National Park. Fragmentation and land cover in Andean ecosystems (Cauca). Figueroa, A. and Valencia, M. Ed. Popayán, Universidad del Cauca: pp. 137-155. ISBN 978-958-732-009-1.

Montenegro A, Vargas O (2008). Caracterización de bordes de bosque altoandino e implicaciones para la restauración ecológica en la Reserva Forestal de Cogua (Colombia). Biología Tropical 56 (3):1543-1556.

Mosquera A, Martínez JP, Figueroa A (2009). Microenvironmental and land cover changes in Andean ecotones. Case Study Sector San Rafael, Puracé National Park. J. Colombian Assoc. Biol. Sci. 21: 135 - 136.

Mubiru J, Karume K, Majaliwa M, Banda E, Otiti T (2007). Interpolating methods for solar radiation in Uganda. Theor. Appl. Climatol. (88):259-263. 10.1007/s00704-006-0248-2.

Porensky LM, Young TP (2013). Edge-Effect Interactions in Fragmented and Patchy Landscapes. Conservation Biology 27(3):509-519. 10.2307/23525330.

Ramírez-Marcial N, González M, Williams-Linera G (2001). Anthropogenic disturbance and tree diversity in montane rain forest in Chiapas, Mexico. For. Ecol. Manage. 154:311-326. DOI: 10.1016/S0378-1127(00)00639-3.

Rangel Oz(2002). Biodiversity in the paramo region: Special reference to Colombia. Congreso Mundial de Páramos. MMA, CAR, IDEAM and Colombia, C. Paipa. I:168-200.

Ries L, Fletcher RJ, Battin J, Sisk TD (2004). Ecological Responses to Habitat Edges: Mechanisms, Models, and Variability Explained. Annual Review of Ecology, Evolution, and Systematics 35:491-522. DOI: 10.1146/annurev.ecolsys.35.112202.130148.

Riutta T, Slade EM, Bebber DP, Taylor ME, Malhi Y, Riordan P, Macdonald DW, Morecroft MD (2012). Experimental evidence for the interacting effects of forest edge, moisture and soil macrofauna on leaf litter decomposition. Soil Biol. Biochem. 49(0):124-131. http://dx.doi.org/10.1016/j.soilbio.2012.02.028.

Rodríguez MA, Aizen MA, Novaro AJ (2007). Habitat fragmentation disrupts a plant-disperser mutualism in the temperate forest of South America. Biol. Conservation 139(1-2):195-202. DOI: 10.1016/j.biocon.2007.06.014.

Sarmiento F (2002). Anthropogenic Change in the Landscapes of Highland Ecuador. Geographical Review 92(2):213-234. DOI: 10.2307/4140971.

Williams-Linera G, Domínguez-Gastelú V, García-Zurita M (1998). Microenvironment and floristics of different edges in a fragmented tropical rainforest. Conservation Biol. 12(5):1091-1102. DOI: 10.1046/j.1523-1739.1998.97262.x.

GLOSSARY

Border zone: Line between the edges of adjacent elements in landscape.

Depth of edge influence (DEI): The extent to how far the edge effects on forest boundaries can penetrate into the patch.

Edge effect: Set of biotic and abiotic effects of the matrix on the forest fragment, which is manifested in changes within the fragment causing variations in the composition and abundance of species at the outer edge of a patch.

Forest edge: Outer forest area that shows the edge effect. This zone is characterized by high density and diversity of species that usually predominate in the outer part of the border.

Paramo: Complex and varied natural ecosystem, endemic to the tropical Andes of Venezuela, Colombia, Ecuador and Peru, since 3,500 to 4,800 masl. It is characterized by low temperatures (7 to 16°C) with sudden climatic changes.

Transition zone: Semi permeable zone that allows the movement of materials and organism through the landscape units. Two different edges and a border zone arrange the boundary or transition zone.