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The bioclimatic belts of the Venezuelan Andes in the State of Mérida

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with 11 figures, 8 tables and 1 appendix

Abstract. In the present paper we have embarked on the study of the various vegetation belts of the Venezuelan Andes in the State of Mérida, using both bioclimatic and vegetation data as a basis for our research. The first step was to divide the area into various transects or belts across the Andes in the Venezuelan range from Lake Maracaibo (75 msl) up to the peaks of the Sierra de la Culata (4,500 msl). In the same way, the range toward the area of the Barinas flats (189 msl) was also divided into transects. Various catenas have been drawn to relate the vegetation of the slopes and peaks with that found in the arid and semiarid inland valleys.

Special emphasis has been placed on relating the altitudinal sequences of vegetation with the data collected from 15 different climate stations located at altitudes from 130 msl to 4,126 msl. The climate data from each station has been analyzed in accordance with the model established by Rivas-Martínez (2004), including the hydric data and graphics, which have been coordinated with the vegetation found in each of the belts studied. After classifying the various belts using the criteria set out by Rivas-Martínez *loc. cit*., we then undertook a comparative analysis of the classifications of the Venezuelan Andes that had previously been carried out by other researchers.

As a result of this study, five thermotypes have been identified for this area: infratropical, thermotropical, mesotropical, supratropical, and orotropical. In addition, four ombrotypes have been established: subhumid, humid, hyperhumid, and semi-arid, with different levels for each type, distributed throughout the different thermotypes. The final result was the identification of 15 different bioclimatic belts for this area.

The results of this study are, we feel, applicable for the management and conservation of this particular terrain.

Keywords: bioclimatology, vegetative formations, biogeography, conservation, land use management.

1 Introduction

Establishing vegetation zones in the Venezuelan Andes and bioclimatic belts has been an objective since the time of Humboldt (1807). He defined various mountainside bands of vegetation zone with a relatively homogene-

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ous appearance and characteristic composition, thereby establishing the first altitudinal stratification of vegetation endemic to the Andes. For Venezuela in particular Goebel (1891) and Jahn (1931) presented the first study containing references to the locations of different types of vegetation, taking as their primary reference the "Páramo" belt. Nevertheless, it was Cuatrecasas (1958) who finally elaborated a proposal, in this case for the northern Andes, which found general acceptance. This proposal has been recently updated by Cleef (1981) and Rangel (2000). Also worth mentioning is the work carried out in the Ecuadorian Andes by Acosta Solis (1968), Harling (1979), Cañadas Cruz (1983), and Jorgensen & Ulloa (1994).

Other important historical antecedents for this type of study for the Venezuelan Andes include the work of Pittier (1938), which established the megathermal, mesothermal, meso-microthermal, and microthermal belts by taking into account the mean annual temperature. Also of interest is the proposal of Ewel, Madriz & Tosi (1976), which on the basis of Holdridge's (1947) method elaborated an ecological map of Venezuela consisting of 22 different life zones. These zones define and delimit a series of altitudinal belts for the tropical region. The life zones recognized in the ecological map elaborated by Marnr (1985) are as follows: Tropical Moist Forest, Tropical Dry Forest, Tropical Very Dry Forest, Tropical Thorn Forest, Premontane Moist Forest, Premontane Dry Forest, Premontane Thorn Forest, Premontane Very Dry Forest, Lower Montane Moist Forest, Lower Montane Dry Forest, Montane Moist Forest, Subalpine Moist Forest, Montane Dry Forest, Premontane Very Dry Forest, Alpine Moist Páramo, and Tundra.

For a summary review of the various proposals that have been made to date, see Petit (1984) and Estrada (2003).

For the specific analysis of the vegetation belts of the Venezuelan Andes, Cuatrecasas's (1958) classification has been taken as the reference by authors such as Vareschi (1970), Sarmiento et al. (1971), Monasterio (1980), Huber & Alarcón (1988), Bono (1996), Luteyn (1999), and Ataroff & Sarmiento (2003). All the research carried out to date has been of great value and adds enormously to the knowledge and understanding of the mechanisms, which influence the distribution of vegetation throughout the Andes. One of the most valuable studies has been that of Monasterio (1980), which characterized both the so-called Andean or lower Páramo belt and the High-Andean or upper Páramo belt for the Venezuelan Páramo, establishing an elevation of 4000 msl as the approximate limit between these zones in this area. Thus, the Andean belt begins at an elevation of 2800 msl and ends at 4000 msl. As such, the permanently snow-capped peaks are considered part of the High-Andean belt. In these belts, seven major types of vegetation or formations have been characterized. The associations were described taking into account classic ecological concepts, morpho-ecological approaches, and fine scale environmental conditions. This results in a classification based on 36 physiognomic-structural associations distributed among the seven formations, which make up the two aforementioned belts. Monasterio's (1980) work was followed by that of Ataroff & Sarmiento (2003), who created a Map of Ecological Units for the State of Mérida, Venezuela.

Another contribution that was important for a better understanding of the vegetation zones of the Venezuelan Andes, was the Map of the Vegetation of Venezuela by Huber & Alarcón (1988), in which the authors represented the mosaic of floristic-physiognomic units organized as belts. This Map establishes a series of units including that of the "Region," the limits of which are based on climatic criteria such as mean annual temperature, average annual rainfall, and altitude (msl). Below the Region are "Subregions," established on the basis of the distribution and extension of the various elements of vegetation and flora. The third hierarchical level of the map is made up of "Sectors," in which geographic-geomorphic criteria are taken into account. Below the Sector level are "Units," which are represented by the types of vegetation that make up the Sector, in this case established with physiognomic-structural criteria.

All the proposals made to date, although of great descriptive value, also have their weaknesses due to the fact that they do not include several of the more important climatic criteria such as maximum and minimum temperatures during the hottest month (the thermicity index). They also ignore various humidity indices such that the proposed units, although important from a physiognomic perspective, lack the bioclimatic data to corroborate their definition. In this paper, we present the definitions and demarcations of the various bioclimatic belts of the Venezuelan Andes in the State of Mérida.

2 Study area

The Venezuelan Andes are formed by two mountain chains: the Andean Range of Mérida and the "Sierra de Perijá", the latter of which forms the western border with neighboring Colombia. The Venezuelan Andes are located between the latitudes 07°30' and 10°20' N, longitude 69°20' W, extending 400 km from southwest to northeast. They constitute a prolongation of the Eastern Range of Colombia, which forks at the junction in Pamplona into the two aforementioned chains. Our study focuses on the eastern branch that comprises the so-called Andes of Mérida, which run from the Táchira depression in the southeast to the Lara depression in the northeast (Vivas 1992). Specifically, we have concentrated on the branch, which forms the Mérida Range, which in turn is divided into two branches by the Chama river. The mid and highest levels of these two branches are protected as National Parks. The southern branch is formed by the "Sierra Nevada de Mérida", in which some of the range's highest peaks, including "Pico Bolivar" (4980 msl) are located, while the northern branch, made up of the so-called Northern Range or "Sierra de la Culata", reaches its highest point at the "Pan de Azúcar" peak (4762 msl) in the Páramo of Piedras Blancas (08°50'N, 71°03'W). Both ranges come together in the orographic junction of the Mucuchíes Páramo, located at 08°52'N 70°49'W at an altitude of 4074 msl. This junction forms two natural passes that serve as important paths of communication. One is situated in the Mucubají saddle and the other at the "Paso del Aguila" (Eagle's Pass). The first connects the Chama and Santo Domingo valleys, leading to the Western Plains, while the second connects the Chama with the Motatán river valley, thus forming a natural path of communication between the central Andes and Lake Maracaibo.

3 Methods

For the Andean range in the region of Mérida, the bioclimatic belts, as delimited by thermic and pluviometric intervals, have never been clearly established. In this paper, we will define and demarcate these belts following the bioclimatic model put forth by Rivas-Martínez (1993, 1994, 1995, 1996, 1997), as well as Rivas-Martínez & Loidi (1999) and Rivas-Martínez et al. (1999). Each belt, along with its endemic vegetation, will be analyzed with the aid of a list of characteristic species. These will then be correlated to the data obtained from the climate stations situated in each established transect, taken when the species are present in the transect and there is enough data. Should this not be the case, the data obtained from stations located in areas with similar conditions will be used in order to make approximate calculations to determine the respective delimitations of each belt.

In this study, we have applied the methodology introduced by Gehu & Rivas-Martínez (1981) and subsequently developed by Rivas-Martínez (1995) in his Bioclimatic Classification of the Earth, to delimit the various bioclimatic and vegetation belts. For these authors, climate constitutes the fundamental factor in the distribution of flora throughout the planet, since both temperature and precipitation directly influence the diverse adaptations that plants undergo to survive and thrive in a given area (Rivas-Martínez 1981, 1984).

We will thus follow the criteria set forth by Rivas-Martínez et al. (1999), who considered the bioclimatic belts to be the particular zones that occur in a given altitudinal or latitudinal climatic series. These, in turn, are delimited by thermoclimatic factors (thermotypes), which take into consideration the thermicity index (It), compensated thermicity index (Itc), and positive temperature (Tp), and by ombroclimatic factors (ombrotypes) determined by the ombrothermic index (Io). All these factors are dynamic and changeable. The goal is to establish for each bioclimatic belt a set of plant species associated with the conditions of the place in order to establish formations and/or specific plant communities, which in turn serve as diagnostic elements for identifying each belt.

In order to define the different bioclimatic belts of the Andes of Mérida, we first demarcated three extensive altitudinal transects as representative of the ecological and vegetative characteristics of this mountain range and its foothill regions stretching from the lake zone in the northwest and to the plains in the southeast.

These transects are situated at different orientations along the two major branches of the Venezuelan Range in the Mérida chain: the "Sierra de la Culata" in the northwest and the "Sierra Nevada de Mérida" to the southeast. In each of the transects the study was conducted from the highest to the lowest altitudes, taking into account the locations of climate stations in which the pluviometric data were collected. In addition, the various mountainous regions of the entire Merida chain were covered in all directions in order to obtain information about the flora, vegetation, ecology, and landscape. All this information has been processed and analyzed in accordance with Rivas-Martínez et al. (1999) methodology with the aim of establishing the bioclimatic belts for this region.

The first transect extends from the shores of Lake Maracaibo (70 msl) to the so-called Páramo of Piedras Blancas (4400 msl). The transect includes part of the Sierra de la Culata, a National Park. The park measures 200,400 ha, and encompasses the mountain peaks as well as their slopes. The mountains and the larger surrounding area outside the park itself contain a great diversity of plant species, many of them endemic, as well as several emblematic animal species, such as the Andean masked bear (*Tremarctos ornatus*) and the Andean condor (*Vultur gryphus*). The transect includes formations described by Ataroff & Sarmiento (2003) as the Andean and high-Andean Páramo (the latter in the highest areas of the transect). The lower belts in the foothills are comprised of cloud forest and montane and basimontane forest which connect with the tropical Moist forest in the lower belt, which reaches to the shores of Lake Maracaibo. At this point, the vegetation consists of edaphohydrophilic flora such as mangroves.

The second transect extends from the Mifafi valley at an altitude of 4400 msl to El Vigía at 130 msl. The highest areas of the transect contain the Páramo-type zones of Piedras Blancas (4400 msl) and the Mifafi Páramo and gorge at the source of the Chama River (4200 msl). From the highest peaks, the transect descends the slopes and folds of the Sierra Nevada of Mérida and the Sierra de la Culata, always via the internal slope which constitutes the Chama Valley, until reaching the Mérida plateau (1490 msl). This transect includes the xerophytic zone of San Juan de Lagunillas (1050 msl), and follows the Chama River until it empties into Lake Maracaibo at an altitude of 130 msl.

The third transect runs between Mucubají peak (3560 msl), in the Sierra Nevada of Mérida, and the city of Barinas at 189 msl. This corresponds to the descent between Mucubají and the plains of the state of Barinas and follows the route of the transandean highway, which runs parallel to the Santo Domingo river. This zone includes part of the Sierra Nevada National Park, declared by a presidential decree number 393 on May 02, 1952.

The same methodology was followed in all three transects; the information obtained from the climate stations in the area was processed and, where there were no stations extant, data from nearby climate stations in similar areas were used. Analyses were made of both the climatic data obtained from the stations and the data concerning flora and vegetation obtained in the field. Once this analysis of the data from the transects outlined above

Table 1. List of the climate stations studied in the Andes in the state of Mérida and their corresponding thermo- and ombrotypes.

Station Name	Altitude (msl)	Thermotypes	Ombrotypes
El Vigía	130	Lower infratropical	Upper subhumid
Barinas	189	Upper infratropical	Lower subhumid
Bocas de Caparo	220	Upper infratropical	Lower humid
La Palmita	600	Lower thermotropical	Lower subhumid
Tovar	952	Lower thermotropical	Lower subhumid
La Azulita	1000	Upper thermotropical	Upper subhumid
San Juan de Lagunillas	1050	Lower thermotropical	Upper semiarid
Mérida – Aeropuerto	1495	Upper thermotropical	Lower humid
Canaguá	1560	Upper thermotropical	Upper subhumid
Santo Domingo	2155	Lower mesotropical	Upper subhumid
La Cuchilla	2280	Lower mesotropical	Lower humid
Mucuchíes	3100	Upper mesotropical	Lower subhumid
Mucubají	3560	Upper supratropical	Upper humid
Los Plantíos	3878	Upper supratropical	Lower humid
Pico El Águila	4126	Upper orotropical	Lower hyperhumid

had been carried out, Rivas-Martínez et al. (1999) methodology was applied. Thus, using as a basis the thermic and pluviometric data obtained from the climate stations located in the area and analyzing them with the computer program DATACLI (Luengo et al. 1996), the corresponding characteristics of each belt and its surroundings could be delimited and defined. The data were taken from a total of 15 climate stations (Table 1) and the result is the characterization of the different bioclimatic belts of the Venezuelan Andes in the state of Mérida.

In the Andean range of Mérida and its foothills, five belts are recognizable, distributed along the lake-side slopes and extending to the plains on the other side of both the Sierra de la Culata and the Sierra Nevada of Mérida, with their respective thermotropic horizons. In this large-scale depiction of belts and horizons, we have listed the various plants that are associated with each of them and which, in turn, characterize and define each belt.

4 Results

We have been able to establish the following bioclimatic belts: Infratropic, Thermotropic, Mesotropic, Supratropic, and Orotropic, outlined in Table 2 with their respective geographic limits, the altitudinal interval they occupy in the mountain chain, and the thermicity index from both the interval in which the zones are located as well as that corresponding to the specific station. The table does not include data for the lower supratropical, the lower orotropical, the upper cryorotropical, or the lower cryorotropical because no climate stations were located in these horizons. Regarding the

Table 2. Thermotypes, limits, intervals, altitudinal ranges and thermal indices in the area of study. Highlighted in bold are the bioclimatic belts present in the Andean Range of Mérida (modified from Rivas-Martínez et al. 1999).

Bioclimatic belts present in the Tropical Macrobioclima	Thermotype horizons	Altitude range (msl)	Itc interval	Itc of the climate stations in the Andes of Mérida
Infratropical	**Lower**	0–200	**810–890**	**811**
Infratropical	**Upper**	180–400	**730–810**	**785–795**
Thermotropical	**Lower**	400–1000	**610–730**	**640–643–716**
Thermotropical	**Upper**	1000–2000	**490–610**	**527–549–578**
Mesotropical	**Lower**	2000–2800	**395–490**	**448–453**
Mesotropical	**Upper**	**2800–3200**	**320–395**	329
Supratropical	Lower	3200–3400	240–320	
Supratropical	**Upper**	**3400–3900**	**160–240**	**178–235**
Orotropical	Lower	3900–4000	105–160	
Orotropical	**Upper**	**4000–4800**	**50–115**	84
Cryorotropical	Lower	4800 >	> 50	
Cryorotropical	Upper		–	

altitudinal ranges assigned to the limits for the lower supratropical, lower orotropical, and cryorotropical belts, these were established based on a review of the various proposals made for the region, as well as from our own field observations and interpretation of data obtained under similar conditions at analogous altitudes.

For each bioclimatic belt there is also a description of its climatic characteristics, potential vegetation, land use and state of conservation.

4.1 Infratropical belt

The area of the infratropical belt stretches through extensive territories located between the shores of Lake Maracaibo and the Andes, in some cases reaching altitudes up to 400 msl on the northwestern slope of the Sierrra de la Culata. It also includes wooded areas currently deforested and used for agriculture or cattle grazing on the southeastern slope of the Sierra Nevada of Mérida down towards the plains of Barinas. In fact, this belt occupies intensively used areas with few remnants of original vegetation, which has been displaced by banana and sugar cane plantations, cattle raising, and other farming and animal husbandry facilities. Remnants of forests still remain, dispersed throughout the farms and pastures. The mean temperature (T) of this belt oscillates between 26 °C and 27 °C, with an annual rainfall between 1500 and 2000 mm, although in the hills near Bocas de Caparo (220 msl) in the area bordering Barinas, precipitation can reach 2905 mm (Table 3). Found within this belt are formations typical of the Tropical Moist Forest (Ataroff & Sarmiento 2003) and the Neotropical Rain Forest (Luteyn 1999).

Table 3. Climate data for the Infratropical belt in the Andes of Mérida. T °C = mean annual temperature; M °C = mean maximum temperature in the coldest month; m °C = mean minimum temperature in the coldest month; Itc = Thermicity index (Rivas-Martínez).

Belts/Horizons	T °C	M °C	m °C	Itc	Altitude (msl)
Lower Infratropical	26.8	31.3	23	811	0–30(200)
Upper Infratropical	26.4–26.6	30.2–30.7	21.7–22.4	785–795	130–400

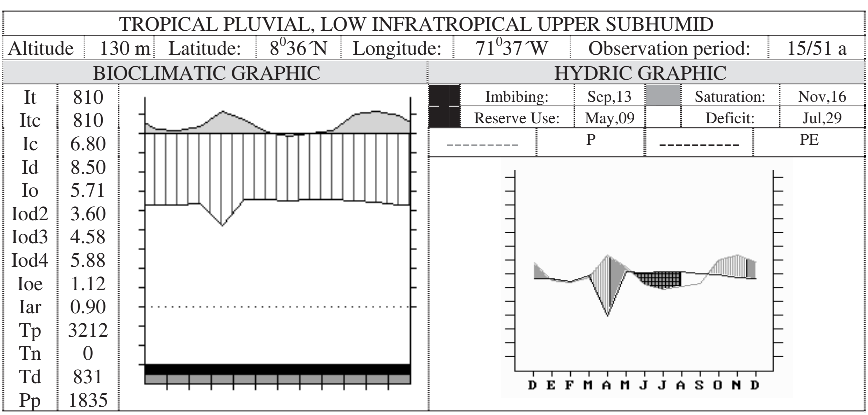
Ombrotype/horizon	Annual rainfall (mm)
Lower subhumid	1553
Upper subhumid	1835
Lower humid	2905

4.1.1 Lower infratropical, upper subhumid

The thermopluvimetric data used for the bioclimatic analysis, which allowed for the classification of this belt as lower infratropical upper subhumid, were collected at the climate station at El Vigía (Fig. 1). The territory around Lake Maracaibo, at the foot of the Andes, corresponds to this belt.

The potential vegetation, although now very deteriorated, can still be studied in small remnants dispersed throughout the area. The belt itself consists of forests differentiated into three strata of trees; the highest 35 m on average, with several specimens emergent measuring up to 60 m. The middle stratum is irregular and ranges from 14 to 20 m, while the lowest stratum measures under 6 m.

Vines and creepers abound. The characteristic trees include: *Ceiba pentandra, Couroupita guianensis, Sterculia apetala, Trichospermum mexicanum, Cedrela fissilis, Copaifera fissicuspis, Herrania albifolia*, *Vitex orinocensis*, *Hymenaea courbaril*, *Sloanea robusta*, *Mouriri myrtifolia*, *Anacar-*



Abbreviations are explained in Appendix.

Fig. 1. Bioclimatic diagnosis of El Vigía station.

dium excelsum, *Astronium graveolens*, *Brosimun alicastrum*, *Hura crepitans*, *Protium caraña, Inga nobilis, Cordia curassavica, Spondias mombin, Triplaris caracasana*, *Xylopia aromatica, Jacaranda copaia*, *Basiloxylom sp., Sterculia caribaea, S. apetala*, with the presence of palms such as *Attalea maracaibensis*. Where there are still remnants of the original vegetation, the following species have been observed (Veillón 1994): *Tabebuia rosea, Erythrina fusca, Ficus insipida, F. obtusifolia, F. prinoides, F. scabrida, Lonchocarpus pentaphyllus, Nectandra globosa, Aniba guianensis, Sapium biglandulosum, Hibiscus tiliaceus, Cousapoa araneosa, Chlorophora tinctoria, Ormosya macrocalyx, Brownea grandiceps, Pterocarpus officinalis, Gustavia yaracuyensis, Cecropia peltata,* and *C. riparia.*

This type of vegetation corresponds to that defined by Ataroff & Sarmiento (2003) as typical of the Tropical Moist Forest, as well as of the Basimontane/Submontane Ombrophilic Forests and Subevergreens of the macrothermal belt described by Huber & Alarcón (1988).

The areas to the south of Lake Maracaibo, in which the lower subhumid infratropical belt is amply distributed, are considered the most fertile in the country. This has led to enormous pressure from agricultural interests. The terrain has been drastically transformed and where once stood vast expanses of continuous forest, interrupted only by numerous rivers rushing down the mountain slopes, are hectares of pastures that have been cleared for cattle (both dairy and beef). The good quality of the soil has meant a spectacular expansion of intensive agriculture at the expense of old forest. Noteworthy are the large plantations of bananas (*Musa paradisiaca*), plantains (*Musa sapientum*), passion fruit (*Passiflora edulis*), custard apples (*Annona muricata*), papayas (*Carica papaya*), sugar cane (*Saccharum officinarum*), and manioc (*Manihot sculenta*).

4.1.2 Upper infratropical, lower subhumid

The thermalpluvimetric data used for the bioclimatic analysis, which allowed for the definition of this belt as upper infratropical lower subhumid, were collected at Barinas Airport (Fig. 2). This belt extends from the area of the Barinas plains to the foothills of the Andes on their southeastern slope.

The vegetation of the territories comprising this unit grows on the plains at the foot of the mountains and currently consists of sparse herbaceous and scrub communities with small trees dispersed throughout the area. Among the latter, the following are common: *Bowdichia virgiliodes, Curatella americana*, *Byrsonima crassifolia, Byrsonima coccolobifolia*, and the palm species *Acrocomia sclerocarpa.* Large extensions of territory in this belt correspond to terrain which was originally wooded, but which has been transformed for agricultural and animal husbandry use. The deforestation has been especially intense as a result of the extraction of wood for lumber starting in the 1950s. Currently there are still small remnants of vegetation dispersed throughout the large tracts of grazing land in which representative species can still be found, including: *Pithecellobium guachap-*

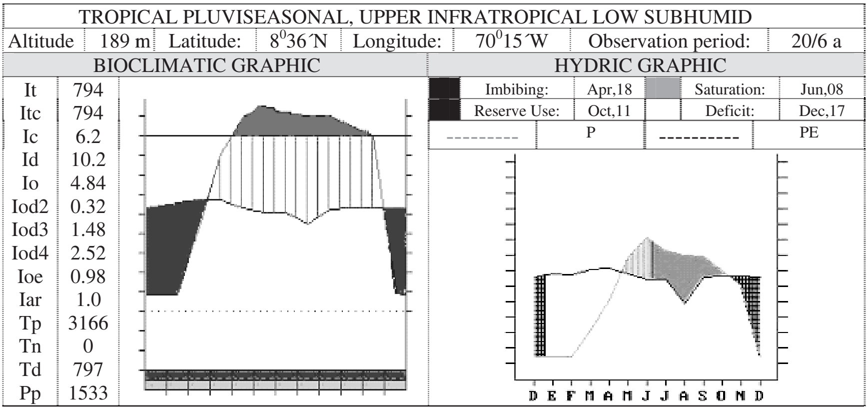


Fig. 2. Bioclimatic diagnosis of Barinas station.

ele, Gustavia poeppigiana, *Trichilia maynasiana*, *Pachira quinata*, *Chrysophyllum sericeum*, *Pouteria sp.*, *Guazuma tomentosa*, *Cordia thaisiania,* and the palm *Roystonea venezuelana*.

The vegetation of this bioclimate corresponds to that typical of the Tropical Moist Forest described by Ataroff & Sarmiento (2003), along with the areas that Huber & Alarcón (1988) denoted as “Land for Agriculture and Cattle Raising.”

The vast private grazing lands and plantations (“Latifundios”), with enormous areas of cultivated pasture for cattle, are a constant in the landscape. Although the principal use of land here is for extensive cattle raising, there are also large areas dedicated to crops such as corn, sorghum, cotton, and oil-seeds.

4.1.3 Upper infratropical, lower humid

The thermalpluvimetric data used in the bioclimatic analysis, which led to the definition of this belt as upper infratropical lower humid, were gathered at “Bocas de Caparo” (Fig. 3). This belt comprises the territory in the area of the hills and at the foot of the mountains on the southeastern slope of the Sierra Nevada of Mérida and the foothills of Barinas. Its altitude ranges from 200 to 400 msl and the mean annual temperature is 26.6 °C. The rainfall in the Bocas de Caparo sector can be up to 2905 mm. In the vegetation of this belt the most outstanding feature is the presence of large trees of the following species: *Cedrela odorata*, *Astronium graveolens, Lonchocarpus pictus, Pouteria anibaefolia, Samanea saman, Mouriri barinensis, Brosimun alicastrum*, along with the palm *Attalea maripa* and *Syagrus sancona*. The territory in this belt corresponds with the Tropical Moist Forest, of Ataroff & Sarmiento (2003) on the southeastern slope of the Sierra Nevada of Mérida, as well as with the Basimontane/Submontane Ombrophilic Forest of the macrothermal belt described by Huber & Alarcón (1988).

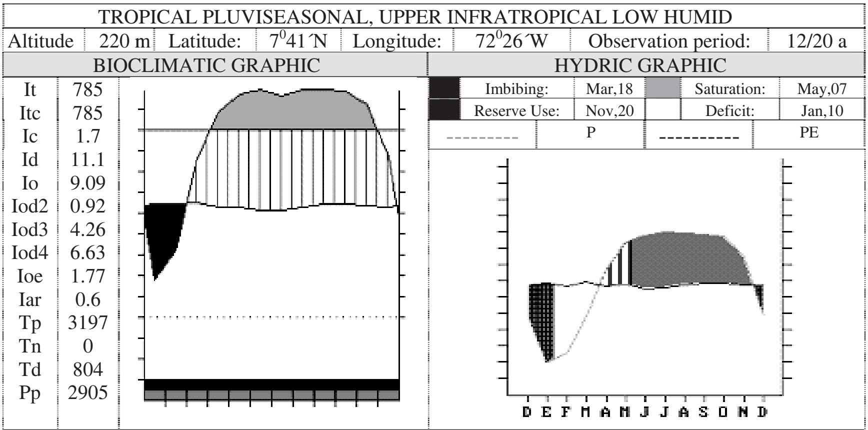


Fig. 3. Bioclimatic diagnosis of Bocas de Caparo station.

All the territory in this belt is of great value for agriculture and cattle, as it is situated in areas slightly higher than the plains and is therefore not affected by flooding during the rainy season. This allows for the planting of expansive pastures for fattening cattle. The main utilization of this belt is thus for extensive and intensive cattle production, with the exception of areas around the larger cities and some foothill towns in which both the industrial and urban service sectors have occupied what were once woodland areas. Agriculture is also present in this belt, with corn, sorghum, and oil-seeds (including sunflower and sesame) occupying important expanses.

Smaller “conucos” or subsistence farms, are not rare in this belt. These small-scale farms grow crops such as “topocho,” a musaceous plant widely used in the region (*Musa. acuminata x M. balbisiana*), along with several types of legumes such as kidney beans (*Phaseolus vulgaris*) and pigeon peas (*Cajanus cajan*), plantains, manioc, and other vegetables for local consumption. The exploitation of wood for lumber has contributed to deforestation of these areas.

Because the principal economic activity in the region is cattle, there is not a great deal of interest in conservation of the so-called “matas” (groves) or small patches of natural woodland; on the contrary, these are considered risks as they can offer shelter to larger carnivorous animals which could attack the cattle. Such animals include the jaguar (*Panthera onca*), which is now forced to hide in small woodland plots because the continuous old grouth forest, has been extirpated.

4.2 Thermotropical belt

The thermotropical belt is amply distributed in the Andes of Mérida. Both its upper and lower horizons are discernable and its ombrotype indicates that it contains the following horizons: lower subhumid, upper subhumid,

Table 4. Climate data of the Thermotropical belt. T °C = mean annual temperature; M °C = mean maximum temperature of the coldest month; m °C = mean minimum temperature of the coldest month; Itc= thermicity index (Rivas-Martínez).

Belts/Horizons	T °C	M °C	m °C	Itc	Altitude (msl)
Lower Thermotropical	22 –24.4	26.6–27	15.7–20.2	643–716	600–1050
Upper Thermotropical	18.8–20.5	22.8–25	12.3–13.3	549–578	1000–1495

Ombrotype/horizon	Annual rainfall (mm)
Upper Semiarid	510
Lower Subhumid	1227
Upper Subhumid	1447
Lower Humid	1770

lower humid, and (in exceptional and special topographical locations) upper semiarid (Table 4). The altitudinal range in 400–2000 msl and it occupies an extensive region on the northwestern slope of the Sierra de la Culata as well as an enormous expanse of territory on the interior slopes of both the Sierra Nevada and the Sierra de la Culata, in areas extending to the Chama river valley. Part of the belt is also located in the area of the so-called "Pueblos del Sur" in the Sierra Nevada of Mérida (Canaguá).

Ombric variability stands out as an extraordinarily valuable element of the thermotropical belt, underscoring the presence in its lower horizon of the upper semiarid ombrotype. There is a stress gradient in precipitation in this belt, caused by the internal valley effect and which favors a xeric flora with notable endemic characteristics. The vegetation of this belt is a thorn scrub corresponding to Submontane Moist Forest, the Montane Semideciduous Forest, and Low Montane Cloud Forest (Ataroff & Sarmiento 2003).

The thermotropical belt is home to a significant number of industries involved in agriculture and cattle raising. Important urban areas and smaller towns are also spread throughout the belt. The cultivation of coffee, cocoa, sugar cane, and musaceous species such as plantains and bananas in the lower and medium portions of the thermotropic, along with the presence of vegetable crops, wheat, and dairy farming in the higher areas, have shaped a landscape in which natural landscapes are mixed with agriculture and farming.

4.2.1 Lower thermotropical, lower subhumid

The thermopluvimetric data used in the bioclimatic analysis were collected at La Palmita (Fig. 4).

The area of this bioclimatic belt covers Andean slopes on the northwestern side of the Sierra de la Culata at altitudes between 400 and 1000 msl. This area contains forests representative of the region, along with woodland and scrub areas of the internal slopes of the Sierra Nevada and the Sierra

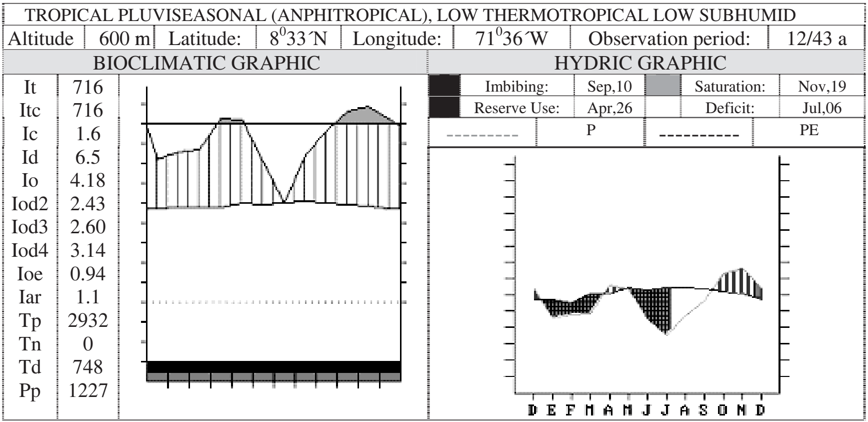


Fig. 4. Bioclimatic diagnosis of La Palmita station.

de la Culata, which descend toward the Chama river valley in the same altitudinal range. These forests have a dense canopy measuring between 15 and 25 m in height, with discontinuous emergents to 40 m. Characteristic species found here, including several deciduous species, are the following: *Ochoterenaea colombiana, Henriettella fissanthera, Pourouma bicolor, Graffenrieda gracilis, Piper arboreum, Warszewiczia coccinea, Ecclinusa lanceolata, Clusia minor, Inga spuria, Vismia ferruginea*, and *Ficus sp.* The palms *Bactris macana*, *Euterpe karsteniana*, *Geonoma interrupta, Attalea butyracea*, and *A. maracaibensis* are present, as are woody vines and creepers, the most characteristic of which are *Mandevilla subsagittata, Peltastes colombianus, Adenocalymma inundatum, Mansoa kerere, Xylophragma seemannianum*, and *Dioscorea coriacea.*

This vegetation corresponds to that found in Basimontane and Submontane Ombrophilic Forest and Subevergreens, as defined by Huber & Alarcón (1988), as well as with that found in the Submontane Moist Forest described by Ataroff & Sarmiento (2003).

These areas currently suffer a high level of disturbance from agricultural activity an, cattle raising. The original vegetation is restricted to small areas on mountain slopes and ridges. Cash crops such as coffee, cocoa, and musaceous plants amply dominate all the areas which are topographically suitable for this type of activity. In this belt, many families have settled and established villages and towns on the banks of the rivers that come down from the Sierra de la Culata on its lakeside slope, as well as on its internal slope toward the Chama river valley. Small, but numerous horticultural plots, fruit orchards, chicken and pig farms, small dairy farms, etc, have supplanted the greater part of the woodland throughout this belt. Currently there is a tendency to substitute old shade plantations with coffee fields exposed to direct sun, a trend that has contributed to deforestation and erosion. Taken together, these factors have exacerbated the effects of periods of intense rain in the past few years, formating gorges, ravines and mudslides, with no possibility of restoring the landscape.

4.2.2 Lower thermotropical, upper semiarid

The thermopluvimetric data used in the bioclimatic analysis which aided in the definition of this belt were obtained at San Juan de Lagunillas (Fig. 5). An unusual aspect of certain internal valleys in the Venezuelan Andes is that they are totally enclosed by mountains, which causes the annual rainfall to be low favoring a vegetation dominated by thorny microforests and cacti. These valleys are known locally as "xerophytic zones." They are situated at altitudes between 500 and 1500 msl and are subject to the action of arid winds, popularly called the "Caldereta." In these conditions the mean temperature is around 22 °C, which is somewhat higher than normal at these altitudes. The effect of low air humidity < 20 %, is also noticeable. Annual rainfall is 500 mm. All these factors have a drastic effect on the vegetation. This phenomenon and the vegetation associated with it are present in various Andean valleys such as San Juan de Lagunillas, as well as in areas such as the high basin of the Chama river in the Cacute-Mucuchíes sector, the medium basin of the Motatán river, located in the branch of the Andean range that extends down to Trujillo, and in the Lobatera sector of the state of Táchira (Rondón 2001).

The vegetation is dominated by columnar cacti, popularly called "cardonales" in America, as well as by several thorned mimosaceae with a shrub-like appearance, known locally as "cujíes".

The vegetation of this belt is comprised of small forests of shrubs and thorned trees along with columnar cactaceae. The following plants are characteristic: *Acacia macracantha*, *Capparis odoratisima*, *Calliandra magdalenae*, *Cylindropuntia caribaea*, *Croton pedicellatus*, *C. leptostachyus*, *Hylocereus lemairei*, *Selenicereus inermes*, *Opuntia caracasana*, *O. caribaea*, *O.*

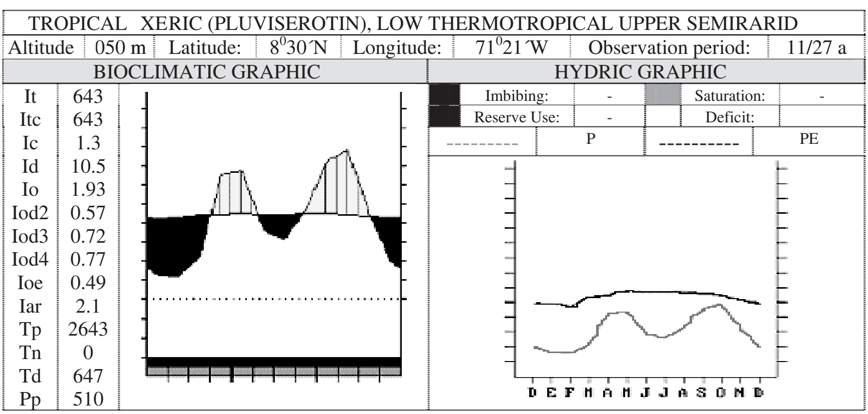


Fig. 5. Bioclimatic diagnosis of San Juan de Lagunillas station.

depauperata, *Monvillea smithiana*, *Pereskia guamacho*, *Cereus hexagonus*, *Acanthocereus tetragonus*, *Subpilocereus repandus*, *Stenocereus griseus*, *Matelea maritima*, *Rhipsalis baccifera*, *Petiveria alliacae*, and *Bromelia spp*.

The Andean xerophytic vegetation corresponds to what Huber & Alarcón (1988) dubbed Xerophilic Scrub and what Ataroff & Sarmiento (2003) called Thistle Land (cardonal) and Tropical Thorn Woodland.

All of these original xeric areas are currently the preferred area for urban and industrial expansion of the cities of Mérida and Ejido. This has been exacerbated by their having been declared a tax-free area known as a “Free Zone for Science and Technology”, which has attracted service companies into the area. In addition, the establishment of landfills to deal with solid waste from the city of Mérida and the surrounding towns and villages, adds to the threat to the conservation of these rare ecological enclaves.

4.2.3 Upper thermotropical, upper subhumid

The temperature and rainfall data used in the bioclimatic analysis of this belt were obtained at Canaguá (Fig. 6). This belt has an altitude range of 1000 to 1700 msl along various slopes of the Andean Range, in some cases reaching 2000 msl.

The vegetation of this belt is comprised of medium-sized forests, which generally consist of two to three tree strata. The forests are dense, with a very irregular canopy, the first stratum being 20–35 m, with emergents to 40 m. Some characteristic tree species are: *Tabebuia ochracea*, *Piper ronaldii*, *Heliocarpus popayanensis*, *Erythrina poeppigiana*, *E. glauca*, *Inga oerstediana*, *I. edulis*, *Ficus maitin*, *Solanum arboreum*, *Sterigmapetalum tachirense*, and *Cedrela* sp. Species found in the lower stratum (12 m) include: *Vismia baccifera*, *Miconia lonchophylla*, *Piper prunifolium*, *Solanum leucocarpon*, and *Urera caracasana*. In this belt, vines and epiphytes are

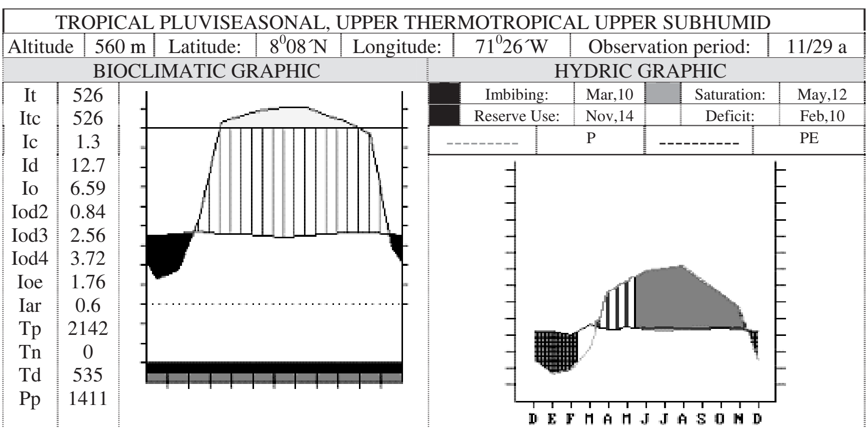


Fig. 6. Bioclimatic diagnosis of Canaguá station.

scarce. This belt corresponds to the Montane Semideciduous Forest of Ataroff & Sarmiento (2003) and the Ombrophilic Subevergreen Forest described by Huber & Alarcón (1988).

Land use centers around agricultural activity. From an economic point of view, agriculture is the motor of the region, although the crops grown here are different from those grown in the surrounding belts. Even more noteworthy, however, is the generally lower impact caused by cattle raising. This region is dominated by large coffee plantations, together with areas for the cultivation of plantains (*Musa sapientum*) and several other legumes and vegetables. The crops are more prevalent in the spurs of the mountain chain on the southeastern slope of the Sierra Nevada and in the Pueblos del Sur, where cattle raising is a bit more common.

On the northwestern slope of the Sierra de la Culata, animal husbandry, which consists mostly of cattle raising, is limited to small herds sufficient for meeting the needs of local residents, but not enough to generate a surplus for trade. Also worth noting is the cultivation of arracacha (*Arracacia xanthorrhiza*) in the upper limit of this unit or vegetation band. This is important since arracacha dominates large parts of farmland in the belt immediately above this one. Another activity that has emerged in the past decade is that of ecotourism, manifested by the conversion of old plantations and houses into inns and hotels, which has led to a rise in hiking and camping in the surrounding mountain areas.

4.2.4 Upper thermotropical, lower humid

The thermopluvimetric data for this belt were obtained at the Mérida Airport (Fig. 7). The belt itself is distributed between both the internal and external slopes of the Sierra de la Culata and the Sierra Nevada de Mérida, at altitudes of 1400 – 2000 msl. The vegetation is characterized by dense for-

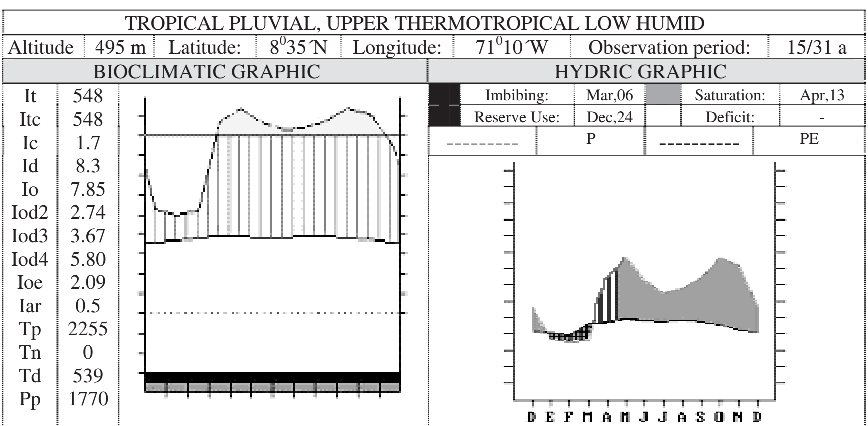


Fig. 7. Bioclimatic diagnosis of Mérida station.

ests with several tree strata between 25 and 35 m high (with some trees reaching up to 40 m). The most characteristic species include: *Axinea grandifolia*, *Byrsonima kariniana*, *Brunellia integrifolia*, *Cedrela montana*, *Ceroxylon klopstockia*, *Clethra fagifolia*, *Clusia minor*, *Montanoa quadrangularis*, *Myrsine guianensis*, and *Podocarpus oleifolius.*

The lower stratum contains a number of species that were introduced during the colonial period, when vast coffee plantations were stablished. The plantations are mostly abandoned nowadays, hence the presence of tree species such as *Psidium caudatum* and C*alycolpus moritzianus*. The latter is quite popular due to its use in the furniture industry. The vegetation of this belt corresponds to that of the Montane Semideciduous Forest described by Ataroff & Sarmiento (2003) and that of the Montane Ombrophilic Evergreen Forests delineated by Huber & Alarcón (1988).

The upper thermotropical, lower humid belt occupies a group of territories that were historically areas of the largest concentrations of population in the Venezuelan Andes. Most of these villages and towns were set up along the banks of the Chama river. The principal uses of this belt, in the river valley area, are urban and agricultural. Those areas that have benefited by some measure of protection (National Park) are well conserved, while the rest has deteriorated.

4.3 Mesotropical belt

The mesotropical belt is an irregular territory located in the Andes of Mérida along various internal and external slopes of the range. It has a large altitudinal span of 2000–3200 msl. The vegetation of this belt is made up of amply distributed forests, sometimes situated on semi-abrupt 20–35° slopes, and it appears to be well conserved in the shelter of enclosed V-shaped valleys.

The thermopluvimetric data used in the bioclimatic analysis, were obtained in Santo Domingo (2155 msl), La Cuchilla (2280 msl), and Mucuchíes (3100 msl). The mean temperature range at these climate stations oscillates between 11.3 °C in Mucuchíes and 15.6 °C in Santo Domingo (Table 5). Rainfall also varies with local conditions, for example it is low in Mucuchíes (683 mm), which is located in an area protected from rain, but it is higher

Table 5. Climate data of the Mesotropical belt. T °C = mean annual temperature; M °C = mean maximum temperature of the coldest month; m °C = mean minimum temperature of the coldest month; Itc = thermicity index (Rivas-Martínez).

Belts/Horizons	T °C	M °C	m °C	Itc	Altitude (msl)
Lower Mesotropical	15.5–15.6	19.5–20.3	8.9–10.3	448–453	2155–2280
Upper Mesotropical	10.4	15.7	6.3	324	3100

Ombrotype/horizon	Annual rainfall (mm)
Upper subhumid	682–1226
Lower humid	2280

in la Cuchilla (1470 mm), which is on the lakeside slope of the Sierra de la Culata.

The potential vegetation of this belt is optimally an evergreen forest, with a great amount of biodiversity, including > 150 species of trees, the canopy is between 20 and 35 m in height, with lower strata that are difficult to delimit. Characteristic species include: *Zanthoxylum rhoifolium*, *Ocotea calophylla, Cinchona pubescens, Hedyosmum glabratum*, *Clethra fagifolia*, *Meliosma meridensis*, and *Myrica pubescens*. Among the most important tree species are: *Decussocarpus rospigliosii*, *Alchornea grandiflora*, *Cecropia telenitida*, *Billia columbiana, llex laurina, Protium tovarense, Guettarda steyermarkii, Brunellia integrifolia*, and *Weinmannia balbisiana*. The most characteristic vines and creepers include: *Anthurium subsagittatum*, *Philodendron karstenianum*, and *Bomarea purpurea.* In the understory are *Miconia meridensis, Piper diffamatum, Palicourea venezuelensis, Psychotria meridensis, Chusquea fendleri*, and *Solanum perfidum.* Epiphytes are of great significance in these forests, with the most important being *Tillandsia usneoides, T. denudata, Odontoglossum odoratum, Oncidium zebrinum*, and *Peperomia aquilae.*

These formations were characterized by Ataroff & Sarmiento (2003) as typical of both the High and Low Montane Cloud Forest while Luteyn (1999) defined them simply as Andean Forest and Huber & Alarcón (1988) dubbed them Montane Ombrophilic Evergreen Forests. The belt itself was defined by Monasterio (1980) as the Andean Belt.

Crops have replaced a large portion of natural forest in this region, with the exception of protected areas.

Forests have been deteriorating since the colonial period, but in more recent years the landscape has been absolutely transformed due to extensive agriculture specializing in crops such as African kikuyu grass (*Pennisetum clandestinum*), which has spread to almost dangerous levels and covers large tracts of land. Likewise, the uncontrolled spread of crops such as "creole arracacha" (*Arracacia xanthorrhiza*) is causing a clear deterioration of vegetation, accompanied by irreversible erosion. The increased presence of this crop is due to the fact that it thrives under these particular climatic conditions, with the harvest taking place 10–12 months after sowing and with a yield of 2000–4000 kg/ha (Briceño 1975). The soil can support a maximum of four harvests, after which the field is abandoned and new areas for arracacha fields are cleared.

4.3.1 Lower mesotropical, lower humid

The thermopluvimetric data used in the bioclimatic analysis of this belt were taken at La Cuchilla (Fig. 8). The structure of the forests in this belt do not allow for an easy differentiation of various strata. The canopy is high, ranging from 25 to 30 m, but decreases as the belt ascends the mountain slopes so that at the upper limit the canopy is barely 10 m high. The belt has an elevation of 2000–2800 msl. Mean temperature is 15.5 °C and

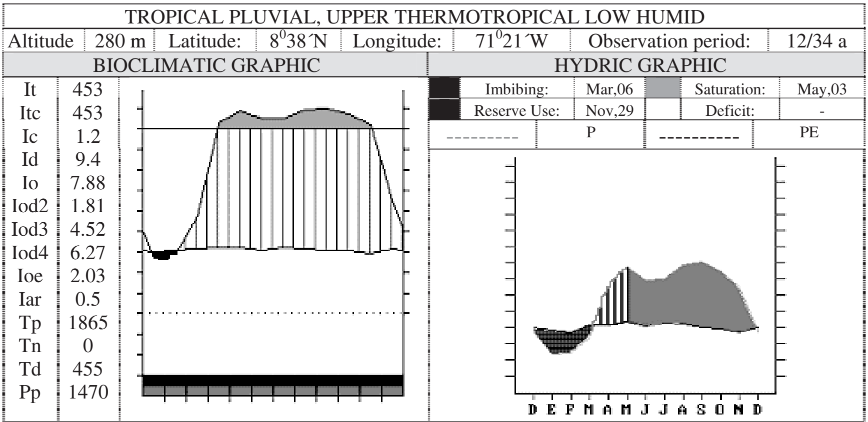


Fig. 8. Bioclimatic diagnosis of La Cuchilla station.

annual rainfall is 1470 mm. Throughout the year, this belt is cloudy with high relative humidity and low sunlight. The vegetation has a high capacity to trap horizontal precipitation (up to 300 mm/yr) in the form of mist. The forests in this belt are continuous and contain a great deal of physonomic diversity, which at the belt's upper limits, comes into contact with the vegetation of the Páramo.

The dominant overlong tree species include *Podocarpus oleifolius*, *Oreopanax moritzii*, *Hedyosmum brasiliense*, *Havetia laurifolia*, *Ocotea calophylla, Billia columbiana, Brunellia acutangula, Persea mutisii, Weinmannia jahnii*, and *Clusia multiflora.* The lower stratum includes *Palicourea demissa, Psychotria aubletiana, Solanum meridense, Monochaetum meridense, Fuchsia venusta, Begonia mariae*, and *Dodonaea viscosa.* Vines and creepers are *Anthurium gehrigeri, A. julianii, Passiflora mollissima, Bomarea multiflora*, and *Mikania spp.* As in the previous belt, epiphytes are important and include: *Tillandsia tetrantha, T. biflora, Epidendrum dendrobii, Oncidium falcipetalum, Pleurothallis roseo-punctata*, and *Peperomia microphylla.*

4.3.2 Upper mesotropical, lower subhumid

The temperature and rainfall data, used for the bioclimatic characterization of this belt, were obtained at Mucuchíes (Fig. 9). Located high in the Andean range of Mérida, the vegetation occupies an altitude of 2800–3200 msl and includes in its lower reaches the transition zone between the high cloud forests of the lower mesotropical, lower humid belt and the Páramo. Indeed, this belt includes the lower finger Andean Páramo, an dry slopes down to 2700 msl, whereas on more humid slopes is above 3000 msl. The mean minimum temperature of the coldest month is an estimated 6.3 °C, which is the minimum temperature tolerated by many species. Rainfall va-

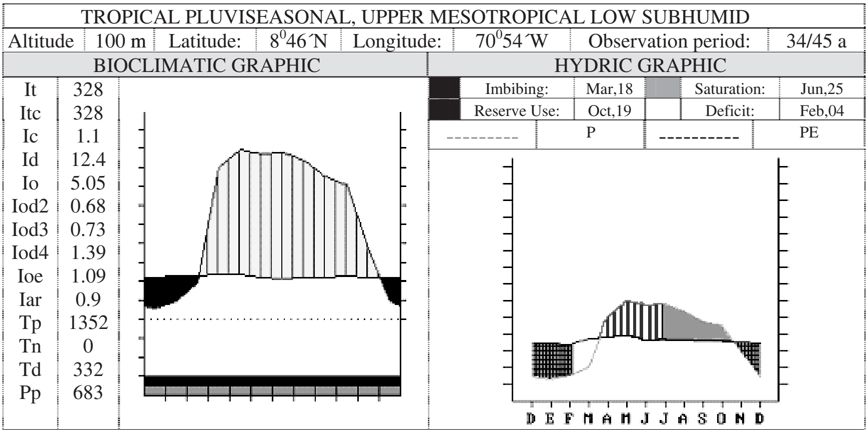


Fig. 9. Bioclimatic diagnosis of Mucuchíes station.

ries depending on the slope in question and can range from 800 to 1100 mm, although in the case of Mucuchíes it is as low as 683 mm due to the internal valley effect.

The vegetation is a combination of shrub and herbaceous communities; the most common of these have an upper stratum reaching from 50 to 150 cm in which rosette plants and other bushes abound. There is a middle stratum of bushes and grasses measuring between 20 and 50 cm, and the lower stratum, less than 10 cm in height. The principal species are *Espeletia schultzii, E. batata, Hypericum laricifolium, Baccharis prunifolia, Stevia lucida, Sisyrinchium micranthum, Lachemilla moritziana, Geranium multiceps, Agrostis trichodes, Echeveria venezuelensis*, *Chaetolepis lindeniana, Aciachne pulvinata, Diplostephium rosmarinifolium*, *Gynoxys violaceae*, and *Gnaphalium spp*. There are two types of subPáramo microforests: the low subPáramo or scrub, measuring between 3 and 5 m, and containing species such as *Arcytophyllum nitidum, Escallonia floribunda, Bejaria aestuans, Symplocos rigidissima, Berberis discolor, Hypericum laricifolium*, *Dodonaea viscosa, Gaultheria alnifolia, G. cordifolia*, and *G. buxifolia,* and the "Alisal" or alder grove, which is well represented in the Páramo of the Pueblos del Sur. It is dominated by *Alnus acuminata (*canopy 15 m) and *Espeletia neriifolia.* It also contains a scrub forest of 2 or 3 m in height where species such as *Prunus myrtifolia, Baccharis nitida, Myrsine guianensis* and *Hypericum bolivaricum*, etc.

These territories are located for the most part in areas protected as part of a National Park, with the current land use being basically reserved for low-impact tourism and research. Still, wheat is grown in this belt in small plots, but only for family consumption rather than as a commercial activity. It is an area of great scenic beauty and of enormous value as a natural landscape.

4.4 Supratropical belt

The data used for the characterization of this belt were obtained at Los Plantíos (on the internal slope of the Sierra Nevada of Mérida, at an altitude of 3878 msl and with an annual rainfall of 1000 mm) and at Mucubají, at an altitude of 3560 msl (Table 6). Apart from being at a lower altitude, the latter station also experiences less precipitation (895 mm). The wind in this area, however, has a more pronounced effect on the vegetation, giving rise to plants with a set of morphological, anatomical, and physiological adaptations that allow them to survive in the windy conditions of this altitude. The recurring periods of frost in January and brief snow in both July and August are frequent. This belt forms part of the Andean Páramo, which is situated at altitudes between 3400 and 4000 msl.

Table 6. Climate data of the Supratropical belt. T °C = mean annual temperature; M °C = mean maximum temperature of the coldest month; m °C = mean minimum temperature of the coldest month; Itc = thermicity index (Rivas-Martínez).

Belts/Horizons	T °C	M °C	m °C	Itc	Altitude (msl)
Upper Supratropical	5.9–8.1	11.5–13.2–	0.4–2.2	178–235	3560–3878

Ombrotype/horizon	Annual rainfall (mm)
Lower humid	991
Upper humid	895

The upper supratropical, upper humid belt is situated in the extensive formation of the Páramos of the Andes in Mérida. Its optimal distribution is between 3200 and 3900 msl and exhibits notable differences, both in flora and vegetation, from the lower mesotropical belt.

The vegetation corresponds to that of the Andean Páramo of Mérida. It consists of three strata: one with rosette bushes and shrubs, another comprising grasses, and a lower stratum with tussocks and grasses measuring < 10 cm. In this belt, the presence and dominance of *E. schultzii* is maintained from the previous one, but *Espeletia semiglobulta* also appears in places where there is an accumulation of humidity. Likewise, *Hypericum laricifolium* is still present, but in this belt it is accompanied by other species such as *Castilleja fissisfolia, Draba bellardii, Senecio formosum, Acaena elongata, A. cylindrostachya, Gnaphalium meridanum, Sisyrinchium iridifolium*, *Festuca hirtella*, and *Rumex acetosella.* The meadows are home to *Aciachne acicularis* and *A. pulvinata*, with a sprinkling of *Hypochaeris setousa, Malvastrun acaule, Geranium chamaense*, and *Geranium multiceps.*

In general, this belt is well conserved, protected by its status as a National Park.

4.4.1 Upper supratropical, lower humid

The thermopluvimetric data used in the bioclimatic analysis of this belt were taken at Los Plantíos (Fig. 10). This belt corresponds with the territo-

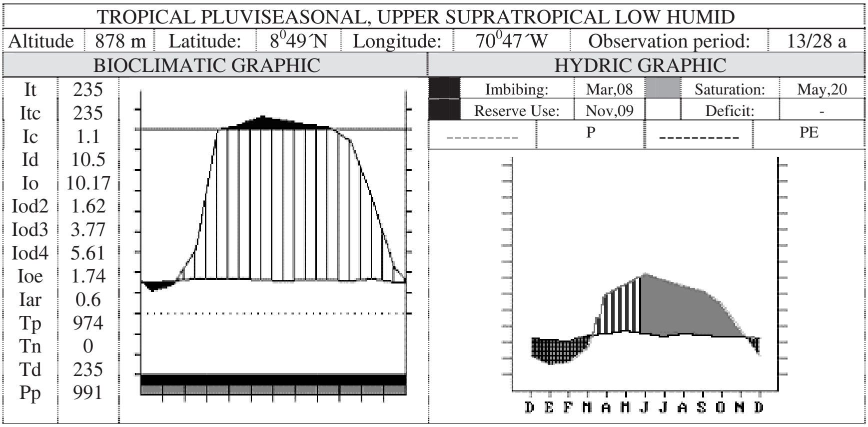


Fig. 10. Bioclimatic diagnosis of Los Plantíos station.

ries making up the highest part of the Andean Páramo of Mérida and contains a vegetation at altitudes between 3400 and 3900 msl. On the more humid slopes, it reaches an altitude of up to 4300 msl.

The vegetation of this bioclimatic unit consists of rosette bushes, including *Espeletia schultzii*, which was found in the previous belts, although it is less dominant here. Where the slope is less pronounced, this species is joined by *E. batata* and *E. weddellii*, which actually predominate in some cases. One of the most interesting and original formations of this belt consists of the high-Andean microforests of *Polylepis sericea* (ruddy or "coloradito"), which are accompanied by an important number of grass and shrub species such as *Geranium multiceps*, *Pernettya prostrata*, *Valeriana phyliciodes*, *V. parviflora*, and *Hesperomeles pernettyoides*, among others.

This belt is quite well conserved and its current use is principally for tourism. The entire belt enjoys the legal status of a National Park.

4.5 Orotropical belt

The orotropical belt dominates dry slopes between 3900 and 4800 msl, and humid slopes between 4300 and 4800 msl. This vast territory has a mean

Table 7. Climate data of the Orotropical belt. T °C = mean annual temperature; M °C = mean maximum temperature of the coldest month; m °C = mean minimum temperature of the coldest month; Itc = thermicity index (Rivas-Martínez).

Belts/Horizons	T °C	M °C	m °C	Itc	Altitude (msl)
Upper Orotropical	3.4	5.2	−0.2	84	4126

Ombrotype/horizon	Annual rainfall (mm)
Lower hyperhumid	872

temperature that oscillates between +3 and −2 °C, with frost quite frequent throughout the year. Rainfall on the dry slopes is 700–1000 mm but on humid slopes it is 1000–1600 mm (Table 7). The vegetation is low, with a low stratum dominated by bushes and tussocks < 40 cm high and upper stratum 3–4 m in height in which rosette bushes of the genus *Coespeletia* are predominant. This belt also contains the high Andean microforest or scrub forest in isolated patches within the vegetation of the supratropical and orotropical belts, where they occupy areas with special conditions such as rocky periglacial drifts, gorges, and ridges between 3700 and 4300 msl. These small wooded areas, comprised of *Polylepis sericea* and *Aragoa lucidula* subsp. *lanata*, which are endemic to the Sierra de la Culata, are unique and of great ecological value.

4.5.1 Upper orotropical, lower hyperhumid

In the Andean Range of Mérida, the upper orotropical, lower hyperhumid belt is defined as high Andean Páramo. This belt extends to the permanent snow line, where the cryorotropical belt begins. The data for this belt were collected at "Pico El Águila" (Fig. 11).

The vegetation of this belt is characterized by a low stratum of bushes and tussocks < 40 cm in height and, sometimes, by a uper stratum 3–4 m tall of giant rosette bushes *Coespeletia timotensis* and *C. spicata*. In some areas of escarpments and ridges, species such as *Coespeletia moritziana* are common, along with *Draba arbuscula* and *Hinterhubera columbica*, among others. Also common in this belt, especially in areas where the water drains or accumulates, are patches of *Espeletia semiglobulata* accompanied by *Gentiana nevadensis*. In the lower stratum, the predominant species are *Arenaria jahnii*, *Azorella julianii*, *Aciachne pulvinata*, and *Malvastrum acaule*.

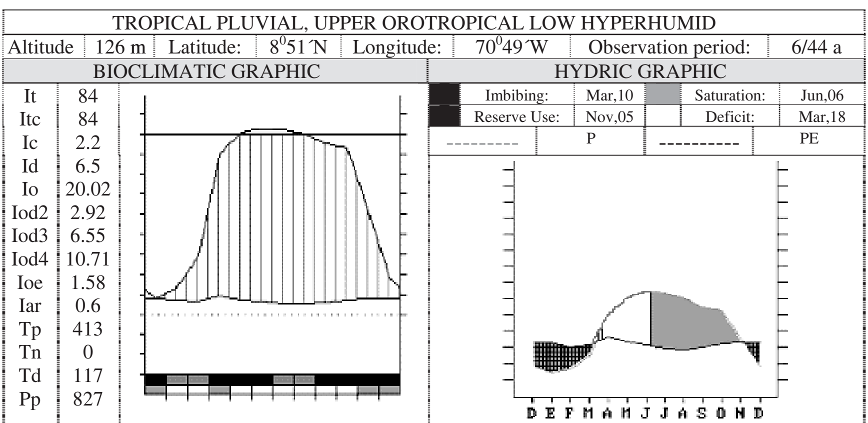


Fig. 11. Bioclimatic diagnosis of Pico El Águila station.

The other noteworthy element of this belt is scrub forest, otherwise known as microforest or high Andean forest. It is found in isolated patches in areas with special substrate conditions, including rocky periglacial drift, and at an altitude between 4000 and 4300 msl. This microforest characteristically consists of stocky trees with a canopy 3–7 m in height. Nevertheless, in our field work we discovered a formation of forest made up of *Polylepis sericea* with exceptional proportions, some with trunks measuring up to 60 cm in diameter and with heights of up to 14 m. These forests also contained *Gynoxys meridana, G. moritziana, G. violacea, Baccharis prunifolia*, and *Diplostephium venezuelense.* In the middle stratum, *Hypericum laricifolium, Pentacalia pachypus, Monticalia andicola, Chaetolepis lindeniana, Ottoa oenanthoides*, and *Ribes canescens* were predominant.

Another unique and highly important formation in this belt are the microforests of *Aragoa lucidula* subsp. *lanata*, which are found in the highest areas with constant humidity, due to permanent mist, above 4000 msl in the Sierra de La Culata, and the Sierra Nevada de Mérida. They are home to a unique set of formations and are the natural habitat of several endemic species, including *Coespeletia timotensis.* Due to the harsh climatic conditions, there is no human activity in this belt which could seriously alter the environment. Land use is basically restricted to tourism and winter sports, consequently the area is well conserved. The entire belt stands under the legal protection afforded it by its status as the National Park of Sierra de la Culata, which is administered by the Institute for National Parks in Venezuela.

5 Summary and conclusions

In summary, the following bioclimatic belts have been delimited and defined for the Andean Range of Mérida, Venezuela:

- **The infratropical belt:** Both the lower and upper horizons have been determined, with the ombrotypes lower subhumid, upper subhumid, and lower humid located at altitudes below 400 msl on lower slopes and plains.
- **The thermotropical belt:** Both the lower and upper horizons have been determined, with the ombrotypes upper semiarid, lower subhumid, upper subhumid, and lower humid situated at altitudes between 400 and 2000 msl.
- **The mesotropical belt:** Both the lower and upper horizons have been determined, with the ombrotypes upper subhumid and lower humid at altitudes between 2000 and 3200 msl.
- **The supratropical belt:** Only the upper thermotype horizon could be determined, with the ombrotypes lower humid and upper humid at altitudes between 3200 and 3900 msl.
- **The orotropical belt:** Only the upper thermotype horizon could be determined, with the ombrotype lower hyperhumid at altitudes between 3900 and 4800 msl.

- **The cryorotropical belt**: Located at altitudes above 4800 msl, this belt is situated in patches and on ridges with recurring frost and year-long snow.

In addition, Table 8 relates these bioclimatic belts with the ecological formations of the entire study area.

Table 8. Equivalence among the bioclimatic belts and the classification of ecological formations elaborated by Ataroff & Sarmiento (2003).

Formation	Altitude (msl)	Bioclimatic Belt	Representative Places
Tropical Moist Forest	0– 200	Lower infratropical upper subhumid	El Vigía (130 msl)
		Upper infratropical lower subhumid	Barinas (189 msl)
Submontane Moist Forest	200– 800	Upper infratropical lower humid	Bocas de Caparo (220 msl)
		Lower thermotropical lower subhumid	La Palmita (600 msl)
Montane Semideciduous Forest	800–1700	Upper thermotropical upper subhumid	La Azulita (1000 msl)
		Upper thermotropical lower humid	Mérida (1495 msl)
		Upper thermotropical upper subhumid	Canaguá (1560 msl)
Thorned Woodland	500–1800	Lower thermotropical upper semiarid	San Juan de Lagunillas (1050 msl)
Low Montane Cloud Forest	1700–2200	Lower mesotropical upper subhumid	Santo Domingo (2155 msl)
High Montane Cloud Forest	2200–3000	Lower mesotropical lower humid	La Cuchilla (2280 msl)
Andean Paramo	3000–4000	Upper mesotropical lower subhumid	Mucuchíes (3100 msl)
		Upper supratropical upper humid	Mucubají (3560 msl)
		Upper supratropical lower humid	Los Plantíos (3878 msl).
High Andean Paramo	4000–4800	Upper orotropical lower hyperhumid	El Águila (4126 msl)

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Appendix. Abbreviations

Thermicity index	**It**
Compensated thermicity index	**Itc**
Simple continentality index	**Ic**
Diurnality index	**Id**
Annual ombrothermic index	**Io**
Bimonthly dry ombrothermic index	**Iod2**
Threemonthly dry ombrothermic index	**Iod3**
Fourmonthly dry ombrothermic index	**Iod4**
Annual ombro-evaporation index	**Ioe**
Annual aridity index	**Iar**
Annual positive temperature	**Tp**
Annual negative temperature	**Tn**
Dry season temperature	**Td**
Positive precipitation	**Pp**