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ORIGINAL RESEARCH ARTICLE

Microclimatic variations in the interior and exterior of the Caldén Forest (*Prosopis caldenia*), Argentina

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ABSTRACT

Climate and vegetation are variables of the physical space that have a dynamic and interdependent relationship. Flora modifies climatic elements and gives rise to a microclimate whose characterization is a function of regional climatic conditions and vegetation structure. The objective of this work was to compare the climatic variations (inside and outside) of the Caldén Forest in the Parque Luro Provincial Reserve. Temperature, relative humidity, wind speed, wind direction and precipitation data from two meteorological stations for 2012 were analyzed and statistically compared. The influence of the forest on climatic parameters was demonstrated and it was found that the greatest variations were in wind speed, daily temperature and precipitation.

Keywords: Caldén Forest; Weather Stations; Microclimate; Climatic Parameters; Parque Luro Provincial Reserve

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1. Introduction

Microclimatology is the study of climate in relation to living beings[1]. The forest generates a particular microenvironment due to its height and its large horizontal extension that allows the formation of a microclimate[2]. There are different authors who deal with the subject, such as Von Arx[3], Chen *et al.*[4], Heuveldop *et al.*[2], Pareja Millán[5], Promis, Caldentey and Ibarra[6] and Uribe de Camargo[7], who conducted their studies in different forests: Nothofagus, Chapultec, Yungas, etc.

Heuveldop *et al.*[2] stated that the microclimate is characterized by "the quality of diffuse radiation, the relative homogeneity of temperature, high humidity and the absence of winds". Depending on different factors, such as the species, the structure, the topography of the area and the nature of the soil, the micro-climate may vary from one sector to another within the same forest. Promis *et al.*[6] defined microclimate as the "set of climatic conditions specific to a geographical point or reduced area and represents a local modification of the general climate of the region due to the influence of different ecological factors". The microclimate plays an important ecological role since it is the main driver of biological responses in its relationship with the physical environment in which each individual settles. Thus, the study of local climatic conditions helps to understand the structure, composition and dynamism of forest ecosystems[8]. Forests have a great influence on energy exchanges between the atmosphere and the soil through biomass accumulation and tree dimensions[9].

The microclimatic conditions inside and under a forest canopy vary with respect to those outside it. In a forest environment, meteorological variables: light, air temperature, wind speed, atmospheric humidity, have an influence on the vegetation, so that local climatic conditions differ from regional ones[8]. Microclimatic studies in forests are relevant to understanding and predicting processes such as photosynthesis, regeneration, recovery, nutrient cycling and organic matter degradation.

Its research is also important in protected areas because management actions are established in these spaces, and for this, the dynamics of the ecosystem as a whole must be known in order to optimize its conservation. The objective of the study was to compare the microclimatic variations between the interior and exterior of a Caldén Forest (*Prosopis caldenia* Burkart) in an area with a temperate semi-desert climate. The area of analysis is the Parque Luro Provincial Reserve located in the province of La Pampa, Argentina. The samplings carried out are significantly important because this is the most extensive area of the Caldenal in the province. In this regard, there is no bibliography on the subject in this endemic forest of Argentina. Therefore, the conclusions formulated by researchers whose studies were applied in different forest areas were taken as a reference, and also those that arise from the characteristics of the study area were considered.

Knowledge of microclimatic conditions determines the optimal planning of tasks to be carried out in protected areas. For example, fires, which are one of the most important problems in Parque Luro, are generated under certain conditions of temperature, wind and humidity. The study of vegetation-atmosphere interaction in the forest and open spaces with the atmosphere makes it possible to know which are the periods with the greatest possibility of fires. In this way, this research ultimately contributes to the management and conservation of the study area.

2. The influence of vegetation on climatic parameters

The forest has a complex and heterogeneous structure that modifies the form and intensity with which certain environmental factors affect it. Horizontal heterogeneity within the forest can be observed in the presence of spaces with relatively dense closed canopies and other open areas[4].

In the closed areas of the forest, the conditions of the meteorological parameters experience less variability compared to the locations close to the forest, which are devoid of vegetation. The vegetation cover reduces the extreme values of the variables by dampening the general climatic conditions. Wind speed, light conditions and air temperature range decrease while relative humidity, mean and minimum air temperature increase under the canopy compared to outside the canopy. This situation depends on the density and type of vegetation[8].

The term canopy was used in this work as the upper level of a forest formed by the tree canopy[10]. Knowledge of it allows us to understand the influence on vegetation-atmosphere interaction. The vegetation cover affects the distribution of precipitation and light, as well as humidity, temperature and wind[6].

Uribe de Camargo[7] states that there is a difference in air temperature inside and outside the forest because the trees absorb a considerable amount of daily solar radiation. The latter is reflected (10%), transmitted and absorbed (9%) by the vegetation. The plants use the radiation received for assimilation, for air and biomass heating and, as a consequence, the subsequent terrestrial radiation is reduced. The forest canopy causes the temperature of the forest to be lower during the day and, on the contrary, higher in relation to the uncovered sites during the night. On the other hand, temperatures recorded in the warm thermal season are lower in vegetated sites, and on the contrary, they are higher in winter than those recorded on bare ground. The thermal amplitude is lower under the vegetation cover than outside it.

The more closed and more stratified the forest, the lower the temperature inside it[2]. There are also thermal differences between deciduous and evergreen forests. In deciduous forests, thermal differences between seasons are more pronounced than in evergreen forests[8]. In a vegetation community, luminosity decreases from top to bottom due to the interception of light radiation by the different vegetation strata[11].

With respect to air humidity, it is retained under the vegetation cover, and therefore, this space is relatively more humid regardless of the seasons. The forest canopy retains, according to its density, nature and the importance of precipitation-quantity, intensity, duration-a variable proportion of atmospheric water. Therefore, the forest microclimate is more humid than a bare soil site. In addition, wind speed is lower inside the forest than outside because the vegetation acts as an obstacle or barrier to its entry[4].

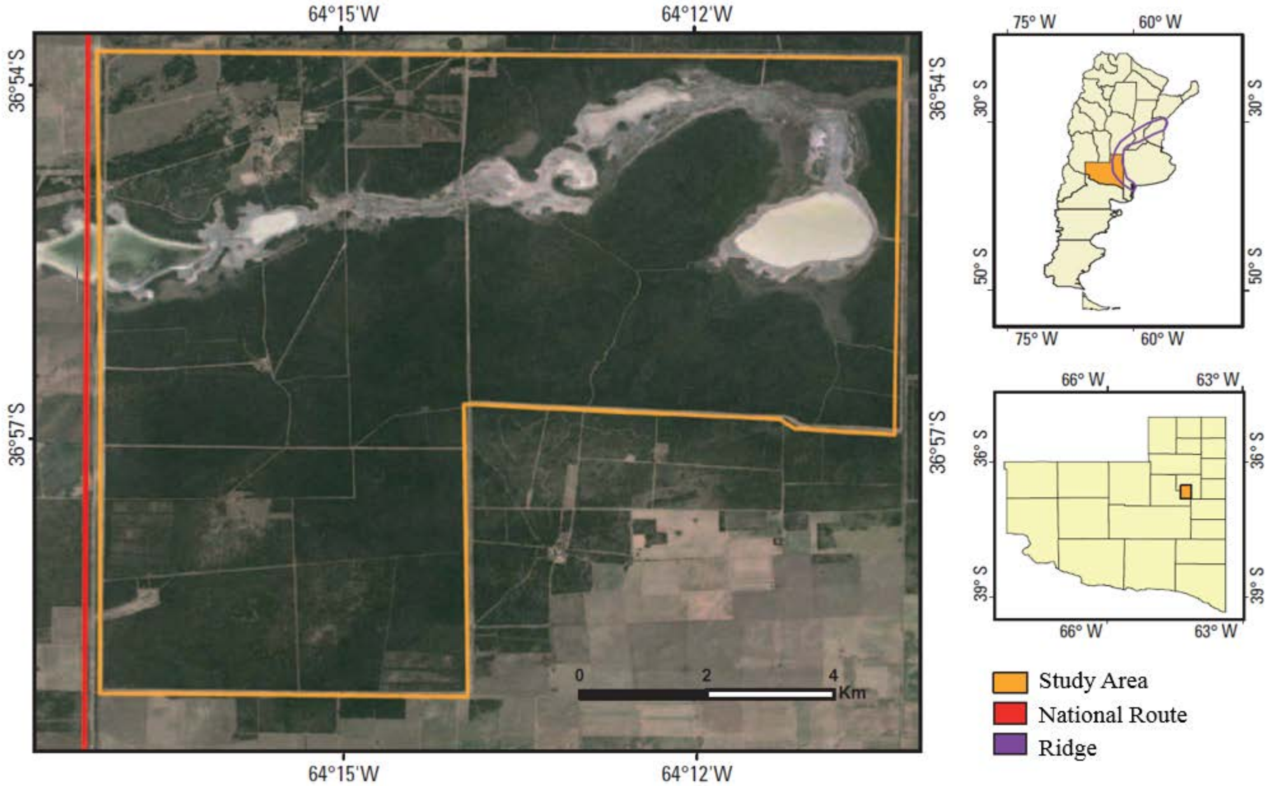

Figure 1. Location of Parque Luro Provincial Reserve. Data: Google™ Earth Mapping Service Digital Globe 2016.

3. Study area

The Parque Luro Provincial Reserve is located in the department of Toay, in the central-eastern part of the province of La Pampa (Argentina) (**Figure 1**). It covers 7,608 hm^2 and was created in 1996 to protect a small portion of the Caldenal. This is a deciduous forest that grows in the area between the 400 and 600 mm isohyets and whose dominant species is *Prosopis caldenia*[12].

According to Cabrera[13], it is part of the spinal ecoregion located in the Chaco-Pampean plain. Matteucci[14] determines that this area belongs to the Chaco-Pampean Plain Subregion with Caldenal and the Sandy Pampas Complex with Grassland Shrubland. The representative vegetation type of the area is the Caldenal and grasslands that form the Caldenal floor, with variations according to topography and soil type. Most of the area is located in the province of La Pampa. In terms of physiognomy, open forest predominates, with *Prosopis caldenia* and *Prosopis flexuosa* D.C. (**Figure 2**). Other species that are significant in terms of their representation are Geoffrea decorticans Gillies ex Hook. & Arn., *Schinus fasciculatus* Johnst and *Jodina rhombifolia* H. et A.[14].

The original Caldenal was composed of the arboreal and herbaceous stratum, mainly summer and winter grasses. The conditions of the environment were modified due to anthropogenic action through economic activities such as cattle ranching and agriculture. Thus, the shrub stratum was incorporated, which currently has greater coverage in the forest structure.

According to the law of minimum budgets for the environmental protection of native forests[15] approved in 2007, this forest has a category 1 (red) because it is a sector with very high conservation value, which should not be cleared or used for timber extraction and should be maintained as forest.

Figure 2. Caldén Forest in Parque Luro Provincial Reserve. Photographs by Valeria S. Duval, February 2016.

4. Methodology

Two meteorological stations located in different sectors of the reserve were used to study the forest microclimate: the first is located in an open space, Administration Station-hereafter, EA-, near the reserve's administration (36°54.85′ S–64°15.6′ W) and the second Forest Station-hereafter, EB-is located inside the Caldén Forest (36°54.97′ S–64°15.60′ W) (**Figure 3**). The EB is located in a sector of modified forest with a semi-open cover due to the presence of a denser shrub layer. Both weather stations belong to the Department of Geography and Tourism of the Universidad Nacional del Sur—hereinafter, UNS.

The meteorological variables selected were: air temperature, precipitation, relative humidity and wind speed and direction. The data were taken with continuous recording equipment, with a frequency of half an hour and simultaneously during 2012. Due to technical failures, no data were obtained at the EB during the month of November. Daily averages were calculated for the selected climatic elements. As a result of the statistical processing, different graphs were obtained to establish the variations of the meteorological elements inside and outside the Caldén Forest.

The analyses were performed monthly and by thermal season. In addition, the daily temperature variation in typical winter and summer days was considered. The days chosen were June 21 and December 21, 2012, coinciding with the dates on which the sun's rays fall perpendicularly on the tropics of Cancer and Capricorn, respectively. From this, some characteristics of the meteorological variables within the Caldenal were established.

5. Results and discussion

The results of the analysis of the annual, monthly and daily microclimatic variables using data from the aforementioned meteorological stations are presented below. In the second part, the linkage of this study for this protected area is explained.

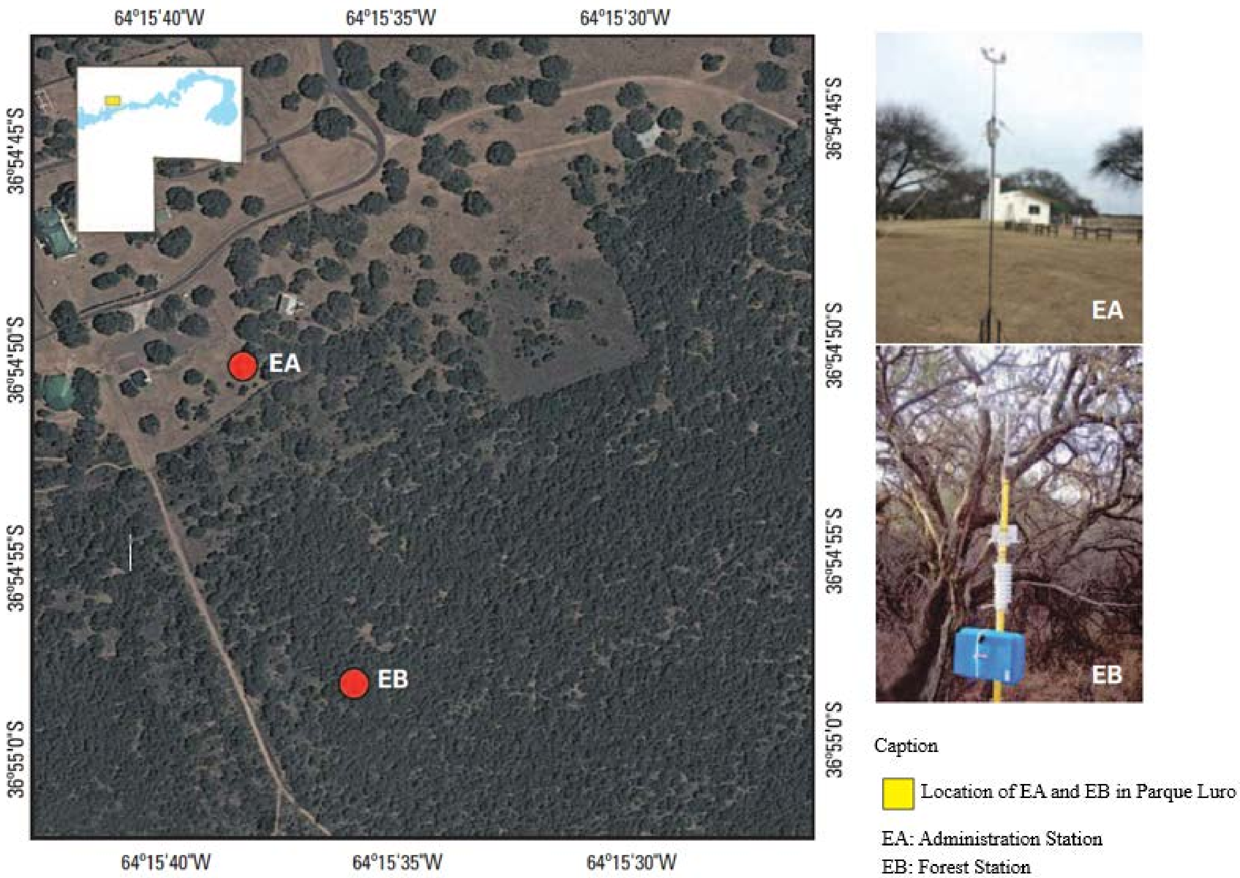

Figure 3. Location of meteorological stations in Parque Luro. Data: Google Earth, photographs by Valeria S. Duval, March 016.

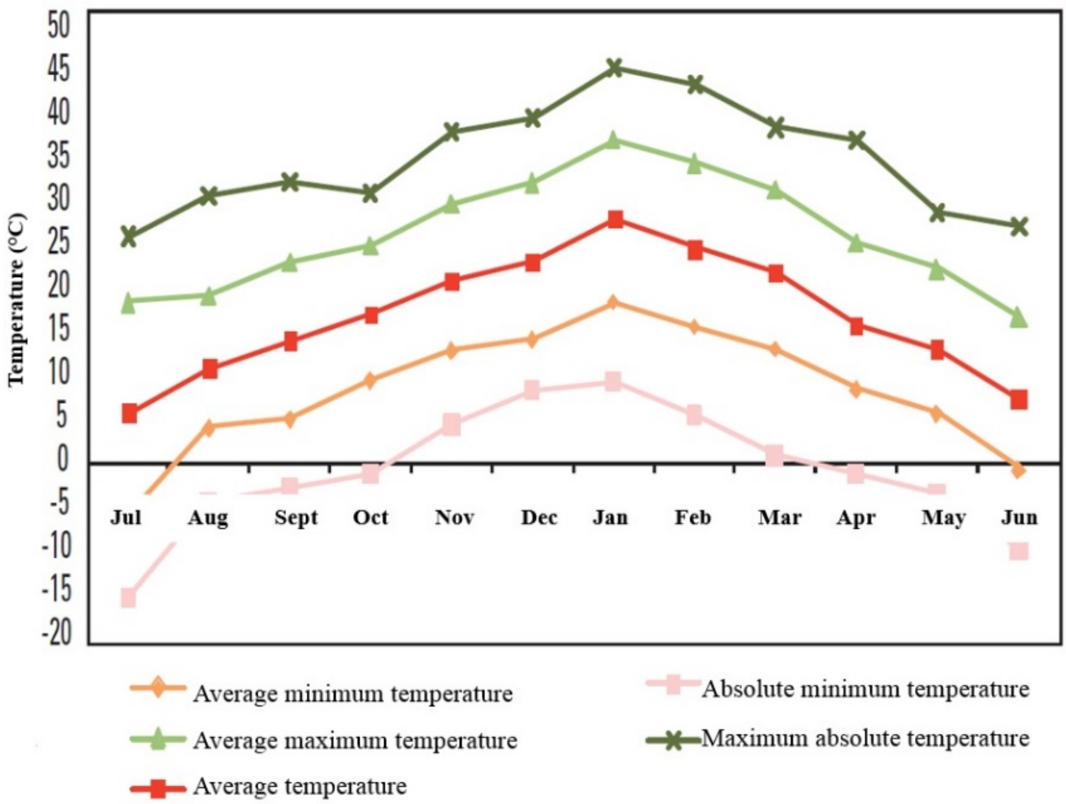

Figure 4. Annual temperature distribution for 2012 in EA. Data: UNS weather stations 2016.

5.1 Analysis of microclimatic variables

According to the EA, the Parque Luro Provincial Reserve recorded a mean annual temperature of 16.1 °C for 2012. The thermal amplitude was 21.5 °C, which demonstrates the effect of continentality with differentiated thermal summers and winters. The lowest mean minimum temperatures were observed between June and August, being lower than 0 °C and the mean annual value of 7.9 °C (**Figure 4**). The absolute minimum temperatures below 0 °C were recorded between June and October.

In the warm thermal season, the absolute minimum values ranged from 5.3 °C to 8 °C. On the other hand, the highest average maximum temperatures were recorded from December to March and exceeded 30 °C. January was the month with the highest average temperature of 35.7 °C. The annual mean value was 25.2 °C. The absolute maximum temperature for the period had the lowest thermal values in winter, which in all cases exceeded 25 °C, and the maximum in summer exceeded 38 °C. January was the month with the highest temperature, which was 43.7 °C. Average monthly thermal variations were greatest between March–April and December–January.

The decrease in temperature occurred from January to June and from this month to December, on the contrary, there was an increase in temperature. The monthly thermal differences expressed the degree of continentality.

Figure 5 shows the mean, mean maximum and mean minimum temperature curves for station EB for 2012. During this year, the EB recorded an average annual temperature of 14.8 °C and an annual variation of 22.2 °C. With respect to the average values, June, July and August were the months with the lowest temperatures, June being the minimum with 4 °C, and the highest temperatures were in December, January and February, with a maximum in January of 26.2 °C.

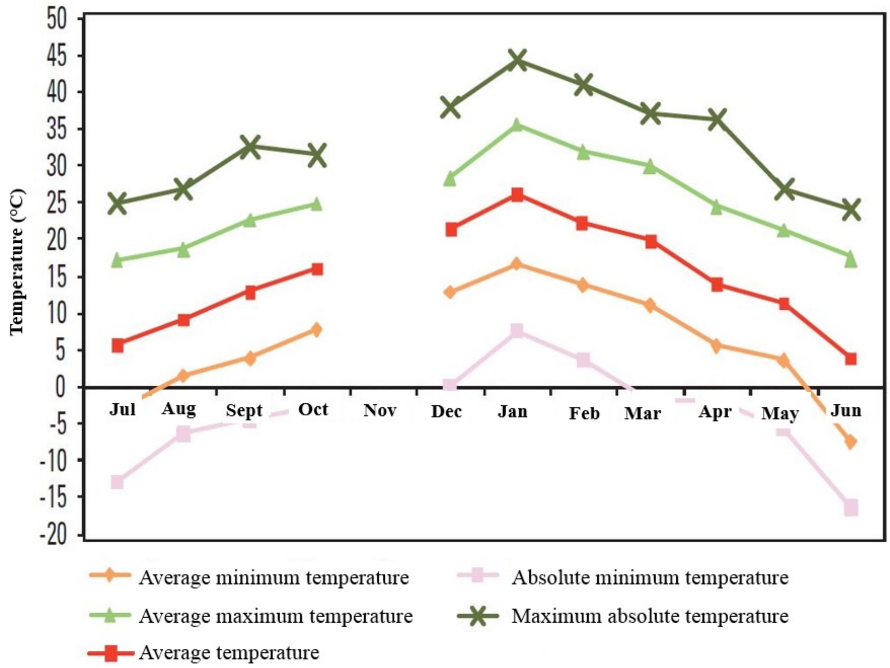

Figure 5. Annual temperature distribution for 2012 in EB. Data: UNS weather stations 2016.

The months with average minimum temperatures below 0 °C were June and July. The annual absolute minimum was 16.3 °C in June. The average maximum values were recorded in January and February, exceeding 30 °C. The maximum absolute annual temperature was 44.4 °C in January. With respect to the average monthly thermal variations, the greatest variation occurred between May-June and December-January. The decrease in temperature was recorded from January to June and from this month to December, on the contrary, there was an increase in temperature. The average monthly thermal variations of both meteorological stations are presented in **Table 1**.

Table 1. Annual thermal variation at Administration and Forest Stations.

Months	Thermal variation at Administration Station (°C)	Thermal variation at Forest Station (°C)
Jan–Feb	3.4	4.1
Feb–Mar	2.7	2.2
Mar–Apr	5.8	5.8
Apr–May	2.6	2.7
May–Jun	5.6	7.4
Jun–Jul	1.4	-1.
Jul–Aug	-4.8	-3.35
Aug–Sep	-3.1	-3.8
Sept–Oct	-3	-3.1
Oct–Nov	-3.6	s/d
Nov–Dec	-2.2	s/d
Dec–Jan	-4.8	-4.8

Data: UNS weather stations 2016.

Variations of the parameter between EA and EB were small. The mean monthly temperatures, in general, were higher in the EA than in the EB because the shading effect generated by the canopy cover in the forest generates a reduction of the radiation received. The average oscillation of monthly mean temperatures between the two stations was 1 °C. The mean temperature differences between the two sites were greater in autumn and summer, and to a lesser extent in winter (**Figure 6**). The representative tree of the forest, *Prosopis caldenia*, has a small leaf and a more open crown, which allows more light to enter the lower strata, the shrub and herbaceous.

During the cold thermal season, the forest had lower temperatures than the unvegetated sector due to the expiration of certain species. During the summer, the non-vegetated surfaces received more radiation, which generated a warming of the surface and, therefore, an increase in air temperature. In contrast, the canopy attenuated the maximum temperatures and, therefore, the summer heat inside the forest was lower than outside. The thermal amplitude was higher in the forest and lower in the unvegetated site.

The different studies on forest microclimate[16-19] concluded that the most frequent situation is that under the forest canopy the daily and annual maximum air temperatures are lower than in nearby outdoor areas. In addition, minimum temperatures are higher in the forest, which reduces the risk of frost. In the Caldenal these situations could be due to the specific characteristics of this vegetation formation.

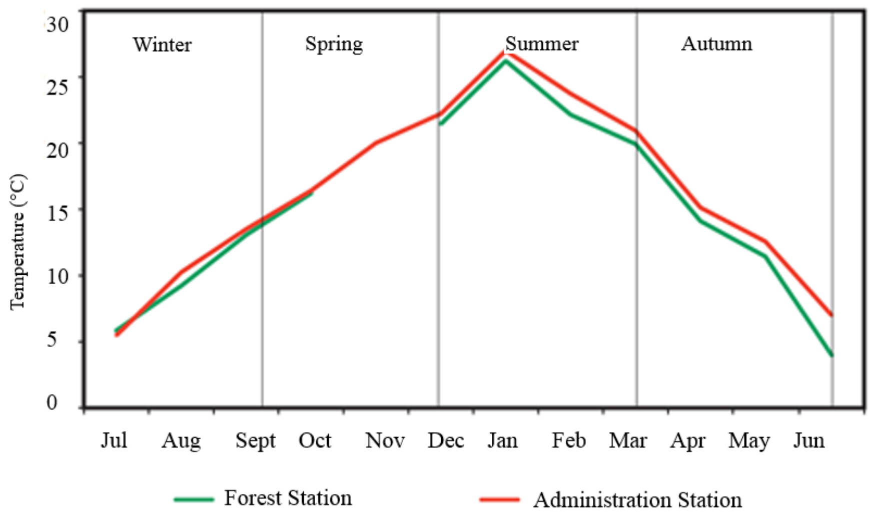

Figure 6. Annual distribution of mean temperature in 2012. Data: UNS weather stations 2016.

Figure 7 shows that the absolute maximum temperatures were higher during five months in the forest, with respect to the management season, mainly during autumn and spring. In the month of August the absolute maximum temperature was the same. During winter and summer temperatures were always higher on the unvegetated ground, relative to the forest area. This condition also departs from research that determined that absolute maximum temperatures occur at sites devoid of vegetation.

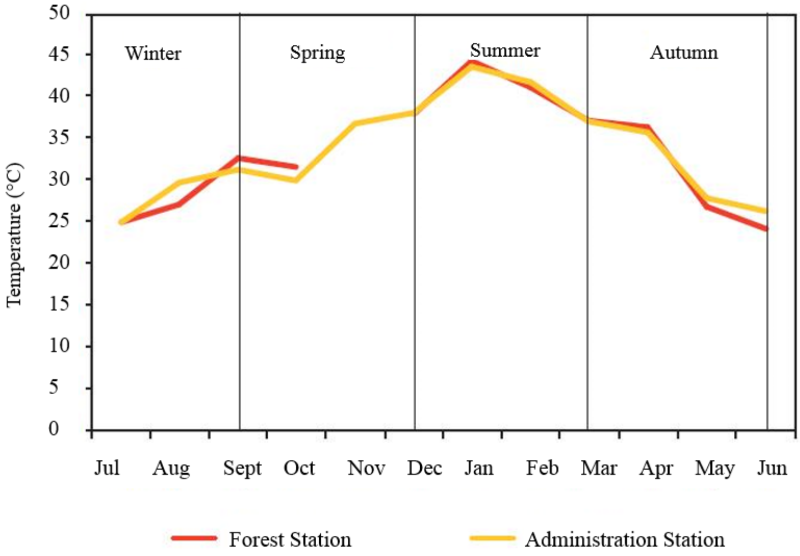

Figure 7. Annual distribution of absolute maximum temperature in 2012. Data: UNS weather stations 2016.

In **Figure 8,** the absolute minimum temperatures were lower in the EB than in the EA for seven months, mainly in the fall and spring seasons. The largest temperature differences occurred in the month of December and June, being 8 ℃ and 6.8 ℃, respectively. In both cases the absolute minimum temperatures were lower in EB than in EA.

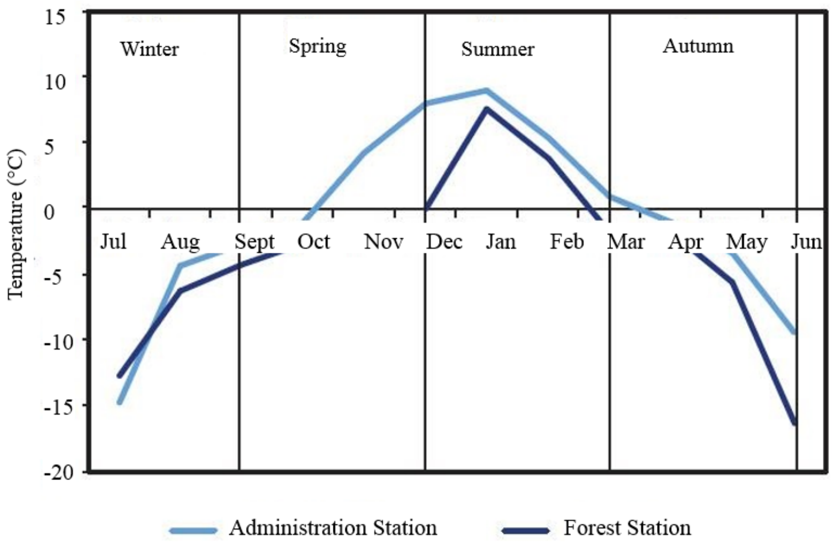

Figure 8. Annual distribution of absolute minimum temperature in 2012.Data: UNS weather stations 2016. Data: UNS weather stations 2016.

On the other hand, the behavior of climatic elements during the day should be observed. Hufty[20] determined that daily variations are less wide in a forest due to air humidity: less diurnal warming and little nocturnal cooling. During June 21, the mean daily temperature was higher in the EA with respect to the EB, being 8.6 ℃ and 6 ℃, respectively (**Figure 9**). This is due to the fact that in winter the radiation input is lower and the effect of the forest on the microclimate decreases[16]. The maximum hourly temperature inside the forest was recorded at 15 h with 18.6 ℃ and the absolute minimum was -1.7 ℃ at 23 h. At the site devoid of vegetation, the absolute minimum was 0.3 ℃ at 23 h and the hourly absolute maximum was recorded at 16 h with 19.1 ℃. Throughout the day, the outdoor temperature was higher compared to the indoor temperature, and the largest differences between the daily mean temperature curves were established in the early morning (from 0 to 4 h) and in the evening (from 18 to 23 h). This situation could be attributed to the deciduousness of the vegetation that favors lower than usual thermal conditions with respect to its exterior. The loss of leaves reduces the interception and absorption of radiation by the vegetation[16].

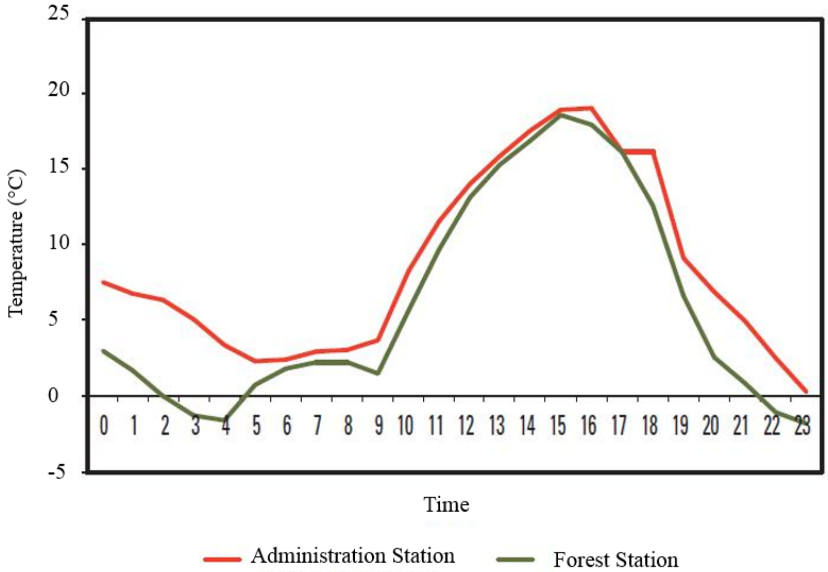

Figure 9. Hourly temperature distribution on June 21. Data: UNS weather stations 2016.

During December 21, the mean daily temperature was higher in the EA than in the EB, being 19.1 ℃ and 18.9 ℃ respectively (**Figure 10**). The absolute minimum temperature inside the forest was 8.5 ℃ at 6 am and the absolute maximum was 27.8 ℃ at 4 pm. In EA, the absolute minimum was 8.1 ℃ at 5 h and the daily absolute maximum was recorded at 16 h and 17 h being 27.7 ℃. Throughout the early morning and night, the temperature at EB was higher, being from 6 h to 16 h the positive range in favor of EA.

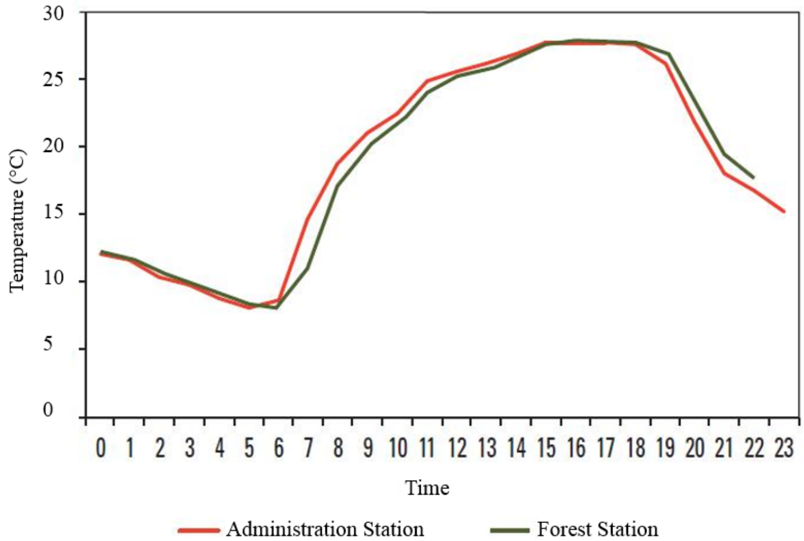

Figure 10. Hourly temperature distribution on December 21. Data: UNS weather stations 2016.

During the day, the upper stratum of the forest captures most of the sunlight, with less than 10% penetrating the soil. As a result, the lower tree layer is more humid and less warm than the upper layer[5]. In summer, the forest retains heat during the night due to the presence of the vegetation cover that prevents the radiation emitted by the earth's surface from returning to the outside[16]. In accordance with this circumstance, the EA had its highest temperatures between 7 am and 3 pm, favored by the incident radiation on the ground, which generated an increase in air temperature.

Total precipitation was 998 mm, with maximums in spring and minimums in the winter months (**Figure 11**). In summer, rainfall was 476 mm, in autumn 95 mm, in winter 137 mm concentrated in the month of August and 290 mm in spring. The vegetation cover prevented the recording of rainfall, so that in all months the rain gauge did not record rainfall.

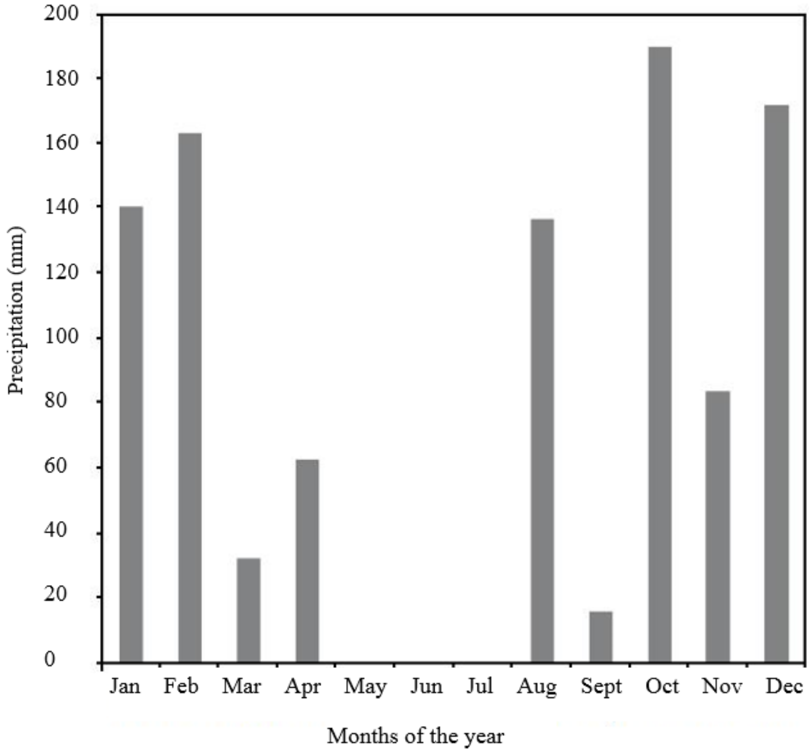

Figure 11. Monthly distribution of total precipitation. Data: UNS weather stations 2016.

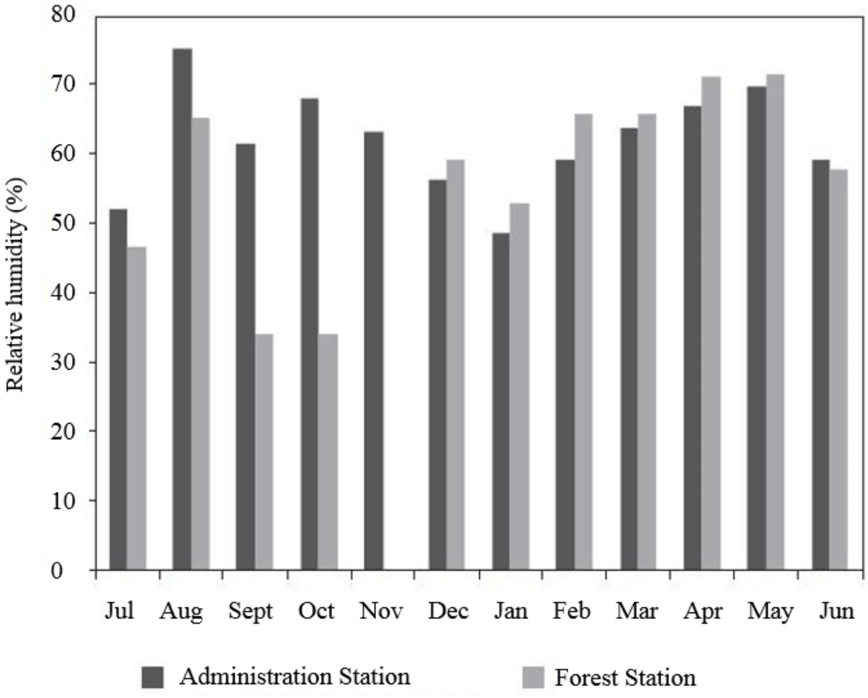

Figure 12. Comparative relative humidity between EA and EB. Data: UNS weather stations 2016.

Regarding humidity, Uribe de Camargo[7] determined that in the forest, vegetation retains water vapor and causes the humidity inside the forest to be higher than that recorded outside. In the case of Parque Luro, this relationship was observed in the months from January to May and December (**Figure 12**). These coincide with the warmest season and autumn. The relative humidity preserved under the canopy was higher than in the area without vegetation. In the winter and spring months, the humidity of EB was lower than that of EA, a situation contrary to normal.

Wind is an important climate element for the analysis of forest microclimate, as it is easy to detect variations between vegetated and non-vegetated areas. In the case of the EA, the frequency of wind was higher in the NE (192%), O (120%) and NO (118%) quadrants. The frequency of calm was 78.4%. For EB, the highest frequencies were recorded from the SE direction with 39.9%, S with 36.6% and NO with 35.1%. The calm frequency was 747.7%. The wind speed in the EA was higher from the S sector (8.5 km/h), SE (7.9 km/h) and O (6.7 km/h). The average annual mean wind speed was 6.8 km/h. In the EB, the wind intensity was higher in the Se sector with 3.2 km/h and O and SO with 3 km/h (**Figure 13**).

In the forest, vegetation influences wind speed by up to one third compared to an open space[2]. Inside the forest, the trunk, branches and leaf surfaces are a source of friction that generates a decrease in wind speed. In this sense, the forest environment is less windy than outside[21]. The forest station recorded values below 2 km/h in all cases, while the EA data greatly exceeded that speed. The highest EA values were generally observed in the summer and the lowest velocities in November and December. With respect to EB, the data were less variable, having their maximums in the months of September and October, and their minimums in March and July. **Figure 14** shows the mean annual wind speed distribution for 2012.

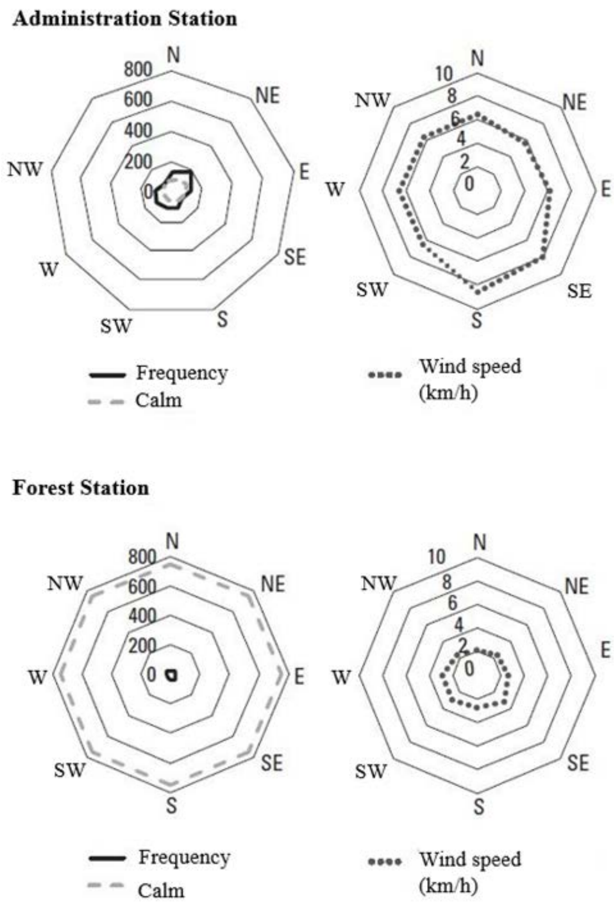

Figure 13. Frequency (%) and wind speed (km/h) in EA and EB. Data: UNS weather stations 2016.

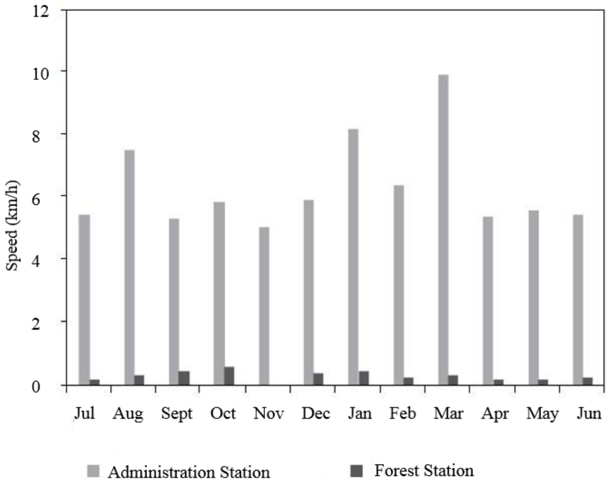

Figure 14. Distribution of mean annual velocity in the EA and EB. Data: UNS weather stations 2016.

6. Conclusions

The vegetation cover of the earth's surface is a particularly dynamic system. The Caldén Forest is an endemic vegetation formation that conditions the atmosphere and generates variations in climatic parameters, such as air temperature, relative humidity, precipitation and wind speed. Just as plant species are conditioned by climate and soil, vegetation also generates a particular microenvironment due to its structure and physiognomy.

There is no specific bibliography on the subject for this endemic forest of Argentina, so this research represents a beginning to understand its dynamics. In order to establish some conclusions on the subject, the contributions of microclimate research in forests with different characteristics were considered, although the characteristics of the study area were always taken into account.

The air temperature in the forest showed small differences with respect to the bare ground, being higher in the records in the EA. These differences were accentuated in autumn and summer and reduced during the winter. Absolute maximum temperatures were higher in the bare ground compared to the forest, although during five months temperatures were higher in the latter, mainly during the summer. This departs from the general situation described in which the absolute maximum temperature is always higher in the bare ground than in the forest.

The absolute minimum temperatures recorded were always lower in the forest than in the unvegetated site except for the month of July. This does not correspond to the situation in other forests. For example, in the *Nothofagus pumilio* forest temperatures are higher than in the bare area. This is due to the fact that during the winter the vegetation moderates the temperature avoiding frosts. In the case of the Caldenal, the record could be due to the deciduousness of the vegetation in winter and the reduction of light in the lower strata of the forest in the summer.

With respect to the daily temperature trend, variations in this situation could be observed. While in the early morning and at night the temperatures in the forest were higher than outside, higher temperatures were recorded in the forest from 8:00 am to 4:00 pm. It is inferred that during the night and early morning, the vegetation regulates the temperature, and therefore, the temperature drops less than in the area devoid of flora.

The relative humidity according to the above mentioned authors is always higher in the forest in relation to the area without vegetation. For the Caldenal, the relative humidity patterns show that, during the winter, the humidity is higher in the soil without vegetation, while in the rest of the year the opposite happens. The lower relative humidity in the forest during the winter could be due to the correspondence with the dry period. Rainfall is distributed mainly in the warm thermal season. In relation to wind speed, it was always higher outside than inside the forest because the trees and shrubs produce a barrier that prevents the circulation of winds. This situation corresponds to that studied with the authors in other forests.

The results obtained from the statistical analysis of the data show the need to continue with the study of the microclimate of the Caldenal, since it is an endemic forest and it is of vital importance to know its dynamics. It was found that the generalities described by the authors as "forest microclimate" or "forest microclimate" cannot always be applied to all wooded areas. That is why this article presents a background and a beginning in the development of the analysis of the microclimate of the Caldenal.

Conflict of interest

The authors declare that they have no conflict of interest

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