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# Native Forest and Climate Change — The Role of the Subtropical Forest, Potentials, and Threats

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Additional information is available at the end of the chapter

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## Abstract

The subtropical rainforest of Argentina, called Yungas, has been subjected to rapid deforestation and degradation processes in recent years, especially in the lower district: "Pedemontana Jungle" (PJ;  $\leq 900$  m.a.s.l.). In Salta, in the north of the country, the rate of deforestation is around three times higher than the world average. The disappearance of PJ significantly limits the area of contact between Yungas and Chaco forest, which could have important consequences for natural and cultural biodiversity in the region (the largest number of aboriginal ethnic groups live here, most of which depend on native forest for their existence and identity). In addition, the loss and degradation of forests is the second largest sector of greenhouse gas (GHG) emissions to the atmosphere (about 18%), affecting the world climate. We present a synthesis of different studies developed in PJ forests, observing its role as reservoirs of carbon and discussing issues that could influence the total capacity of carbon sequestration of the same. This will contribute to build the reliable database on the sequestration potential, which will facilitate standardization of units, reduction of uncertainties, and contribution to a more efficient strategy to limit the GHG emission to the environment, providing some learning and useful recommendations.

**Keywords:** biomass, carbon sequestration, edge effect, fragmentation, native forest

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## 1. Introduction

### 1.1. Deforestation, fragmentation, and climate change

According to recent studies, the forests covering about 30% of the earth's surface [1] contain 80% terrestrial biomass and provide habitat for about half of the world's known species of plants and animals [2]. Forests provide a wide range of ecological, economic, and social assets, as well as services such as climate regulation through the storage of carbon in complex physical,

chemical, and biological processes [3–5]. Despite a wide recognition of the importance of native forests, recent data show that the loss of forest cover over the planet (deforestation) in 2000–2012 was 2.3 million km<sup>2</sup>, while the gain (grown or planted) was 0.8 million km<sup>2</sup> [6]. Conversely, Keenan et al. reported a rate of 0.08% of forest loss in 2010–2015, while farmland continued expanding in 70% of the countries [1].

Native forests have been affected in terms of not only the total amount of existing surface (deforestation) but also the quality of the remaining fragments (degradation) [5, 7], therefore the biomass availability and its derived flow, which means a source of ecosystem goods and services, has been doubly modified. Several of them, such as soil protection, gas and climate regulation, water regulation, nutrient cycling, providing habitat and refuge, food production, raw materials and genetic resources, the provision of medicinal and ornamental resources, and others related to culture (recreation, aesthetics, and spirituality), are associated with biomass existence and generation [2, 4, 5]. Similarly, there are an increasing number of studies showing the interrelationship between the aboveground and subterranean processes, and particularly among the aboveground biomass (AGB) and soil, links that determine the abundance of species, coexistence, and succession [8, 9]. Therefore, any changes in the biomass, including degradation – although it is a hardly measureable phenomenon [10] – will affect soil characteristics, which, in turn, will modify reproduction patterns and survival of typical plants in the ecosystem in question and their associated fauna [2, 8, 9].

Deforestation and fragmentation of forests, have been an object of study of the scientific community for many years, but attention to these phenomena has begun to rise from the perspective of their contribution to global warming by greenhouse gas emissions [3, 10–15]. It is recognized that the change in land use (including forest degradation and deforestation) is the second sector of global importance in terms of GHG emissions (so-called LULUCF or land use, land use change and forestry) and is responsible for 20% of total emissions [16]; therefore, it is an important component of human impact on global climate.

Variations in the soil cover are one of the natural and anthropogenic forces that operate on different scales, influencing changes in regional and global climates [3, 13, 16]. Malhi et al. [13] document some interrelations in the Amazon forests, noting that they have a great influence on regional and global climates. They mention that the extraction of water from the soil, through the tree roots up to 10 m depth, and its return to the atmosphere (“perspiration service”) is, perhaps, the most important regional ecosystem service. Therefore, the removal of trees through deforestation can become a driver for climate change and a positive feedback for externally forced climate change. In agreement with the other authors, forest loss also results in (i) decreased cloud cover and an increase in insulation; (ii) increase in the reflectance of the earth's surface, approximately offsetting the effect of clouds; (iii) changes in the aerosol loading of the atmosphere from a hyperclean “green ocean” atmosphere to a smoky and dusty continental atmosphere that can modify rainfall patterns; and (iv) changes in the surface roughness (and therefore the wind speed) and a large-scale convergence of atmospheric humidity, which generates precipitation [14, 15]. These large-scale interrelations repeat on lesser scales, although they have not been sufficiently studied.

Deforestation and fragmentation could increase the vulnerability of forests to climate change [2, 3, 17, 18], being two interlinked processes, since deforestation to open up new land for cultivation is concentrated in the periphery of existing forest fragments, reducing them in size and/or making them disappear. Both processes have been recognized as important drivers of biodiversity loss [2, 4, 5, 19–21].

## 1.2. Climate change in Argentina

In 2015, Argentina presented its Third National Communication (TNC) on Climate Change [22], with an updated GHG inventory as part of the fulfillment of their assumed commitments to the United Nations Framework Convention on Climate Change (UNFCCC). They inform that national emissions in 2012 imply a 0.88% participation in global emissions (429,437 Gg CO<sub>2eq</sub>). The six sectors surveyed were as follows: (1) energy (43% of total emissions), (2) industrial processes (3.6%), (3) use of solvents and other products (0%), (4) agriculture and livestock (27.8 %), (5) land use change and forestry (LUCF) (21.1%), and (6) waste (6%). Within the LUCF sector – the third most important – the subsector of “forest and other land conversion” contributes 67% of emissions.

Of the total native forests, in 2002 (33 million ha), Yungas occupied 11.2% of the surface (3.7 million ha). A TNC report mentions that the loss of native forests in 2002–2010 was 3.5 million hectares (computed in “conversion of forests and other land”) corresponding to the 8% loss of Yungas (280,300 ha), which caused a reduction of 7.5% of the total area. The rest of the removed area corresponded to the Chaco region, whose surface involved 70% of the total forests in the country (larger ecosystem) that year.

In effect, the Intergovernmental Panel on Climate Change (IPCC), in which more than 300 scientists from all over the world participate, warned that, in 2014, 4.3% of global deforestation occurred in Argentina [16]. At a local level, the Secretary of Environment for the Nation published, in the same year, the report “Monitoring of the area of native forest in Argentina,” pointing out that between November 2007 (when the National Forest Act was enacted) and the end of 2013, 1.9 million hectares were removed – an average of 1 ha/2 min. Eighty percent of the deforestation is concentrated in four provinces: Santiago del Estero, Salta, Formosa, and Chaco [23].

At the same time, variations in local and regional climate had begun to be noticed in the country. The average annual temperature increased from 1960 to 2010 in almost all the northwest subregions (and Cuyo); in many areas (more than 0.5°C), the most notable changes were observed in spring. From 1950 to 2010, the annual average temperature, through the region was 0.6°C and it reached 0.7°C in Salta and Jujuy [22]. At a national level, the average temperature increases from ½ to 1°C. The possibility of increasingly intense heat waves has been forecast. In the northwest, an increase of 4–5° is projected by 2030, one of the highest on the planet. In the west and, notably, in the north of the country, there has been a shift toward the extension of dry winters. This could be generating problems with water availability for the populace, more favorable conditions for wildfires in forests and grasslands, as well as stress on livestock. This could bring implications on the biodiversity of the native forest remnants in

Yungas [22], and, at the same time, the disappearance of such remnants, which could provide feedback for those changes that are taking place at an atmospheric level.

Improving the understanding of biomass and carbon stocks in forests, therefore, provides valuable information for use land planning and designing comprehensive strategies in the context of global climate change. The purpose of this chapter is to present a synthesis of some of the different works developed in the subtropical forest of the Pedemontana Jungle, based on years of studies in the area. Studies were focused on the northern of the country, noting its role as carbon reservoirs and discussing factors that could influence the carbon sequestration total capacity of the same. The information presented here, without doubt, will contribute to the construction of a reliable database of this potential, which will facilitate standardization of units, reduction of uncertainties, and contribution to a more efficient strategy to limit GHG emissions, providing some learning and useful recommendations. Inasmuch as this ecosystem extends to Venezuela, the results obtained will provide a frame of reference for future studies on this ecological zone. This information is also necessary to improve the understanding of the distribution patterns of biomass and carbon at the global level and to describe patterns of land use. The results presented could guide in designing plans and management policies for these types of forests, at national and international levels.

## **2. Materials and methods**

### **2.1. The Yungas ecosystem: Pedemontana Jungle**

The phytogeographic Yungas province borders the Andes mountain range from Venezuela to Argentina [24]. The Argentine Yungas, which constitute a vital habitat for the fundamental role in the regulation of the water basins and protection against erosion, have been subjected to a long history of anthropogenic interventions, especially in low-lying areas, called the Pedemontana Jungles, which have a high agricultural potential [25].

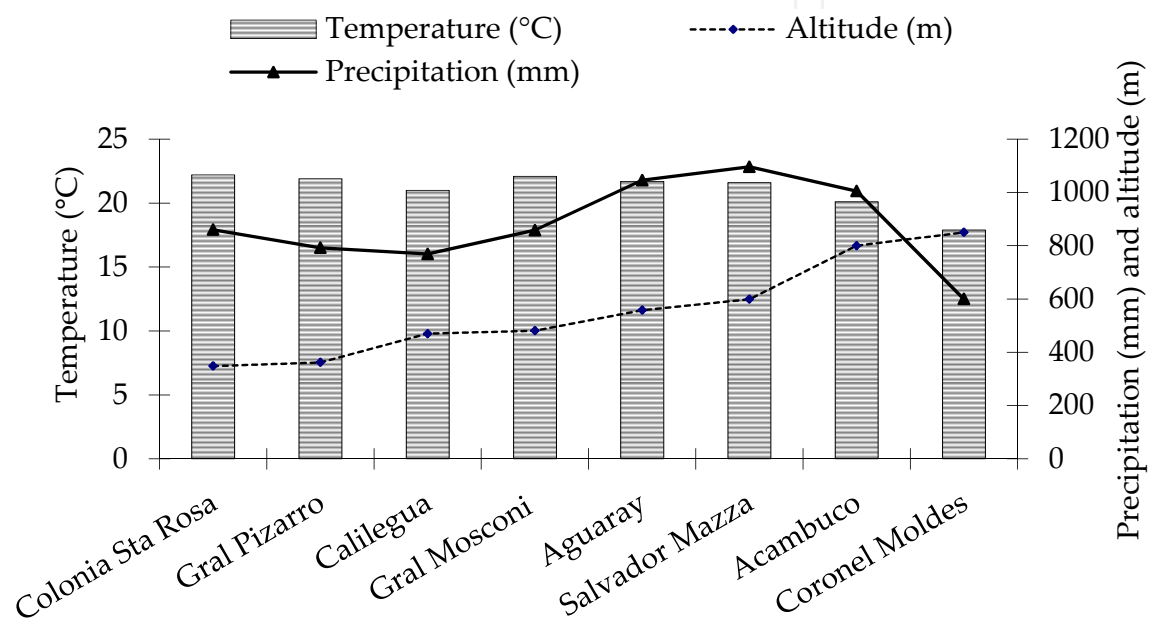
The history of Pedemontana Jungle in the north of Argentina has been closely tied to the railway expansion, necessary for the transport of precious wood, tropical crops, and sugar. More recently, from the 1990s, soybeans won the major role, expanding rapidly in the foothills landscape and its transition to the Chaco plain. The deterioration from the advance of the agricultural frontier, coupled with logging, the commercial bird catching and poaching – among others – are causes for concern because of the almost 5 million hectares that cover the Argentine Yungas, the effectively protected area is only 5% of the total [21].

The Pedemontana Jungle, which stretches from 450 to 900 m.a.s.l. – other authors mention minor ranges [24] – and which represents 25% of the Yungas, has been considered as an ecosystem in danger of extinction, and its deforestation would eliminate 30% of the total Yungas biodiversity [25]. In this region, 120 species of mammals and 8 of the 10 species of neotropical cats are represented. Also, approximately 583 species of birds inhabit it, which represent 60% of the species in Argentina [26]. Likewise, in the Pedemontana Jungle of Argentina and Bolivia, they were identified 18 AICBA (Areas of Importance for the Conser-

vation of the Birds of Argentina), noting that the AICBA including sectors of the Pedemontana Jungle, have a diversity of birds comparable to the cloud mountain forests (ecological zone of higher altitude than the PJ) and higher than the Chaco forests that surround them [27].

The physiography varies from submountain foothills to alluvial descents, presenting a hilly and wavy topography. The soils present in the study area are according to the taxonomic classification of FAO soils of the Phaeozem Haplic and Luvic type [28]. Soils of luvisol calcium were recorded only on the Coronel Moldes site.

The climograph and altitude for each of the studied sites are shown in Figure 1.



**Figure 1.** Annual average rainfall (mm), annual average temperature (°C), and altitude (m.a.s.l.) for different sites studied in the Pedemontana Jungle in northern Argentina (Salta and Jujuy provinces). Source: <http://es.climate-data.org/location/145171/>

## 2.2. Case studies

All the studies summarized in this chapter were carried out in the province of Salta, in northern Argentina, with the exception of case II, which was developed in the province of Jujuy. The province of Salta has an area of 155,500 km<sup>2</sup>, occupying the sixth position at the national level, and with a value similar to the surface of Nepal, has a population of 1.2 million, making it the eighth most populous out of 23 at the national level.

Of the entire surface occupied by the Yungas ecosystem in the country, 61% of it extends through this province, making it essential to focus on studies in this particular region. Also, Salta has 23% of the total surface of the country's native forests, and deforestation in this province is triple the world average [29].

Some of the assumptions, which have been evaluated from various case studies (always focusing on the Pedemontana Jungle), are as follows (more detailed in Table 1):



- i. The subtropical rainforests of the country have a greater capacity for carbon sequestration than subtropical dry forests at identical latitude.
- ii. Carbon sequestration in forests disturbed by human activity is lower than in forests less seized by humans, releasing the difference of carbon into the atmosphere.
- iii. The carbon stock, in legally protected forest sectors, is higher than in other sectors without protection located at identical latitude and under similar conditions.
- iv. The potential for carbon sequestration in the Pedemontana Jungle is less if latitude increases.
- v. The fragmentation of the Pedemontana Jungle generates microclimatic changes at the edges, which could affect carbon sequestration.

Case	I	II	III	IV	V
Legal protection	No	Yes	Yes and no	No	No
Site	Coronel Moldes	National Park Calilegua	Wildlife Reserve of Acambuco and Campo Pizarro	Aguaray and General Pizarro	Colonia Santa Rosa
Plot number	23 main plots (AGB <sub>10</sub> ) for each ecosystem; 23 plots of 50 m <sup>2</sup> (AGB <sub>0</sub> ); 23 plots of 5 m <sup>2</sup> (LUV); 46 plots of 1 m <sup>2</sup> (HUV and LI); 138 soil plots (SOC)	20 main plots (AGB <sub>10</sub> ); 20 plots of 50 m <sup>2</sup> (AGB <sub>0</sub> ); 40 plots of 1 m <sup>2</sup> (HUV and LI); 120 soil plots (SOC)	50 main plots (AGB <sub>10</sub> ); 50 plots of 50 m <sup>2</sup> (AGB <sub>0</sub> ); 250 soil plots (SOC)	50 main plots (AGB <sub>10</sub> ); 50 plots of 50 m <sup>2</sup> (AGB <sub>0</sub> ); 250 soil plots (SOC) and 500 microclimatic instantaneous records (MIC)	78 main plots (AGB <sub>10</sub> ); 78 plots of 50 m <sup>2</sup> ; 468 soil plots (SOC); 156 microclimatic instantaneous records (MIC)
Carbon pool	AGB <sub>0</sub> AGB <sub>10</sub> LI HUV LUV BGB SOC	AGB <sub>0</sub> AGB <sub>10</sub> LI HUV BGB SOC	AGB <sub>0</sub> AGB <sub>10</sub> BGB SOC	AGB <sub>0</sub> AGB <sub>10</sub> BGB SOC MIC	AGB <sub>0</sub> AGB <sub>10</sub> BGB SOC MIC

The acronyms AGB<sub>10</sub>, AGB<sub>0</sub>, HUV, LUV, LI, SOC, MIC are explained in the text.

Table 1. Methodological differences and similarities between the case studies.

2.3. Sampling design

The methodology used for each of the case studies presented in the next section shows some differences that are summarized in Table 1. In most cases, the data were collected following a random sampling design. Only in case V, the sampling was systematic.

The experimental design used was nested plots. Main plots had a total area of 100 m<sup>2</sup> and were rectangular plots. The criterion used to determine sample size for each stratum was an estimation of AGB of trees with a diameter at breast height (dbh)  $\geq 10$  cm during pre-sampling (90% probability and 20% mean standard error).

Carbon represents about 50% of the total oven-dried biomass present in forests [32]. Estimation of carbon pools in forests necessarily involves studying the different strata of biomass present in them. In the different studies, the following carbon pools and variables were measured:

- a. Aboveground tree biomass: AGB refers to the total amount of aboveground living organic matter in trees and shrubs ( $\leq 1$  cm dbh and  $\geq 50$  cm height) expressed as oven-dried tons. Total height (from ground level up to crown point) and dbh were measured in all trees with dbh  $\geq 10$  cm (called AGB<sub>10</sub>) in 100 m<sup>2</sup> plots. When  $1 \leq \text{dbh} \leq 10$  cm and height  $\geq 50$  cm (called AGB<sub>0</sub>), trees were measured in 50 m<sup>2</sup> plots. In multiple-stemmed trees, only the longest stem was measured. If neither shoot was dominant, an average of similar shoots was calculated. The basal diameter was registered only when the stem was shorter than the dbh. Standing dead trees with dbh  $\geq 1$  cm and fallen trees with dbh  $\geq 10$  cm were measured in the same way as living trees. However, correction factors of 0.8 and 0.7, respectively, were applied to the biomass values obtained. For hollow or ill trees, a factor of 0.9 was applied.
- b. Lignified understory vegetation (LUV): All shrubs shorter than 50 cm were collected in 5 m<sup>2</sup> plots within the corners of the main 100 m<sup>2</sup> plots.
- c. Herbaceous understory vegetation (HUV): This fraction was removed in two 1 m<sup>2</sup> plots. These plots were located in opposite corners within the 100 m<sup>2</sup> plots used to measure AGB<sub>10</sub>.
- d. Litter (LI): Organic debris on the soil surface (including freshly fallen parts of plants, decomposing organic matter, and deadwood) with a diameter no greater than 10 cm were collected in the same plots used for HUV.
- e. Belowground biomass (BGB) (tree roots): Due to the difficulties involved in the measurement of this fraction, it was estimated indirectly as a proportion of AGB<sub>10</sub> for Chaco and Yungas.
- f. Soil: Bulk density and percentage of organic carbon were determined in soil samples collected at a depth of 30 cm [30]. Vegetation and litter were removed from the soil surface prior to sampling. Bulk density was determined in two samples per plot using the cylinder method. Results from these samples were averaged. The percentage of organic carbon was measured following the method described in Walkley and Black. This measurement was performed on a composite sample built from four samples taken at identical distances within a linear transect along the longest axis of the 100 m<sup>2</sup> plots (dimensions of these plots were 5 m  $\times$  20 m).

Wet weight was recorded on site for LUV, HUV, and LI fractions. Dry weight was determined in the lab (registered after drying in an oven at 80°C until constant weight). The equation introduced by Cairns and coworkers [31], for tropical forest and lower latitudes than 25°, was used. The AGB fraction, also called as “biomass density” when expressed as tons of oven-dried



weight per ha [32], is the main source of total biomass in a forest ecosystem. Its relevance as a GHG mitigation option is therefore crucial [11–13]. This fraction was thoroughly assessed using a nondestructive methodology: allometric equations (Table 2).

- g. Solar radiation intensity ( $\text{W}/\text{m}^2$ ): A LICOR 250 pyranometer was used with a silicon sensor with a resolution of  $0.1 \text{ W}/\text{m}^2$ . The measures of global radiation readings are precise to  $\pm 5\%$ .
- h. Air relative humidity (%): This was recorded using a psychrometer or hygrometric probe Vaisala HM 34. Reading is immediate and accuracy is  $\pm 2\%$ . The sensor is the Humicap type. Measurements were taken at 1.5 m from ground level.
- i. Air relative temperature ( $^{\circ}\text{C}$ ): This was registered with a Vaisala HM 34 probe, with temperatures ranging from  $-20$  to  $+60^{\circ}\text{C}$ . Measurements were taken at 1.5 m from ground level.
- j. Soil temperature ( $^{\circ}\text{C}$ ): This was measured with a FLUKE 54 II digital thermometer with accuracy ranging from  $0.05^{\circ}\text{C} + 0.3^{\circ}\text{C}$ . Measurements were taken at 10 cm depth.
- k. Soil humidity (%): This was estimated by two soil samples taken at 10 cm depth per plot.

Authors	Carbon pool	Equation	No.
Chave et al. (2005)	$\text{AGB}_{10}$ and $\text{AGB}_0$	$\text{AGB} = \exp(-2.977 + \ln(\text{S} \cdot \text{D}^2 \cdot \text{H}))$	(1)
Brown et al. (1989)	$\text{AGB}_{10}$ and $\text{AGB}_0$	$\text{AGB} = \exp(-2.4090 + 0.9522 \ln(\text{S} \cdot \text{D}^2 \cdot \text{H}))$	(2)
Chave et al. (2005)	$\text{AGB}_{10}$ and $\text{AGB}_0$	$\text{AGB} = 0.112(\text{S} \cdot \text{D}^2 \cdot \text{H})^{0.916}$	(3)
Gehring et al. (2004)	AGB	$\text{Diameter (30 cm)} = 1.235 \times \text{dap} + 0.002 \times (\text{dap})^2$ $\text{AGB} = \exp(-7.114 + 2.276 \ln(\text{D}_{30}))$	(4)
Cairns et al. (1997)	BGB	$\text{BGB} = \exp(-1.0587 + 0.8836 \ln(\text{AGB}))$	(5)
Macdicken, (1997)	SOC	$\text{SOC} = \text{OC} \times \text{BD} \times \text{D}$	(6)
Sevola (1975)	V	$V = -2.2910 + 0.0558 \times \log(\text{D}^2 \times \text{H})$	(7)
Sevola (1975)	V	$V = -3.2794 - 0.0734 \times \log \text{H}^2 + 1.0580 \times \log(\text{D}^2 \times \text{H})$	(8)
Sevola (1975)	V	$V = -2.4385 + 0.9560 \times \log(\text{D}^2 \times \text{H}) - 0.80350 \times \log(\text{H} / \text{D})$	(9)
Chave et al. (2014)	$\text{AGB}_{10}$ and $\text{AGB}_0$	$\text{AGB} = 0.0673 + (\text{S} \cdot \text{D}^2 \cdot \text{H})^{0.976}$	(10)

AGB = tree aboveground biomass (kg oven-dry); SB = stem biomass; S = wood density (oven-dried biomass per green volume, in  $\text{t}/\text{m}^3$ ); D = diameter at breast height (1.3 m above ground, in cm); D30 = diameter at 30 cm above ground; H = total height (m); BGB = belowground biomass ( $\text{t}/\text{ha}$ ); OC = concentration of organic carbon in the soil (%); BD = soil bulk density ( $\text{g}/\text{cm}^3$ ) and D = depth of soil (cm); V = total tree volume, in  $\text{dm}^3$ , included stem, bark, and branches.

**Table 2.** Allometric equations used in this chapter.

The last five parameters called “microclimate factors” were measured in each preset distance, for each transect study, always at midday between 12 p.m. and 2 p.m. In the case of values per site, the different measurements taken were averaged per plot.

## 2.4. Estimation of biomass and carbon

Once field measurements were carried out, the data were computed clerically, carrying out the biomass estimate for each compartment, transforming it into carbon values (factor of 0.5 [32]) and achieving the sum of all the carbon pools. All equations used are shown in Table 2. Equation (1) was developed by Chave et al. [33] for “moist forest stand,” while equation (3), by the same authors, was developed for “dry forest stands” (applied to the Chaco). Equation (10) was recently developed by these authors and was applied to the *Anadenatnhera colubrina* and *Cedrela angustifolia* species, for which no specific equations were found. Equation (4) was applied only in vines and required converting the dbh into diameters at 30 cm height, and then entering that value into the equation [34]. In the case of volumetric equations (7, 8, and 9) [35], the total biomass conversion was carried out by multiplying the total volume by the basic density of each species. Equation (7) was then applied to the *Calycophyllum multiflorum* species, equation (8) to *Phyllostylon rhamnoides*, and equation (9) to *Astronium urundeuva*, all equations being developed in the region.

The basic wood densities (dry) for different species were obtained from Ref. [36]. A basic density value obtained from the weighted average of the densities of each site’s species was used for the species that for various reasons could not be identified. For estimation of SOC (soil organic carbon), equation (6) was used [30]. For data analysis, the nonparametric type test was chosen. We used the INFOSTAT® software, and a value of 0.05 was considered significant.

## 3. Results and discussion

### 3.1. Effect of temperature and humidity on the carbon stock: dry and humid subtropical forests at the same latitude

Contributors: Manrique, S.M. and Franco, J.

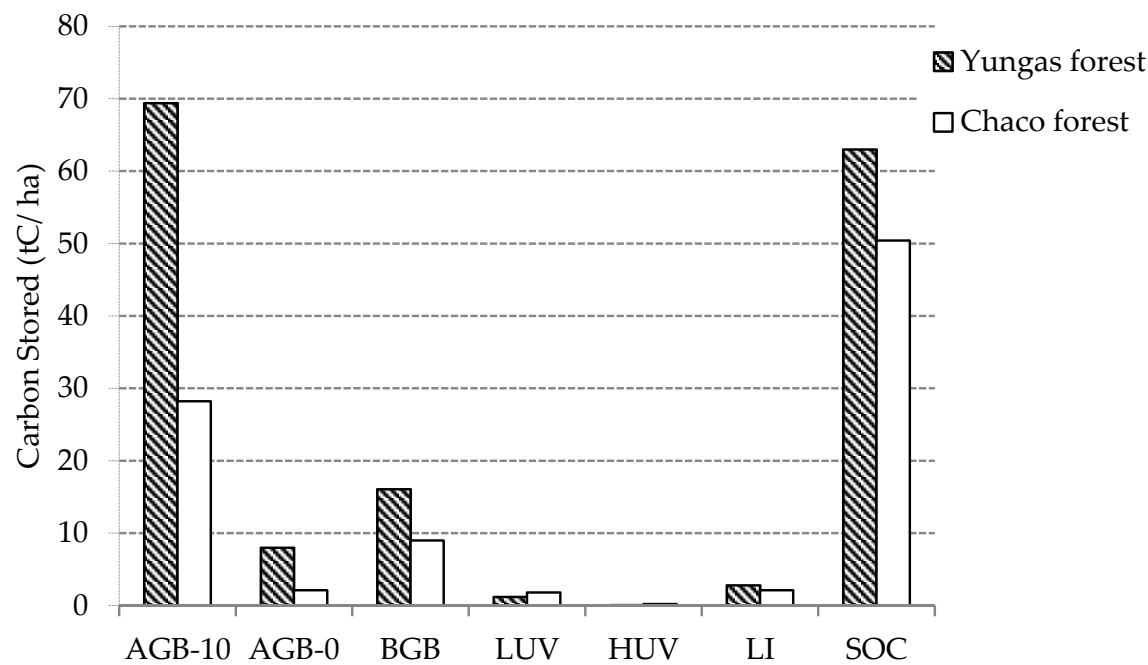
**The subtropical moist forests of the country have a greater capacity of carbon sequestration than subtropical dry forests at identical latitude.**

As was mentioned, the Chaco ecosystem is the largest surface area at the national level. It was interesting to compare facets of this ecosystem with the Yungas Pedemontana Jungle with regard to the potential for carbon sequestration at the same latitude. The work was carried out in the municipality of Coronel Moldes (25°16’00” South latitude and 65°29’00” West longitude), 60 km south of the capital of the province of Salta.

The province’s climate is defined as subtropical mountainous with a dry season. However, the topography does allow the development of contrasting environments. Thus, the moist winds from the southeast enter the province and release their moisture from submountainous ranges

that make up the sub-Andean hills in the north-central region of the country. This allows the spread of vegetation, which is a unique environment that runs along elevations in different altitudes, forming a north–south strip. The Chaco ecosystem develops on the plain that extends from the center of the country to the East, and in Salta two districts are exhibited: the semiarid Chaco and the mountain Chaco. Precipitation decreases as it moves eastward, shrinking from more than 650–700 mm per year in the Pedemontana Jungle ecosystem to values of less than 460 mm in the Chaco ecosystem. Temperatures also suffer a slight increase as it moves west away from the mountains, which have the moisture [37], marking isotherms in the range of tenths of degrees, as the distance between the mountains and the eastern point increases.

The starting points are corroborated in this study: the most humid ecosystem shows a carbon stock 43% larger than that stored in the driest ecosystem (Table 3). In the case of Yungas, the AGB fraction means almost 80% of the total biomass, although the greater fraction ( $AGB_{10}$ ) alone implies 71%, leaving the  $AGB_0$  a reduced participation. The BGB means more than 16% of total biomass, and the rest if divided between the LI (about 3%), the LUV (with almost 2%) and lastly, the negligible participation of HUV (0.1%). For the Chaco, the fraction AGB provides more than 71% of the total biomass, where the trees of larger diameters ( $AGB_{10}$ ) mean 66% of this contribution. In this environment, the BGB takes on greater importance (with more than 21%), and is followed by – in the identical order shown in the Yungas environment – LI fraction (3.2%), LUV (2.6%), and HUV (0.6%) (Figure 2).



**Figure 2.** Carbon stock and contribution of each carbon pool studied. The acronyms  $AGB_{10}$ ,  $AGB_0$ , BGB, HUV, LUV, LI and SOC are explained in the text.

Clearly, the AGB and SOC fractions are the two largest contributors in the two ecosystems. In Yungas, the AGB represents 48% of the total fixed carbon, while the SOC contributes 39%. In the case of the Chaco, 33% of the total carbon in the ecosystem is concentrated in AGB, while

54% remains captured in SOC. Soil is an important reservoir of carbon, becoming the most important fraction in dry environments. However, when we compare the absolute values of SOC in both environments, the soil shows a significant relationship with the vegetation found on the surface. In Yungas, it is 63 tC/ha, while in Chaco it is 50 tC/ha.

Sector	Average	Standard deviation
Yungas forest (Selva Pedemontana)	162	85
Chaco forest (Chaco Serrano)	92	42

**Table 3.** Carbon stock (tC/ha) in both ecosystems, Chaco and Yungas, in Coronel Moldes, Salta, Argentina.

Viglizzo and Jobbágy [21] point out that the carbon stocks in the biomass and in the organic fraction of the soil in Argentina vary from one ecoregion to another. The carbon stock in biomass is directly associated with the availability of vegetation biomass. In the tropical and subtropical regions of Argentina (e.g., Yungas), more than 50% of total carbon is found stored in the AGB fraction, which makes this element vulnerable and easily appropriable by humans. This relationship falls dramatically in areas dominated by grasslands/pastures (e.g., Chaco), and even more (without reaching 10%) in intensively cultivated ecosystems.

In Yungas, the average height was 11 m and average dbh was 17.6 cm, both higher than those for Chaco, although still lower than figures cited for pristine Yungas ecosystem [24, 25, 38]. Estimations made for tropical humid forests around the world range from 150 to 192 t/ha for closed, undisturbed forests and around 50 t/ha for open forests [39]. Certainly, different factors may be influencing these differences (rainfall, soil type and site features, topography, etc.) [32, 33, 39, 40]. Moreover, the structure of the forest in the Yungas area included in this study was clearly disturbed by humans and livestock. Numerous recent and decomposing stumps were found and there were unambiguous signs of wandering animals and persons. *Solanum riparium* was also abundant in this area, a species normally dispersed by wild animals or cattle. The appearance of typically Chaco species in sections of Yungas forest is probably a sign of human intervention in this region [24, 38].

Our results suggest that forest degradation is detectable not only in Yungas but also in Chaco. In environments similar to Chaco, discrepancies between these results (lower) and estimations made in similar environments in other forests of the world might be due to structural differences, altitude, latitude and humidity, gradients (24, 32, 33). However, in our case the level of degradation exerted by human activity in this environment might also be responsible for the discrepancies [20, 21, 41] (further details refer to [43]).

Economic activities such as agriculture and logging, which take place in these ecosystems, are arguably not respecting their carrying capacity. Local institutions do not seem to be capable of stopping, controlling, or regulating these activities. Whether entering into a market-based system like the one promoted by the Kyoto Protocol will be part of the solution to the problem of deforestation and conservation of local native forests remains to be seen. Decisions are highly political and many times the relevant decision makers are thousands of kilometers

away. No decisions affecting the future of these forests should be taken until agreements on this issue are reached or until judiciary processes are properly finished. Competing claims on the ownership of the forestland, the products of the forests, and the provision of ecosystem services must be taken into consideration in a comprehensive forest management.

### 3.2. Effect of human influence on the carbon stock in forests

Contributors: Gallucci, G.B. and Manrique, S.M.

#### **Carbon sequestration in forest disturbed by human activity is lower than in forests less seized by humans.**

In case I, we identified that studied forest sectors clearly show human influence as a factor of degradation of the original structure of the same type. In this case study, it was interesting, particularly, to assess this difference and try to quantify it for samples of the same Pedemontana Jungle ecosystem, but this time as a protected area: Calilegua National Park (23°27'–23°45' South latitude and 64°33'–64° 52'0" West longitude). The park was created in 1979 to protect a representative sector of the Yungas and to protect the headwaters of the Calilegua streams, which are a part of the San Francisco River basin, and provide water to neighboring crops in the protected area. With an area of 76,320 ha, it is the largest national park in the Argentine Northwest. It is approximately 165 km from the city of Salta.

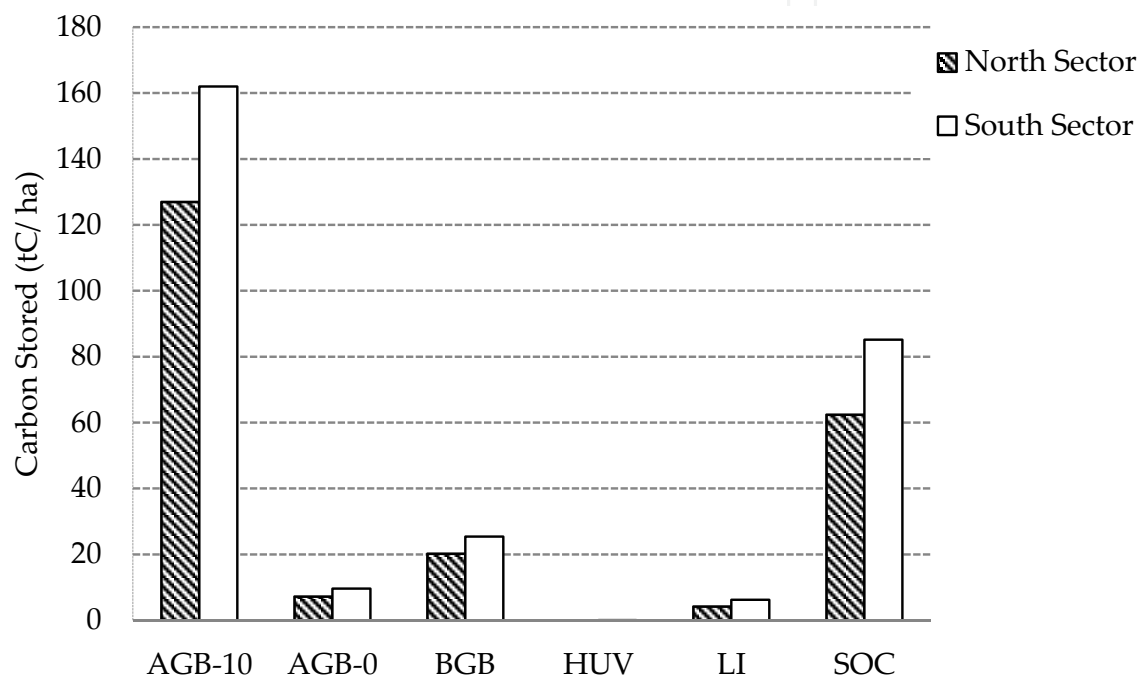
We studied two areas of the park (north and south sectors) separated by only 50 km but which have different accessibility to human influence. The north sector surrounding the town of Caimancito has been invaded by oil companies, which have conducted exploration activities in the area, and therefore have dissected the forest, leaving open “choppings” or paths of prospecting. This has led to the accessibility of nearby residents who have taken advantage of the forest and even have led their animals to graze there. In the south, on the other hand, exploration activities were not carried out and therefore, even if villagers could have accessed the site, on its more sheltered side (the other side of rivers that flow through the park), a better conservation has been maintained, which can be seen in the large, heavily wooded trees, and the high forest value that is still there. Surely, the presence of Park Rangers (Aguas Blancas section) in this sector has helped much in this protection.

Two sectors that maintain homogeneous topographic, edaphic, and climatic conditions were selected. Both sectors were compared through analysis of average annual rainfall records (56 years series) without finding statistically significant differences ( $H = 0.01$ ,  $p > 0.999$ ). Records of minima and maxima were also analyzed. The series of annual average temperatures were not statistically different ( $H = 0.16$ ,  $p = 0.686$ ). In the case of edaphic variables, existing cartographic studies allowed us to associate both sectors with the same series of soils. Organic matter samples taken in the area showed no significant differences ( $H = 4.71$ ,  $p = 0.210$ ). It was assumed that both sectors had identical site conditions.

We evaluated the same carbon pools as in case I with the exception of LUV, which had no relevant participation in the previous case, and therefore it was not included in the pursuit of reducing the fieldwork effort and costs.



The obtained results allow us to advance with the basic assumption: the north sector, subject to anthropogenic influence, it showed a carbon stock 23% lower than the south sector, which had less accessibility and a better state of conservation (Table 4). These differences were statistically significant ( $H = 11.20$ ,  $p < 0.001$ ) only for the AGB stratum, but not for the other strata studied nor for the total carbon stock. Under similar conditions of climate, soil, geomorphology, altitude, and latitude, the human influence could explain these differences, as the AGB stratum is the easiest to appropriate by humans [10, 17, 19, 21]. The AGB make the largest contribution in both sectors to the carbon stock (53, 55%), followed by SOC (28–31%) and finally BGB (8–10%) depending on the sector analyzed (Figure 3).



**Figure 3.** Carbon stock and contribution of each carbon pool studied. The acronyms AGB<sub>10</sub>, AGB<sub>0</sub>, BGB, HUV, LI and SOC are explained in the text.

Sector	Average	Standard deviation
Protected forest degraded (north sector)	221	116
Protected forest better preserved (south sector)	272	129

**Table 4.** Carbon stock (tC/ha) in both sectors, north and south, in Calilegua, Jujuy, Argentina.

Against the results, there is an urgent need to review the administration and safeguards for the Calilegua National Park, with a reinforcement of the Corps of Rangers in the area (currently with few people that must patrol the whole park). Other authors are agreed that the declaration to protect does not always mean adequate protection [43, 44]. The acquisition of more financial resources for the protected areas should be carried out in the light of a strict management plan



and monitoring. Poaching, livestock grazing, and logging without authorization – with the thinning out of valuable wood species – must be eradicated from the core area, so that the Park can fulfill its role with the conservation of biodiversity, which has been included in the international statement “Yungas Biosphere Reserve.”

3.3. Effect of legal protection on the ecosystem

Contributors: Manrique, S.M.; Vacaflor, P.; Fernández, M. and Franco, J.

**The carbon stock in legally protected forest sectors is higher than in unprotected sectors located at the same latitude and under the same conditions.**

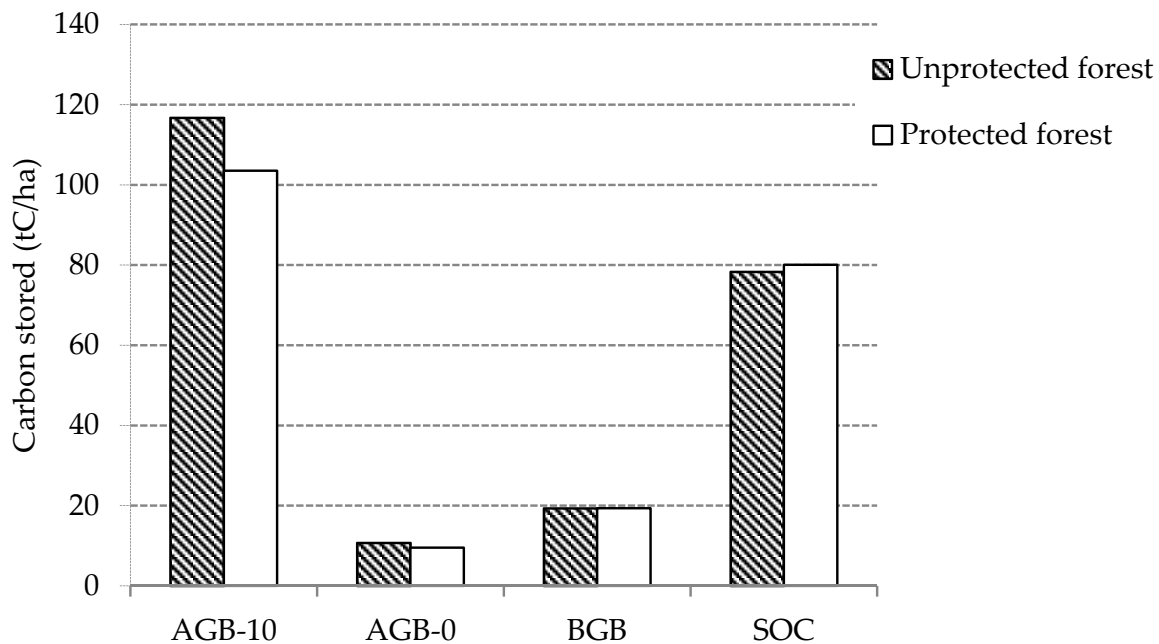
In case II, two sectors of the legally protected Pedemontana Jungle were analyzed, which clearly show differences between them in their accessibility to human influence. It became interesting to continue in this line of study, exploring if the trend found in the former case could be due to a particular situation in the Calilegua National Park. In this case study, we sought to observe comparative sectors inside and outside legally protected regions located at the same latitude and altitude, and under the same conditions. We started to identify protected areas in the province which shelter samples from the Pedemontana Jungle. We finally worked in and out of the Provincial Reserve of Flora and Fauna of Acambuco (PRFFA) (22°12'38.5" South latitude and 63°56'23.1" West longitude) and in the National Reserve of Campo Pizarro (NRCP) (24°11'54.87 and 24°14'21.7" South latitude, and 64° 7'27.00" and 64° 9'23.79" West longitude). The creation of PRFFA dates back to 1979, and currently has an area of 32,000 ha. It is approximately 470 km from the city of Salta to PRFFA. In the case of NRCP, it was created in late 1995 with an area of 25,000 ha, and soon after a process of reversal and social conflict, the NRCP ended up with an area of 21,000 ha. It is approximately 280 km from Salta. In this study, efforts were concentrated in the carbon pools considered most significant in the prior cases, eliminating HUV and LI from the samples.

The results show that, on average, the carbon stock is similar in protected and nonprotected areas (Table 5). Having considered the average of all sectors included in the Reserves and the average of all the studied sectors not protected in them, no significant differences were found ( $H = 0.85$ ,  $p = 0.356$ ), by even analyzing just AGB separately ( $H = 0.98$ ,  $p = 0.322$ ). The initial assumption cannot be confirmed: no case shows that the legal protection has caused differences in the ecosystem it protects, neither favoring nor against. Yet we see different values if we consider the samples of the north sector and south sector separately, as will be discussed in the following section.

Sector	Average	Standard deviation
Protected forest	203	74
Unprotected forest	213	82

**Table 5.** Carbon stock (tC/ha) in both sectors, protected and unprotected forest, in Acambuco and Campo Pizarro, Salta, Argentina.

In terms of the importance of each of the studied carbon pools (Figure 4), the carbon fixed at the fraction of AGB returns to be larger than the fixed carbon in the soil (SOC).



**Figure 4.** Carbon stock and contribution of each carbon pool studied. The acronyms AGB<sub>10</sub>, AGB<sub>0</sub>, BGB and SOC are explained in the text.

The inclusion of Pedemontana Jungle sectors within legal protection figures has not resulted in benefits in terms of their ability to sequester carbon in the different carbon pools. However, this consideration is not conclusive in the role of protected areas. Pedemontana Jungle sectors, within and without the protected areas, could be similar in their capacity to sequester carbon in two possible situations: (i) a good general ecosystem condition level, which still remains a certain continuity of ecosystem, and therefore, either inside or outside the Reserve, is of similar forest samples and show no particular features nor different structural configurations; (ii) a poor state of conservation, which has equally affected protected and nonprotected areas, imprinting similar features in the different sectors, by simultaneous intervention in the different forest sectors. A more in-depth study of other ecosystem variables would perhaps lean toward one alternative or another. However, the different log of measured carbon stock in case II in Calilegua National Park, or the degradation features in the two types of ecosystems (Yungas and Chaco), which were observed in case I, clearly indicates that the forests have not received the attention they should have over the years.

Therefore, these thoughts should be a trigger to continue with deeper and more comprehensive evaluation and to draw attention to the need to review and update control schemes and monitoring of native forests – mainly protected areas. The global community has recognized the importance of forests for biodiversity, and has prioritized the preservation of forest biodiversity and ecosystem functions through multiple multilateral agreements and processes. For example, the Aichi Biodiversity Targets established by the Convention on Biological

Diversity (CBD) in its strategic plan include halving the rate of loss of natural habitats including forests (target 5) and conserving 17% of terrestrial areas through effectively and equitably managed, ecologically representative, and well-connected systems of protected areas (target 11). Currently, designating protected areas is one of the primary strategies for conserving biodiversity. Different authors have discussed the increase in protected areas over the past century; however, they find that many key biodiversity areas are not adequately covered by protected area status [44].

The always-protected system areas will be limited to preserve all the original diversity, but even so, it is imperative that these areas exist and continue to expand with scientific criteria.

3.4. Effect of latitude and altitude on the carbon stock

Contributors: Manrique, S.M.; Vacaflor, P. and Fernández, M.

**The potential of carbon sequestration in the Pedemontana Jungle is less if the latitude increases.**

In case III, the average carbon stock in protected and unprotected areas was approximately similar, although with different values from cases I to II. This led to the analysis of the position within the ecosystem of the studied sites. In case I, with 162 tC/ha, the forest is at 25°16 and 65°29. In case II, with 221–272 tC/ha, the forest is approximately between 23°27 and 64°33. Analyzing other sectors located at different latitudes could confirm the trend of higher values of biomass and the north sector of the Pedemontana Jungle (e.g., Calilegua showing a value 100% greater than the Coronel Moldes value) and values that decrease toward the south. It was interesting, therefore, to explore case III results separately, taking as a northern sector, the plots carried out near Aguaray (22°12 and 63°56) and, as a southern sector, those carried out near General Pizarro (24°11 and 64°7).

Sector	RI (W/m <sup>2</sup> )	RH (%)	RT (°C)	SM (%)	ST (°C)
North sector	0.065 a	43.55 a	26.94 a	9.9 a	22.09 a
	(0.02–0.44)	(21.7–86.7)	(16.6–36.55)	(3.15–17.25)	(20.15–25)
South sector	0.065 a	36.9 a	31.66 b	7.24 ab	24.2 b
	(0.02–0.13)	(16.35–55)	(25.4–37.8)	(2.3–14.4)	(22.85–30.8)

RI = radiation intensity; RH = relative humidity; RT = relative temperature; SH = soil moisture; ST = soil temperature. Mean and range for each variable. Means followed by different letters (a, b) within the same column indicate statistically significant differences (P <0.05).

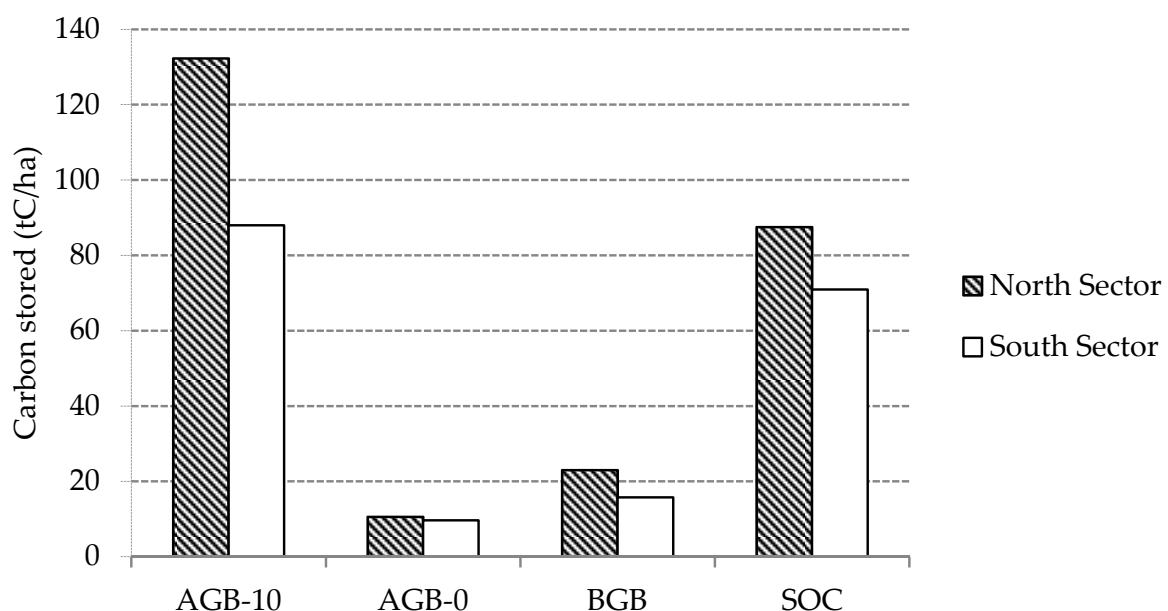
Table 6. Average climatic conditions.

The loss of species diversity and conditions of humidity and altitude from north to south, along the gradient in which the Pedemontana Jungle extends within Argentina, has been previously documented [27, 40]. Therefore, it was interesting to know in this case if this trend was also clearly reflected in the carbon stocks of the studied sectors of the Pedemontana Jungle. If the

previous studies, the participation of the HUV and LUV strata was between 0.01% and 0.02% and the LI carbon pool was between 1.5% and 3%. Therefore, in this study efforts were concentrated in the strata of AGB, BGB, and SOC. The chosen sectors show the average weather conditions (for the same season, day, and year), which differ significantly in air relative temperature (RT), moisture and soil temperature (SM and ST, respectively) (see Table 6).

Studies of carbon stock results show that the two sectors are clearly separated in terms of their potential. The northern sector has the largest records of total carbon with an average of 242 tC/ha, while the southern sector registers an average 28% lower (Table 7) with statistically significant differences ( $H = 12.38$ ;  $p < 0.01$ ). These values can be associated with different microclimates, possibly generated by a latitude effect, whose influence on climatic variables can be seen in Table 6. In all cases, the differences are in favor of a cooler, more humid climate in the northern sector and warmer and drier in the southern. Although the number of analyzed sectors in a latitudinal gradient in the Pedemontana Jungle (narrow strip of north–south direction), are not representative of the whole distribution, the data can be interpreted in light of the existing scientific studies in the area [25, 27, 40].

Once again, the two carbon pools that make a greater contribution to the total ecosystem carbon stock are AGB and SOC, being greater in the case of the northern sector, meaning 52% and 34% of the total carbon stock, respectively (Figure 5). This implies that more than 86% of total carbon is concentrated in these two fractions. In the southern sector, the participation of these carbon pools is 47% and 38% for AGB and SOC, respectively, but with greater involvement of the SOC carbon pool in this case.



**Figure 5.** Carbon stock and contribution of each carbon pool studied. The acronyms AGB<sub>10</sub>, AGB<sub>0</sub>, BGB, and SOC are explained in the text.

Sector	Average	Standard deviation
Forest in the north (22° latitude)	242	96
Forest in the south (24° latitude)	174	68

**Table 7.** Carbon stock (tC/ha) in both sectors, north and south, in Salta, Argentina.

However, always considering the altitude of the Pedemontana Jungle, as the latitude increases, the altitude decreases in general terms. It has been recognized that the floral changes are influenced by complex interactions of weather and edaphic variables in Yungas altitude ranges [24, 25, 40]. Beyond the fact that the associated variables of increasing altitude (which in this study varies between 22° S and 24° S) and/or altitude (which varies between 500 and 700 m.a.s.l. in the southern sector and between 700 and 900 m.a.s.l. in the north) would more or less determine overt changes at the level of species and ecosystems, such variations exist without doubt, and they are defining two sectors of the same forest in terms of carbon sequestration potential.

These observations indicate that it is essential to preserve sectors of different latitudes and altitudes in the Pedemontana Jungle, since there are intrinsic factors that are defining differential features in the biomass and carbon stock, as well as, in every ecosystem functions associated with these particular conditions [40]. Other authors have already pointed out that the recommendation in all cases is to maintain connectivity of Yungas in distribution, safeguarding different sectors of the Pedemontana Jungle, varying in latitude and altitude [27].

Human influence, not analyzed in this study, will, no doubt, imprint differential features over time if their presence is not restricted, since we have observed signs of livestock and logging in the different studied areas. In the southern sector, where the Pedemontana Jungle has been deeply fragmented and immersed in an array of crops, it is considered that there might be a microclimatic influence on the fragments by the existence of rough edges [7, 18]. This aspect will be dealt with in the following section.

**3.5. Effect of fragmentation on the carbon stock**

Contributors: Manrique, S.M.

**Fragmentation of the Pedemontana Jungle generates microclimate changes at its edge, which could affect the sequestration of the carbon stock.**

The fragmentation of forests, reducing surface and insulation, exposes organisms, which remain in the fragment, to conditions differing from their ecosystem, which is primarily manifested in the contact between two different environments, which has been defined as “edge effect” [18], and that impact toward the forest interior.

Microclimatic changes caused as a consequence of contrasting conditions between the remnant forest and the adjacent field, subjected to different uses (cultivation, planting, and pastures), would seem to be the most immediate and apparent fragmentation changes [7]. Several authors have recognized that, at the edge of the fragments is an environmental



gradient toward the interior: generally brightness, evapotranspiration, temperature, and wind speed decrease, while soil moisture and humidity increase toward the interior of the fragment. Biological changes could then arise as a result of these changes in the microclimate of the fragment edges [7, 18].

This study sought to analyze and quantify the possible microclimatic changes generated in the fragment edges of the Pedemontana Jungle, also observing the distribution of five representative tree species (by their frequency [24]). The studied species were as follows: (i) *Calyco-phyllum multiflorum* Griseb, Castelo, (ii) *Phyllostylon rhamnoides* J.Poiss., Taub, (iii) *Astronium urundeuva* Engl., (iv) *Anadenanthera colubrina* Vell., Brenan, and (v) *Cedrela angustifolia* DC. It was estimated that the typical species, “climax” or more conservative ones of the population (e.g., those that have higher demands for their germination or growth requirements and with low tolerance for humidity fluctuations), could be more easily eliminated like those selected for this study. These species, which have a high degree of integration, complexity, and efficient energy use, are recognized as more susceptible to edge changes [18]. Therefore, in fragmented environments, the survival advantage is given to those pioneer species with a maximum tolerance for a wide range of environmental conditions.

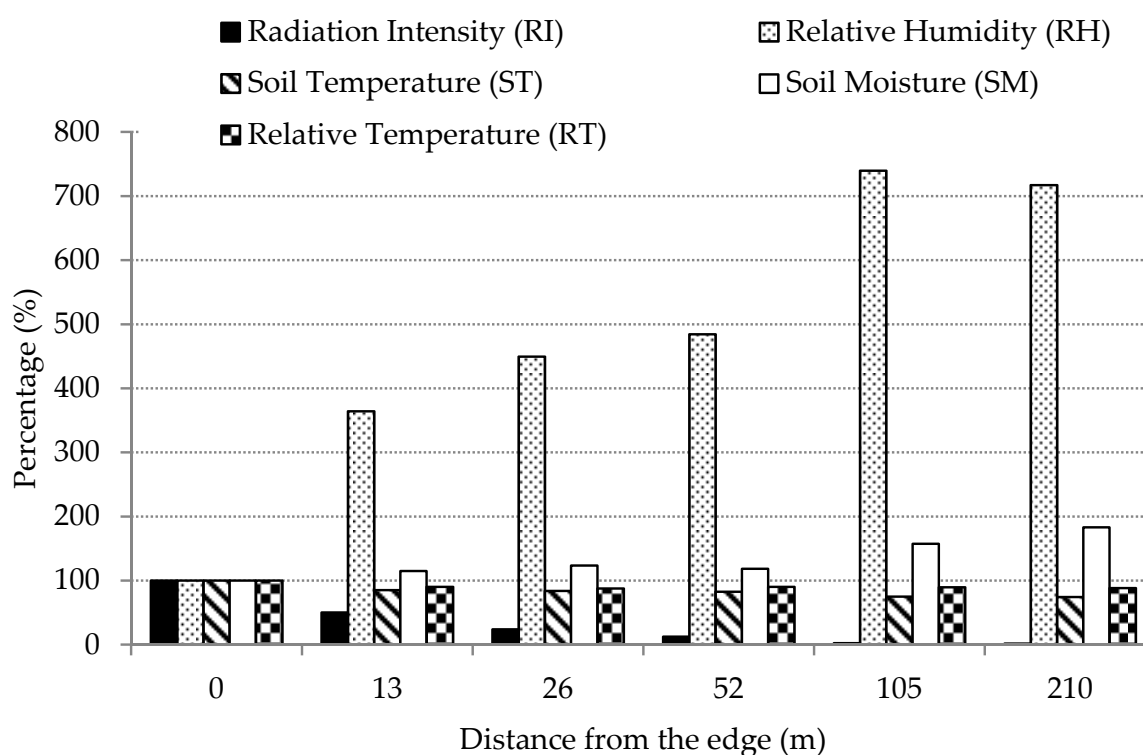
Five forest sectors in the Colonia Santa Rosa municipality were worked (23°20'00 south latitude and 64° 30'15" west longitude): four, clearly turned into fragments, and one continuous (not fragmented) taken as a standard for comparison. The fragments were of distinct sizes: two large (sites 1 and 2 between 160 and 180 ha) and two small (3 and 4 between 3 and 5 ha). The distance from the city of Salta is 250 km.

The results of microclimatic records (taken from the edge toward the inside of the fragments, except in the site 5 as it was not considered the same edge but worked in an inside sector, looking for original ecosystem conditions) suggest that (Figure 6):

- High radiation intensity (RI) values are recorded at the edge (around 800 W/cm<sup>2</sup> on average) and almost constant values under cover (forest interior), which mean, almost, only up to 2% of that value. The differences were statistically significant ( $H = 16.19$ ;  $p < 0.01$ ).
- Soil moisture (SM) in the interior is twice that of the edge (with maximum values of up to 16%) showing significant differences ( $H = 29.20$ ;  $p < 0.001$ ).
- Air relative humidity (RH) increases toward the interior, reaching values up to 7 times higher than those at the edge (up to 53% relative humidity (RH)). The differences are significant ( $H = 5.41$ ;  $p = 0.048$ ).
- Soil temperature (ST) is one of the most stable variables, although differences can be detected: considering 100% at the edge (18°C on average) is reduced to 25% in the interior. The differences are not statistically significant ( $H = 5.94$ ;  $p = 0.311$ ).
- Air relative temperature (RT) decreases by 12% in the interior, showing nonsignificant values ( $H = 5.69$ ;  $p = 0.337$ ).

Changes are not manifested with identical magnitude in all cases. The smaller fragments tend to register values higher or lower for the measured variables (results not shown).





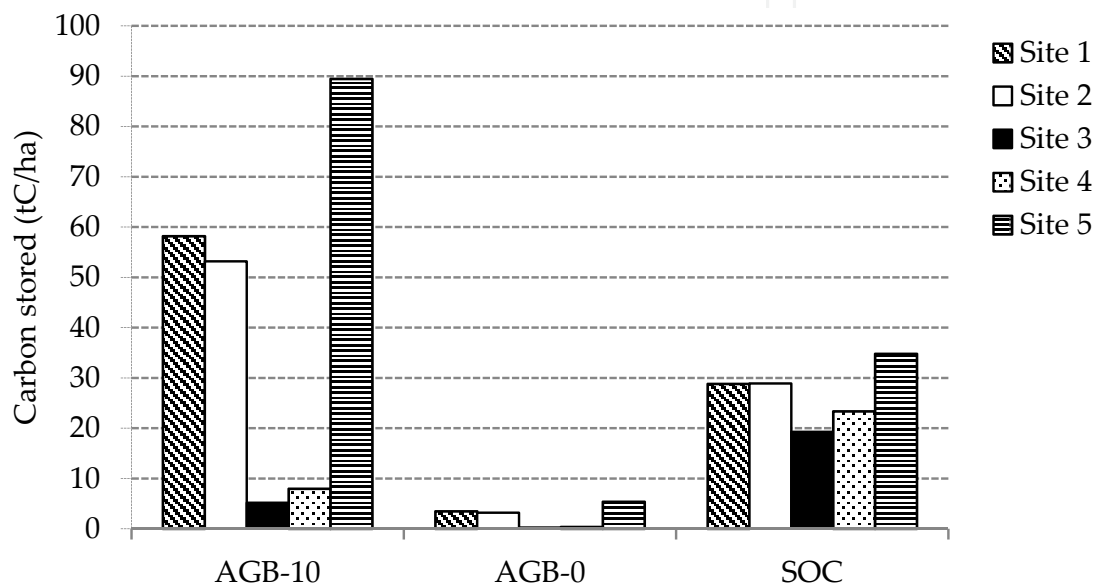
**Figure 6.** Microclimatic variables studied in fragments from edge to inside. Values are expressed in relative terms as a percentage of value at the edge (considered as 100%). The units are the following: RI= W/cm<sup>2</sup>; ST= °C; RT=°C; RH= %; SM= %.

Microclimatic variables are interrelated. Thus, for example, the RH and the RT are inverse and strongly related; the RI and RT relate directly and the RH and RI in reverse. This means that the intensity of radiation reaching the edge of the plot is influencing the relative temperature directly (higher radiation and higher relative temperatures) and inversely with relative humidity (greater radiation and lower relative humidity). In addition, the relative humidity and temperature inversely influence themselves (where there are higher values of relative temperature, there are lower values of relative humidity).

In the AGB case, the relative participation of each species to the biomass stock varies according to site between 9% and 22 % for *C. multiflorum*, 5% and 79% for *P. rhamnoides*, 0% and 15% for *A. urundeuva*, 11% and 48% for *A. colubrina*, and between 0% and 23% for *C. angustifolia*. In general, the best-represented species is *P. rhamnoides*, followed by *A. colubrina*, and *C. multiflorum*. The fraction of ≤10 cm dbh (“sprout”) contributes to their maximum values up to 6% of total AGB per site. AGB decreases significantly ( $H = 53.66$ ;  $p < 0.001$ ) from site 5 ( $179 \pm 36$  t/ha) to site 1 ( $116.4 \pm 32.2$  t/ha), site 2 ( $106 \pm 44.6$  t/ha), site 4 ( $16 \pm 6.7$  t/ha), and lastly site 3 ( $10.37 \pm 4.1$  t/ha). The studied species represent approximately 86–90% of the total in the case of the forest (according to plot). In the fragments, the five studied species not only have lower AGB but also have proliferated heliophyllum species, typical of open environments, and species composition has changes (results not shown). It cannot be concluded that carbon sequestration in vegetation is less because of the microclimatic edge effect. Although there are clear differences in the AGB<sub>10</sub>, the correlation of different distance values does not give significant values

( $r = 0.03$ ;  $p = 0.804$ ), nor in the  $AGB_0$  ( $r = 0.20$ ;  $p = 0.134$ ). The AGB of key species differs among fragments, but it cannot be said that a whole biomass has declined, since other shrubs and herbaceous species have proliferated. Larger studies are necessary to evaluate this aspect in depth.

Carbon sequestration in SOC, estimated up to 10 cm depth, increases from  $19.3 \pm 5$  tC/ha in the site 3 (small forest fragment) to  $23.4 \pm 5$  tC/ha in the site 4 (small forest fragment),  $28.8 \pm 7.5$  tC/ha in the site 1 (large forest fragment),  $28.9 \pm 12.2$  tC/ha in the site 2 (large forest fragment), and  $34.8 \pm 8.8$  tC/ha in the forest or site 5 (Figure 7).



**Figure 7.** Carbon stock and contribution of each carbon pool studied (AGB includes only five species studied). The acronyms  $AGB_{10}$ ,  $AGB_0$  and SOC are explained in the text.

It can be assumed that the influence of these changes will affect, in the middle or long term, the composition and facilitate the establishment the different species, according to their requirements. Mainly, the dominant tree species (climax) could result in changes in its germination and survival, promoting the success of pioneers species implantation, and altering the original composition and structure of the forest [18].

#### 4. Main remarks

The studies presented in this chapter offer insight into the varied potential of the Pedemontana Jungle for sequestration of atmospheric carbon, and how this potential can be influenced by human intervention in processes of deforestation, degradation, and fragmentation.

The carbon stock estimated for the Pedemontana Jungle ranges from 162 tC/ha (in Coronel Moldes) to 272 tC/ha (in Calilegua). In all cases, greater carbon storage occurs in the AGB fraction (from 47% to 55% of the total), where  $AGB_0$  fraction provides between 6 and 10% of

the total stock. Soil (SOC) constitutes the second most important carbon pool. Its contributions range from 28% to 39% according to the site.

The Pedemontana Jungle sequesters 43% more carbon than the Chaco forest at the same latitude. Moreover, the potential of carbon sequestration in the Pedemontana Jungle increases as the latitude decreases, sequestering 28% more carbon at 22° than 24° south latitude.

Carbon sequestration in the Pedemontana Jungle sectors least affected by humans (degradation) is 23% higher than in more degraded areas. There are no advantages for sites that are legally protected (i.e., carbon sequestration is approximately similar). Forest degradation practices such as unsustainable timber production, overharvesting of fuel wood, extensive cattle ranching, and fires at the edge of forest fragments are less easily observed than deforestation, but they can contribute substantially to emissions. Forest degradation can also be a precursor to deforestation. These multiple changes in land use and forest area need to be monitored at the national level.

The Pedemontana Jungle sectors that have been left isolated are subject to edge effect, with changes clearly visible in microclimatic variables. The AGB in fragments is notably reduced for the main five tree species studied, but the species composition has also changed.

The potential impact of climate change on forest remnants is still unpredictable and depends on each one's resilience, on the remnant's adaptive capacity to climate change, and the magnitude and intensity of the phenomenon manifested in each area. At the same time, deforestation, degradation, and fragmentation of the Pedemontana Jungle could be affecting its ecological and social integrity, and the ability to provide ecosystem services of supply and regulation in the long term, and therefore its ability to respond to the global climate change impact.

Human management has taken over the ecosystem services that sustain the most important production systems from an economic standpoint. For example, irrigation water for cattle pastures and soil for agriculture. In many forests, such as the Pedemontana Jungle, other ecosystem services, for example, cultural or climatic regulation, are subordinated to these major objectives. The consequences of this imbalance in handling are shown negatively in the middle and long term, whereas in the short term, it cannot be seen most of the time. Vulnerable ecosystems are thus generated from the biophysical and social point of view, with a reduced capacity to respond to additional disturbances such as global climate change.

Forests require immediate support, with long-term policies independent of the ideologies, and management plans developed on technical bases, which are based on compliance with Article 41 of the National Constitution, "*All citizens enjoy the right to a healthy and balanced environment, suitable for human development and for productive activities that meet present needs without compromising those of future generations; and have the duty to preserve it...*" Land use plans should prioritize the conservation of ecosystems of high ecological value, such as the Pedemontana Jungle or Chaco, moreover, in a province where the natural biodiversity is accompanied by cultural biodiversity (with nine aboriginal ethnic groups), and where the forests are the principal sustainers of life.

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