

Carbon balance in the silvopastoral systems of Caldén forest: sources or sinks of greenhouse gases?

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Abstract

The objective of the following work was to address, through modeling and field data, a carbon balance as a function of forest cover for a silvopastoral breeding system in native *Neltuma caldenia* forest. For this, the herbaceous stratum in different forest covers was measured through sampling. Forage production for each tree density was affected by a use factor and was compared with the feed demand of a herd of breeding cows. The load values were affected by the estimated emissions in cattle breeding in the region (1,427 and 2,407 kg eq-CO₂ animal⁻¹ year⁻¹). The evolution of the parameters of the forest mass was modeled using growth data obtained from 19 dendrometers distributed in 7 permanent plots in different tree densities. The results show that the herbaceous biomass was maximum in the condition of minimum woody cover and that from 8.5 m² ha⁻¹ of basal area (BA) the forage yield decreases significantly ($P < 0.05$). The projected values of the forest flight show that from 2.4 m² ha⁻¹ of BA, the eq-CO₂ captures in the total tree biomass exceed the emissions of livestock supported by forage availability. If the capture of emissions that are trapped in the stem biomass is considered, the capture exceeds the emissions from 17.5 m² ha⁻¹ of BA. It is concluded that managing the Caldén forest with appropriate silvicultural management would allow the production of "carbon neutral meat". The balance did not contemplate the capture of C by the soil.

Introduction

The demand for cattle is increasing rapidly due to the increase in the global human population and economic expansion. In recent years, the livestock sector's contribution to greenhouse gas (GHG) emissions and climate change has been a cause of concern. This sector accounts for the second largest share of anthropogenic GHG emissions after the energy sector (Kumaş and Akyüz 2023).

Agroforestry is important as a carbon sequestration strategy due to the potential for its storage in the edaphic and woody component. Preliminary assessments suggest that some agroforestry systems (AFS) may be CO₂ sinks and temporarily store carbon, while other systems, for example ruminant-based silvopastoral systems, are likely GHG sources (Dixon 1995).

The *Neltuma caldenia* (Burkart) or "Caldenales" forests are located bordering the Argentine pampas and, currently, the main economic activity is breeding cattle, which uses almost exclusively the forage that grows in the undergrowth (SAyDS 2007). The current forest area, according to the latest national forest inventory (MAyDS 2020), is 3,068,089 ha. This important savanna-type forest formation is characterized by a wide range of physiognomies, which is mainly reflected in the variation in tree coverage and density. The balance between tree/grass components is dynamic and is a function of the complex interaction of climate, soil, water availability and disturbances (Gabutti et al. 1999; Morici et al. 2009) that results in a variation in the production of the herbaceous stratum that in turn impacts the livestock carrying capacity and therefore the GHG emissions from livestock.

On the other hand, there is a wide range of studies (Albrecht and Kandji 2003; Montagnini and Nair 2004; Ibrahim et al. 2005; Nair et al. 2009) that support the fact that AFS offer an opportunity for carbon sequestration by the tree layer. Kursten and Burschel (1993) stated that the amount of carbon captured by the woody component in AFS ranges between 3 and 25 Mg C ha⁻¹, being highly dependent on the tree species, density, age, site and the management applied. However, in the dry forests of the South American cone, carbon sequestration in woody forests is much lower than that reported in other regions, mainly due to their low growth rates (Fernández et al. 2018; Díaz et al. 2020). The importance of agroforestry with respect to C sequestration and other CO² mitigation effects is being widely recognized, but there is still a paucity of quantitative data on silvopastoral systems of native forests and, in particular, in caldén forests.

Based on the above, two working hypotheses are proposed for a caldén forest silvopastoral system: 1) *There is a competitive process between the tree species and the herbaceous component species, so the growth of the former is inversely proportional to the density of the latter.* 2) *The increase in woody density increases the rate of carbon capture by tree biomass to the point of offsetting emissions from cattle.* The objective of the following work was to address, through modeling and field data, a carbon balance between capture by woody and livestock emissions based on forest cover for a silvopastoral breeding system in native *N. caldenia* forest.

Materials and methods

Description and location of the study area. The caldenal is a xeric forest dominated by *N. caldenia* and is the predominant tree formation of the caldenal district within the Espinal phytogeographic region (Fig. 1). Its structure is generally associated with other woody trees such as carob (*Neltuma flexuosa* DC), chañar (*Geoffroea decorticans* Burkart) and toro's shadow (*Jodina rhombifolia* Hook. et Arn. Reissek) which is accompanied by a shrub stratum where the following stand out: *Schinus fasciculata* (Griseb.), *Celtis ehrenbergiana* (Klotzsch) Liebm. and *Condalia microphylla* Cav. It has a dense herbaceous layer composed mainly of mixed perennial grasses (Anderson et al. 1970).

The region where the study was carried out is located in the southwest of the province of Córdoba, Argentina and is characterized as semiarid in transition to subhumid monsoon regime. The average annual temperature is 16.6°C and it has an average precipitation of 893 mm, although it presents great interannual variability (average climatological values 1981–2010 from the statistics of the *National Meteorological Service*).

Definition of the silvopastoral module. The study was carried out in the “Estancia Ralicó” establishment (34° 54'25" S; 64° 50'03" W) which has an area of 15,300 ha, of which 9,000 ha correspond to *N. caldenia* forest in different degrees of coverage and conservation (Fig. 1). Historically, the establishment was divided into pastures of approximately 600 hectares. Starting in 2016, a high instantaneous load rotational grazing system was implemented. To do this, a 600-hectare lot was divided into 30 20-hectare plots. The divisions were made using electric wire, searching for spaces within the mountain without

opening fire-break streets. Grazing is carried out by introducing high loads, between 900 and 1,200 animals per plot, in periods of 3 to 4 days, once a year. The number of animals and the duration of time is adjusted depending on forage availability.

Forest inventory. To characterize the forest, a forest inventory was carried out following the guidelines of the First National Forest Inventory (SAyDS 2007). Circular plots of 500 m² were established, with a radius of 12.62 m. Diameter at Breast Height (DBH), which corresponds to the diameter at 1.3 m from the ground, and Total Height (H), which corresponds to the distance from the ground to the top of the tree, were measured by means of Suunto hypsometer. The specific composition at the stand level was evaluated by defining the relative values in number of feet (density) and basal area (BA). A marked dominance of *N. caldenia* (Utello et al. 2021) could be determined over the rest of the species where the average relative percentage of occupancy was greater than 90% of the basal area. The rest of the relative composition was distributed between *N. flexuosa*, *G. decorticans*, *S. fasciculata* and to a lesser extent by *J. rhombifolia*, which usually appears as dispersed individuals. Consequently, the modeling and analysis was approached from the main species (*N. caldenia*) as it was the one that would have the greatest impact on the forage resource and on the capture of C.

Measurement of herbaceous biomass. Once the different forest covers were established, from open forest ($BA \leq 5 \text{ m}^2 \text{ ha}^{-1}$) to closed forest ($BA \geq 25 \text{ m}^2 \text{ ha}^{-1}$), the availability of the herbaceous stratum was determined through completely randomized sampling under the conditions of: projection under glasses and between glasses. 24 repetitions were taken per condition ($n = 96$). Herbaceous biomass sampling was carried out prior to the entry of the animals and the collected material includes that accumulated between two grazing, according to the grazing system set out above. The sampling size for the herbaceous stratum was 0.25 m². In the laboratory, the species that make up the samples were identified and the percentages in terms of occupancy were determined. To obtain dry matter, the samples were placed in a forced air oven for 48 hours until constant weight.

Estimation of the load and emissions of the livestock component. Once the net aerial primary production for each tree density was determined, it was affected by an appropriate use factor (AUF = 50%), which represents the percentage of the annual forage production of a species that can be used without endangering the production, reproduction and longevity in the natural grassland (Holechek et al. 1989). Once the forage supply was obtained, it was compared with the nutritional demand of a herd of breeding cows of 400 kg live weight (LW). A daily allocation of forage in dry matter (% FDM) corresponding to 3% of the LW was proposed, this being a considerable value for the animal to present good reproductive performance (Rovira 1996). The animal load was determined by the ratio of forage supply and demand (Eq. 1).

$$\text{Animal load} = \frac{\text{Forage supply (Kg DM Ha}^{-1}\text{)} \times \text{AUF (50 \%)}}{\text{LW (kg)} \times \% \text{ FDM} \times \text{Rotation length (1 year)}} \quad [1]$$

The load values based on tree density allowed estimating GHG emissions generated by livestock using what was proposed by Nieto et al. (2014) who evaluated GHG emissions from enteric fermentation and

manure management for different categories of cattle with conditions similar to the study site; the result is that cattle breeding generates an average of emissions of 1,427 kg eq-CO² animal⁻¹ year⁻¹. In addition, the emissions generated by the lactating cow category were considered, which reaches the maximum pollution levels of 2,407 kg eq-CO² animal⁻¹ year⁻¹ in the region's breeding systems based on natural grasslands.

Obtaining a diameter distribution model. To establish the diameter distribution model of the woody component under study, the guidelines proposed in the model, or De Liocourt's Law (Madriral 1994), were followed:

$$N_i = N_{max} (1 + a)^{(D_{max} - D_i)/d} \quad [2]$$

Where, N_i : Number of feet of class i ; D_i : Average diameter of class i ; N_{max} : Number of feet of maximum diameter class; D_{max} : Average diameter of the maximum diameter class; d : Interval of diameter classes; and a : model constant.

The exponential model can also be formulated with the expression [3]:

$$N_i = k \cdot e^{-q \cdot D_i} \quad [3]$$

Where k and q are constants, with $q = 1/d \cdot \ln(1 + a)$. The exponential function [3] was transformed into a linear function by applying logarithms [4]:

$$\ln y = \ln k - q \cdot \ln e D_i \quad [4]$$

And then expressed as:

$$Z = \beta_0 + \beta_1 \cdot X_i \quad [5]$$

Where, Z is the number of feet for a basal area value (BA), the maximum diameter (D_{max}) and the De Liocourt quotient “ q ”. The term X_i replaces D_i .

This transformed function allowed us to establish relationships that made it possible to calculate the coefficient β_1 for a chosen value of “ q ” and β_0 for a certain basal area (Araujo 2014).

The quotient between the number of individuals of consecutive diameter classes is equal to the constant “ q ”, therefore, it can be expressed as:

$$\frac{N_i}{N_{i+1}} = \frac{e^{(\beta_0 + \beta_1 \cdot X_i)}}{e^{(\beta_0 + \beta_1 \cdot X_{i+1})}} = q \quad [6]$$

Multiplying the terms of the equation, we obtain:

$$q \cdot e^{(\beta_0 + \beta_1 \cdot X_{i+1})} = e^{(\beta_0 + \beta_1 \cdot X_i)} \quad [7]$$

Applying logarithms and simplifying:

$$\ln q + (\beta_0 + \beta_1 * X_i + 1) \ln e = (\beta_0 + \beta_1 * X_i) \ln e \quad [8]$$

$$\ln q = \beta_0 + \beta_1 * X_i - \beta_0 - \beta_1 * X_i + 1 \quad [9]$$

$$\ln q = \beta_1 * X_i - \beta_1 * X_i + 1 \quad [10]$$

$$\ln q = \beta_1 (X_i - X_i + 1) \quad [11]$$

Solving the term β_1 :

$$\beta_1 = \frac{\ln q}{X_i - X_{i+1}} \quad [12]$$

With this expression, the new value of β_1 was calculated for a certain value of “q”. In the same way, the basal area (BA), expressed in $\text{m}^2 \text{ha}^{-1}$, is defined by:

$$BA = \frac{\pi * D}{40.000} * f + \frac{\pi * D}{40.000} * f + \dots \frac{\pi * D_n}{40.000} * f_n \quad [13]$$

In which $D^2 \dots, D_n^2$ represent the smallest and largest diameter of the distribution and $f \dots, f_n$ are the respective frequencies.

Solving the term $(\pi / 40.000)$, the common factor e^{β_0} and replacing the frequencies f by their value $[e^{(\beta_0 + \beta_1 X_i)}]$ we obtained:

$$BA = \frac{\pi}{40.000} * [e^{\beta_0} (D * e^{(\beta_1 * D)} + D * e^{(\beta_1 * D)} + \dots D_n^2 * e^{(\beta_1 * D_n)})] \quad [13]$$

Where:

$$e^{\beta_0} = \frac{BA * 40.000}{\pi * (D * e^{(\beta_1 * D^1)} + D * e^{(\beta_1 * D^2)} + \dots + D_n^2 * e^{(\beta_1 * D_n)})} \quad [14]$$

Finally, applying natural logarithm, we arrived at the expression that relates the coefficient β_0 to the basal area BA:

$$\beta_0 = \ln * \left[\frac{BA * 40.000}{\pi * (\sum D_i^2 * e^{(\beta_1 * D_i)})} \right] \quad [15]$$

The basis of the method is the determination of proportional parts of BA for the different classes, which are then used to calculate a correct basal area, distributing the desired level of BA in the respective classes. Then, the chosen basal area is transformed into the number of trees to construct the diameter distribution. To define the balanced distribution, a value of $q = 1.46$ was selected, used for the construction of the balance curve, which was obtained from previous adjustments in forests with good coverage status. The BA was raised from $5 \text{ m}^2 \text{ha}^{-1}$, starting at 1 to $25 \text{ m}^2 \text{ha}^{-1}$, this was related to the

BA values in which the forage biomass was evaluated. A maximum diameter for management of 50 cm was used, established from the fact that, under the thinning harvesting regime, the last class is cut, reaching a minimum cutting diameter of 45 cm. When individuals reach that diameter, it guarantees good development, capable of producing abundant seeds and good sawmill performance. Furthermore, as stated by Bogino and Villalba (2008), around that diameter the current annual increment is equal to the average annual increment, establishing the optimal moment of use from a biological point of view.

Forest growth projection. Growth modeling was carried out through a diameter class model, using as a basis the initial equilibrium diameter distribution obtained in the previous section. Assuming the proposal of Silva (1989), the fraction of trees that moves annually throughout the entire class interval, due to diametral growth, can be estimated by a growth index (GI), calculated by Equation [16]:

$$GI = Ci * P/a [16]$$

Where, *GI*: Growth index. *Ci*: Current increments in class diameter. *P*: Number of years in the period considered. *a*: Amplitude of the diameter class.

The current increments (*Ci*) for the year considered were obtained from a total of 19 dendrometers distributed in the trees of each diameter class in 7 permanent sampling plots at different tree densities (16, 20, 21, 23, 32, 36 and 42 m² ha⁻¹ of BA). Knowing the average annual stock in number of individuals per diameter class and the GI, it is possible to calculate the number of years necessary for all the feet of one class to pass to the next and project its diameter distribution.

Determination of total and stem biomass. To estimate biomass and its distribution by class, the allometric functions developed by Risio et al. (2013) [Equation 17]:

$$W = (\beta * BA^2) + \lambda * h [17]$$

Where: *W*: is the weight of dry biomass (kg) of the different fractions of the tree; *BA*: basal area; *h*: tree height; β and λ : estimated model parameters (total biomass: β : 0.000366 and λ : 7.558194; stem biomass: β : 0.000093 and λ : 1.0858).

Height determination was carried out using equation [18], adjusted by Utello et al. (2019):

$$h = \frac{10,94}{1+1,73 \times e^{-3,69 * DBH}} [18]$$

Where, *h*: total height of the tree (m). *DBH*: Diameter at Breast Height (m).

Statistical analysis. The herbaceous biomass data were analyzed by analysis of variance (ANOVA) and Fisher's LSD test for the comparison of means, using the *Infostat* statistical software (Di Rienzo 2018). The same software was used for regression analyzes where it uses the least squares method in linear models and the Nelder-Mead simplex algorithm method for non-linear ones (Nelder and Mead 1965). The

selection of the models was carried out by comparing the coefficient of determination (R^2), the mean square of the error, the level of significance of the parameters, and the values of the Akaike information criterion and the information criterion Bayesian.

Results

In relation to the composition of the grassland, the samples were mainly made up of a dense grass stratum mainly represented, in terms of average biomass, by 44% of *Stipa brachychaeta* Godron, 23% of *Nassella hyalina* Nees, 4.2% *Melica argyrea* Hack, and in lower values by *Setaria leucopila* (Scribn. et Merr.) K.Schum, *Cyperus cayennensis* Britton, *Nassella tenuissima* Barkworth and *Carex sororia* Kunth. Within the broadleaf trees, 3.8% *Clematis montevidensis* Spreng, 1.4% *Solanum hieronymi* Kuntze, 1.3% *Solanum chenopodioides* Lam were found. and to a lesser extent *Miconandra camareoides* Griseb. In the grasses, an average of 10% of senescent material was observed.

Regarding the availability of herbaceous biomass, of the 7 situations evaluated (Table 1), it was observed that production was maximum in the condition of minimum woody coverage and that from 8.2 m² ha⁻¹ of BA, which is equivalent to 26% projected canopy coverage, forage yield decreases significantly ($P < 0.05$). Based on the above, as the woody coverage increases, the livestock carrying capacity of the system and therefore GHG emissions decrease (Table 1, Fig. 2).

Table 1

Herbaceous biomass total area, animal load and emissions of kg eq-CO₂ ha⁻¹ year⁻¹ depending on the density of the tree layer in *N. caldenia* forest.

Forest type		Herbaceous biomass total area (Kg DM ha ⁻¹ year ⁻¹)	Animal load (Eq Cow ha ⁻¹ year ⁻¹)	Average livestock emissions (Kg eq-CO ₂ ha ⁻¹ year ⁻¹)	Lactating cow emissions (Kg eq-CO ₂ ha ⁻¹ year ⁻¹)
Basal area (m ² ha ⁻¹)	Tree canopy cover (%)				
4,0	12,8	3466,88 a	0,40	952,60	564,75
5,4	17,2	3807,22 a	0,43	1046,12	620,19
8,2	25,9	3067,28 a	0,35	842,80	499,65
17,8	56,7	1940,55 b	0,22	533,21	316,11
21,8	69,3	1216,30 b	0,14	334,20	198,13
23,0	73,1	1186,25 b	0,14	325,95	193,23
23,3	74,2	1037,13 b	0,12	284,97	168,94
<i>P</i>		< 0,0001			

P: limiting probabilities in ANOVA. Different letters indicate significant differences (LSD Fisher, $P < 0.05$).

In relation to the tree component, the values of diametric growth observed in dendrometers for each forest density (BA) showed an association expressed in a coefficient of determination $R^2 = 0.61$. The highest values of growth without competition reached $3.86 \text{ mm year}^{-1}$, and a decrease of 0.1 mm of diametric growth per unit of increase in BA ($\text{m}^2 \text{ ha}^{-1}$) ($\text{SE} = 0.03$; min. -0.16 (95%) and max -0.04 (95%); $n = 19$).

The projected values of C accumulated in the entire tree biomass, expressed in kg CO_2 equivalent $\text{ha}^{-1} \text{ year}^{-1}$ (Fig. 2), greatly exceed the emissions from the livestock component supported by forage availability from 2.4 (density equivalent to regenerating forest) and $4.5 \text{ m}^2 \text{ ha}^{-1}$ of BA for the bovine breeding and lactating cow subsystem, respectively (Fig. 2). If we consider the capture of emissions that would be trapped in the stem biomass, which would present a much higher turnover than the C retained in branches and roots (extraction of wood for various purposes), the capture exceeds the emissions from $11 \text{ m}^2 \text{ ha}^{-1}$ of AB, when the average emissions of all categories of a bovine breeding subsystem (empty cow, pregnant cow, lactating cow, bulls and calves) are considered. Now, if only the category of maximum pollution is considered (Nieto et al. 2014), the capture by woody plants exceeds the emissions from $17.5 \text{ m}^2 \text{ ha}^{-1}$ of BA, which is equivalent to a forest of 55.65% projected canopy coverage.

Discussion

The results of the herbaceous component suggest that the levels of competition in the tree stratum above 30% crown cover begin to have significant negative impacts on the performance of the herbaceous plant and, consequently, on the livestock carrying capacity (Table 1). In a previous study carried out in the same silvopastoral module, Utello et al. (2021) found that the yield of herbaceous biomass in open forest (10 to $15 \text{ m}^2 \text{ ha}^{-1}$ of BA) was significantly higher compared to a condition of closed forest (25 to $30 \text{ m}^2 \text{ ha}^{-1}$ of BA). On the other hand, other authors such as Fernández et al. (2002) have found that radiation attenuation above 50% begins to have a negative impact on the growth of herbaceous plants. This means not rejecting the hypothesis that as the density of the tree layer increases, the density of herbaceous plants decreases.

In relation to the growth of the trees, it is necessary to mention that the average growth values of 2.86 to $0.31 \text{ mm year}^{-1}$ obtained from the dendrometers were relatively low if we compare it with the values of 5.4 and 8 mm year^{-1} found by Bogino and Villalba (2008) in the extreme north of Caldenal (province of San Luis) or what was reported by Dussart et al. (1997) of 4.4 and 8 mm year^{-1} to the south of our area study (Province of La Pampa). The differences may be due to the fact that the growth values measured for the year considered coincide with one of the driest periods that have occurred in recent decades in the central area of the Argentine Republic. In any case, the concrete thing is that the growth values in drought circumstances ensure that GHG capture in tree biomass exceeds emissions from certain densities as mentioned above.

Montagnini and Nair (2004) state that potential C sequestration rates range between 1.5 and $3.5 \text{ Mg C ha}^{-1} \text{ year}^{-1}$ in tropical forests. Ibrahim et al. (2005) states that carbon storage can vary between 20 and

204 Mg C ha⁻¹, with the majority of this carbon stored in soils, and may even have annual C increases that can vary between 1.8 and 5.2 Mg C ha⁻¹. Nair et al. (2009) showed that carbon sequestration from above and belowground biomass in AFS varied from 0.29 Mg C ha⁻¹ year⁻¹ in a forage bank in West Africa to 15.2 Mg C ha⁻¹ year⁻¹ in mixed plots in Puerto Rico. In this experience, a maximum sequestration of 0.68 Mg C ha⁻¹ year⁻¹ and a stock of 44.4 Mg C ha⁻¹ in the total tree biomass was reached in the condition of 20 m² ha⁻¹ of BA. These low values are more similar to those reported by Díaz et al. (2020) where the C captured year⁻¹ in a silvopastoral system of the central Paraguayan Chaco was only 0.047 Mg C ha⁻¹.

Finally, if the capture by all tree biomass is considered, compensation for emissions is achieved when the *N. caldenia* forest barely achieves a density of 2.4 m² ha⁻¹ of BA (7.63% coverage). which is equivalent to a stock of 5.33 Mg C ha⁻¹. If the capture of C by the stem biomass is considered, the compensation point, using the category of lactating cow, is reached when the forest has a capture rate of 0.67 Mg C ha⁻¹ year⁻¹ and a stock of 38.86 Mg C ha⁻¹ of total standing biomass and a density of 17.5 m² ha⁻¹ of BA. These values would correspond to a forest condition of 56% projected canopy cover, 850 feet arranged exponentially ($q = 1.46$), and a maximum diameter of 50 cm. This means not rejecting the second hypothesis, as the density of the tree layer increases, the capture rates in the woody layer manage to compensate for the emissions from cattle.

Conclusions

Based on the first hypothesis, it is concluded that, as the density of the tree stratum of the Caldén forest increases, it generates a significant decrease in the herbaceous component, which leads to a decrease in the global livestock load and, in the same sense, GHG emissions.

According to the second hypothesis, it is concluded that, as the density of the woody species increases, the GHG capture equivalent increases up to a maximum from which a greater number of feet does not compensate for the decreasing diameter increases. If only the capture by the stem biomass is considered, the balance becomes neutral when intermediate forest cover is reached, which would indicate that managing the caldén forest with appropriate silvicultural management would allow the production of “carbon neutral meat.”

The balance presented here did not consider carbon capture by the soil. It is necessary to incorporate this component since many authors, in some circumstances, consider it a more important sink in terms of capture than forest biomass. Furthermore, it is necessary to deepen the study of the dynamics of forest growth based on intensive silvicultural management, as well as the technical, economic and environmental sustainability of the intervention technologies that are developed for forest management.

Declarations

Author Contribution

All authors contributed to the study conception and design. Material preparation and field sampling were performed by Marco Jesús Utello, Juan Carlos Tarico and José Omar Plevich. The data analysis was performed by Marco Jesús Utello. The first draft of the manuscript was written by Marco Jesús Utello and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. Funding acquisition were performed by José Omar Plevich.

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Figures

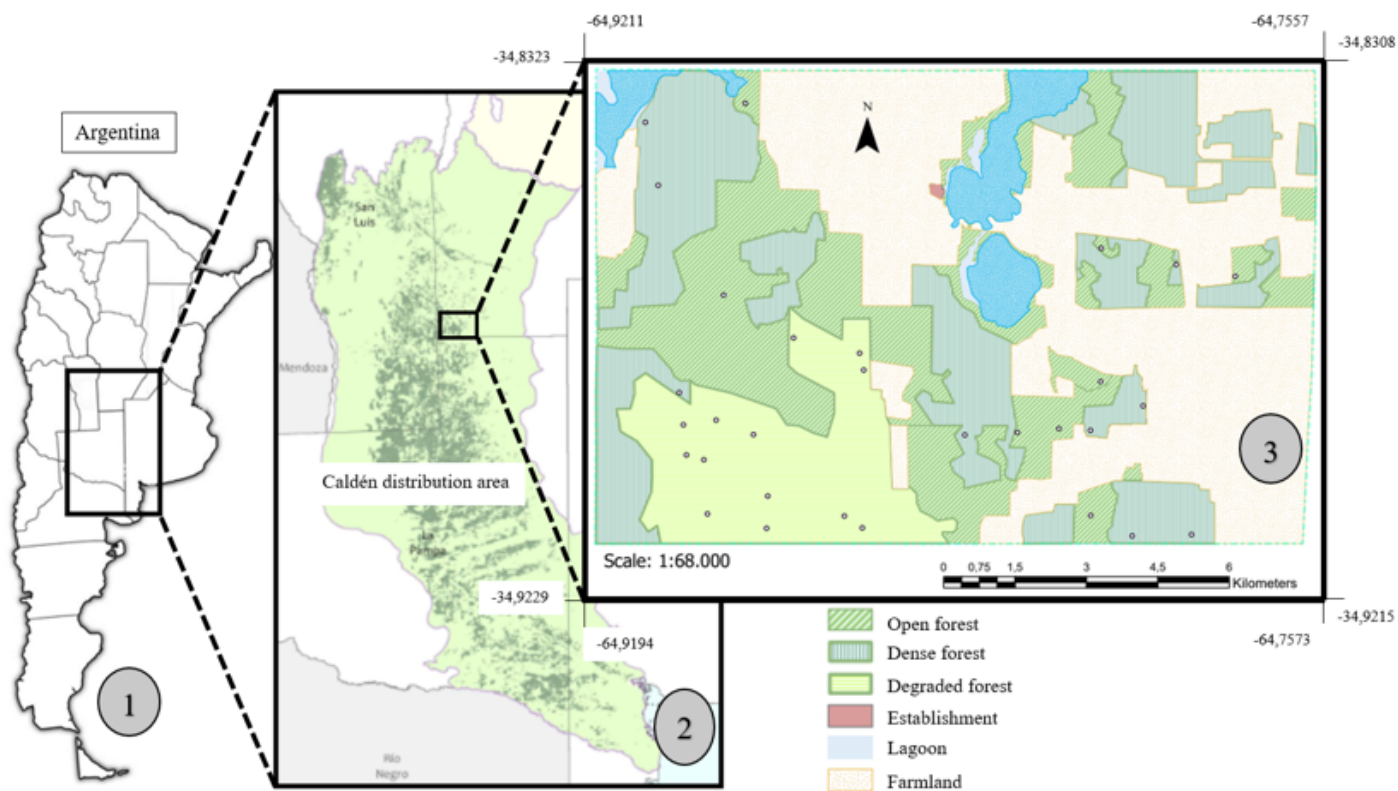


Figure 1.

Figure 1

Location of the study area: 1) Argentine Republic. 2) Distribution of the native caldén forest, National Native Forest Monitoring System (MAyDS 2020) 3) “Estancia Ralico” Establishment.

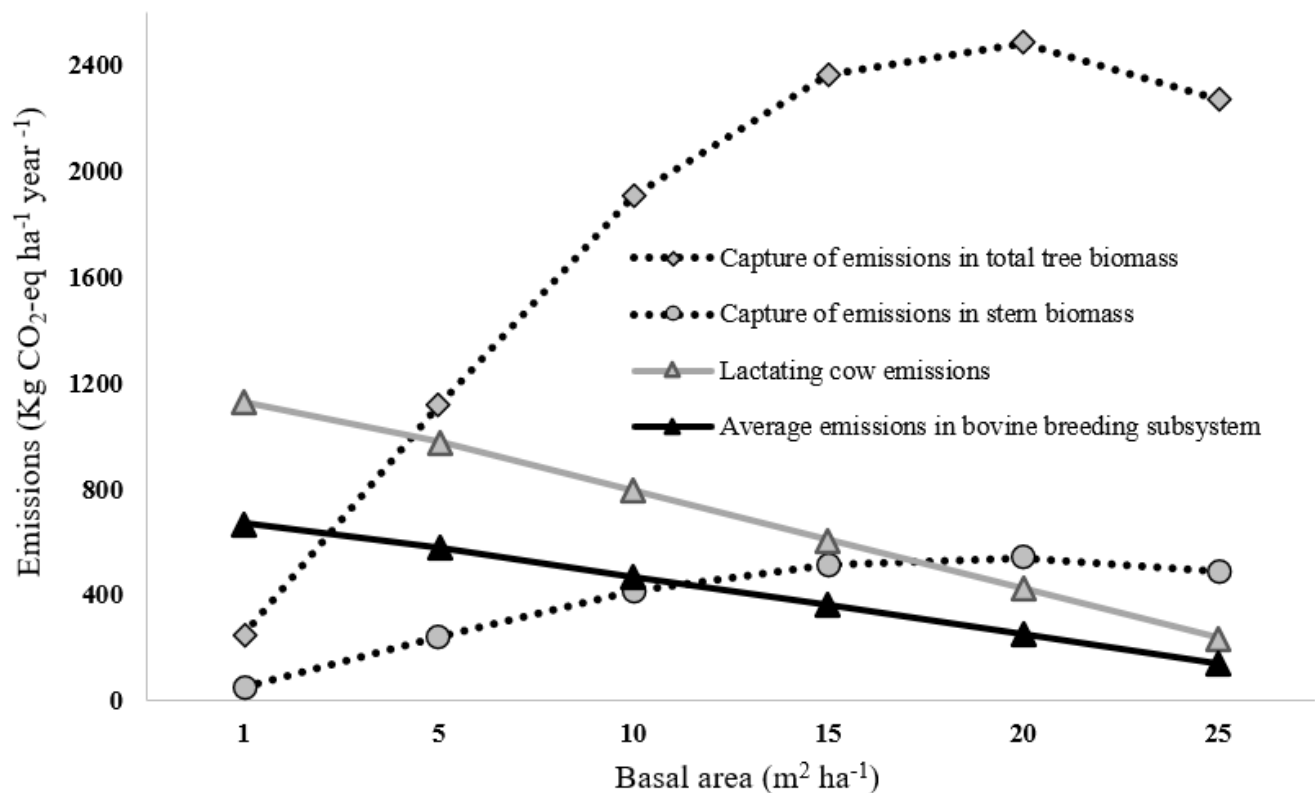


Figure 2.

Figure 2
Greenhouse gas emissions from cattle breeding and emission capture by total and stem forest biomass as a function of basal area in *N. caldenia* forest.