CAN ARAUCARIA FOREST REMNANTS REGENERATE AFTER 70 YEARS OF ANIMAL HUSBANDRY? A CASE STUDY ON CAÍVAS IN SOUTHERN BRAZIL

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INTRODUCTION

Due to its economic, ecological, and cultural benefits, agroforestry is an important land use strategy that has been implemented worldwide (FAO, 2016) and may include systems with the presence of grazing animals (PIGNATARO et al., 2016).

Over generations, communities have developed Traditional Ecological Knowledge (TEK), enabling them to implement forest management practices that combine sustainability of food resources and healthy forests with various crops, trees, and animal husbandry (MICHON et al., 2007). Although agroforestry practices may be important for biodiversity conservation, antagonism towards traditional management systems remains as these systems are viewed as being in conflict with nature conservation (REIS et al., 2013; LACERDA, 2016). The intense degradation of some ecosystems, combined with a resistance to incorporate TEK into environmental policies, have prevented or even prohibited small-scale farmers from managing forests through agroforestry systems (MICHON et al., 2007, LACERDA 2016).

In this context, we present a case study to assess the long-term sustainability of one traditional agroforestry system in Southern Brazil – caívas – an agroforestry system based on the production of erva-mate.
and bovine husbandry (HANISCH et al., 2010). Because the management of forests is integral to caíva, landowners have maintained forest cover that varies in terms of canopy cover, forest structure, and diversity, and management strategies depend directly on the production objectives of the farm (MELLO and PERONI, 2015). Several authors have suggested that the remaining forest fragments found in Southern Brazil continue to exist because traditional systems have protected the forests (REIS et al., 2013, PINOTTI et al., 2018).

As an agroforestry system, caíva are poorly understood, although the presence of animals is generally regarded as having a negative impact on the maintenance of forest biodiversity (SOUZA et al., 2010, VIBRANS et al., 2011).

Considering that caíva have historically been able to self-perpetuate within native forest cover in Southern Brazil, these systems likely play a crucial role in the conservation of forest fragment biodiversity (HANISCH et al., 2016). From this perspective, understanding the regenerative processes of the tree component among different caíva management strategies is an important consideration, since behavioral responses observed in the regeneration after disturbances informs the development of indicators for restoration (KANIESKI et al., 2012). However, the long-term sustainability of this agroforestry system has yet to be assessed.

In this context, this study aimed to provide a better understanding of the forest dynamics (trees and regeneration) in response to animal grazing of the herbaceous stratum in a caíva on a rural property in the Northern Plateau of Santa Catarina State, Brazil. Specifically, we sought to verify if there were differences in structure and diversity over a period of six years, assess changes over time, and ultimately infer the long-term sustainability of caíva. We also assessed the environmental resilience of caíva in terms of regeneration capacity of the managed forest fragment without the presence of animals. Based on the results obtained, we discuss the possibilities for conservation and sustainable use of these remnants to maintain healthy and diverse forests while they continue to be used for productive purposes.

MATERIAL AND METHODS

Characterization of the study area

This case study was carried out on a small-scale farm with a typical caíva system in Canoinhas (26°13′23″ S and 50°27′7″ W, climate Cfb, 810 m above sea level), Santa Catarina State, Brazil. The landscape is characterized by gently undulating terrain with a predominance of Oxisols.

The 22 ha rural property is an intermixed mosaic of land use including agriculture, animal husbandry, agroforestry, and commercial forest plantations. The farm has a variety of productive systems including annual crops (soy and corn), dairy cow production in managed pastures, and a 10 ha caíva with native erva-mate trees and dairy cow grazing. The caíva has been managed for at least 70 years, with no pasture division management and a mean annual stocking rate of 0.4 AU/ha (animal unit = 500 kg live weight).

The forest in the caíva has never been clear-cut, although selective logging took place approximately 20 years ago and focused on valuable timber species (Araucaria angustifolia and Ocotea porosa, among others). The understory is cleared annually by mowing (particularly to manage the abundant, fast-growing tree Curitiba prismaticata), to facilitate erva-mate harvesting and animal grazing. Periodically, trees are pruned or removed to provide light for pasture and erva-mate development.

Data collection and analysis

We monitored the adult population (diameter at breast height = dbh ≥ 5 cm) in a 4320 m² (60 x 72 m) plot within in the caíva, where we identified and measured the total height and dbh of all trees in 2010, 2013, and 2015.

In the same area, three randomly distributed plots of 160 m² (8 x 20 m) were fenced, where monitoring of natural regeneration was conducted. The plots were fenced to protect seedlings from animal grazing and mowing/trimming. In these three plots, the seedlings (height ≥ 5 cm; dbh ≤ 5 cm) were tagged and monitored in 2010 (six months after the plots were fenced), 2012, 2013, and 2015. Seedlings were categorized into size classes (H) using a modified system based on Finol (1971): class 1 = 0.05 > H < 1.49 m; class 2 = 1.50 > H < 3 m; and class 3 = H > 3.01 m to 5 cm dbh.

For both adult and regenerating trees the botanical identification was conducted in the field and samples were collected for confirmation and curation in the herbarium of Escola de Florestas de Curitiba (EFC) of the Federal University of Paraná (UFPR). Scientific names were based on the APG IV system (ANGIOSPERM PHYLOGENY GROUP 2016). Confirmation of the species found and an update of their botanical nomenclatures were carried out using the Tropicos and Flora Brasil (2016) websites. Information on successional status and those related to the species dispersion syndrome were obtained in Meyer et al., (2013). Following Budowski (1965), we classified species into ecological groups as pioneer, secondary, and late successional.

We used EstimateS v9.1 (COLWELL 2013) to calculate species richness (S), number of shared species between years (Sshared; without replacement configuration), and number of species exclusive to each year (Excl).
RESULTS

Adult tree species diversity and structure

During the six-year monitoring of the caíva system, 23 tree species were recorded with varying levels of total diversity over time. Specifically, a 14% reduction in richness was observed in the first interval (2010-2013) after which the level of diversity remained stable (2013-2015; Figure 1). Concurrent with the variation in species diversity, the number of trees decreased during the analysis although with a much more evident reduction (-34%) in 2013 after which a subtle negative trend was recorded in 2015 (-4%; Table 1).

![Figure 1. Variation of tree species density (N trees/ha) and richness (S) in a caíva system between 2010 and 2015 (Canoinhas, Santa Catarina State, Southern Brazil).](image)

**Table 1.** Floristic composition, density by species and ecological group, and dynamics in the density of trees and ecological group, in a caíva system between 2010 and 2015 (Canoinhas, Santa Catarina State, Southern Brazil).

| SPECIES NAME                        | 2010  | 2013  | 2015  |
|-------------------------------------|-------|-------|-------|
|                                     | (N.ha⁻¹) |       |       |
| *Ilex paraguariensis* A.St.-Hil. (S) | 543   | 463 (-15%)* | 412 (-11%) |
| *Curitiba prismatica* (D.Legrand) Salywon & Landrum (S) | 203   | 100 (-51%) | 116 (16%) |
| *Annona neosalicifolia* H.Rainer (S) | 111   | 31 (-72%)  | 33 (6%)   |
| *Ilex theezen* Mart. ex Reissek (S) | 44    | 0 (-100%)  | 0 (0%)    |
| *Sapium glandulosum* (L.) Morong (P) | 33    | 21 (-37%)  | 23 (10%)  |
| *Ilex brevicupis* Reissek (S)       | 31    | 13 (-57%)  | 13 (0%)   |
| *Ocotea porosa* (Nees & Mart.) Barroso (L) | 28    | 31 (12%)   | 31 (0%)   |
| *Casearia decandra* Jacq. Guaçatunga (S) | 21    | 5 (-74%)   | 5 (0%)    |
| *Araucaria angustifolia* (Bert.) O. Kuntze (C) | 8     | 8 (0%)     | 8 (0%)    |
| *Nectandra lanceolata* Nees (S)     | 8     | 13 (71%)   | 10 (-25%) |
| *Allophylus edulis* (A.St.-Hil. et al.) Hieron. ex Niederl.(S) | 8     | 3 (-63%)   | 3 (0%)    |
| *Gymnanthes klotzschiana* Müll.Arg. (S) | 5     | 0 (-100%)  | 0 (0%)    |
| *Drimys brasiliensis* Miers (S)     | 5     | 3 (-40%)   | 3 (0%)    |
| *Campomanesia xanthocarpa* (Mart.) O.Berg (S) | 5     | 0 (-100%)  | 0 (0%)    |
| *Zanthoxylum rhoifolium* Lam. (S)   | 5     | 0 (-100%)  | 0 (0%)    |
| *Cinnamodendron divinis* Schwacke (P) | 5     | 3 (-40%)   | 3 (0%)    |
| *Cedrela fissilis* Vell. (S)        | 3     | 3 (0%)     | 3 (0%)    |
| *Myrcuegenia myricoides* (Cambess.) O.Berg (L) | 3     | 8 (166%)   | 8 (0%)    |
| *Agonandra brasiliensis* Miers ex Benth. & Hook.f. (S) | 3     | 3 (0%)     | 3 (0%)    |
| *Syagrus romanzoffiana* (Cham.) Glassman (P) | 3     | 3 (0%)     | 3 (0%)    |
Despite the negative general trend in the number of trees, changes in density affected each species differently. *Ilex paraguariensis* (the species with greatest density throughout the analysis) showed a relatively small reduction (between 11 and 15%) while *C. prismatica* (second in density) had its population reduced by 51% in 2013 with a 16% increase by 2015 (Table 1). In 2015, most species showed no change in density, three species presented increased density, and *I. paraguariensis* and *Nectandra lanceolata* showed a population reduction. Despite such variation, the species relative density did not change significantly between years and species with greater densities (i.e., species that account for at least 50% of the total number of trees) remained stable.

The species density dynamics in relation to ecological group showed that pioneer and secondary species were particularly affected in the first period (−37% and −35%, respectively; Table 1). During the second monitoring period, these groups showed divergent trends with less dramatic changes. Late successional species presented an initial increase (17%) after which the population remained stable.

In relation to forest structure, the community showed relatively stable patterns of dbh and height distribution. We observed a concentration of trees in thedbh class between 5 and 20 cm and a dominance of trees in the lower height classes (Figure 2). The overall distribution of trees in the lower height categories showed a negative trend towards higher classes resembling a negative exponential distribution (LIOCOURT 1898; MEYER 1952). Ninety-one percent of the trees in the lowest height class are *I. paraguariensis*, which are maintained at heights suitable for harvesting, demonstrating a clear absence of diversity in the lowest height class which is not seen in the other classes.

**Natural regeneration diversity and structure**

A significant increase in the number of tree seedlings in the plots fenced-off from cattle grazing was observed during the evaluation, indicating a substantial resilience of the tree component in the *caívas*. During the six years in which the plots remained fenced, without animal access or mowing, 46 tree species were registered, and only one did not belong to the native vegetation of the Araucaria Forest (Table 2). The species richness of the regeneration showed a continuous increase over the study period, from 21 species in 2010 to 37 in 2013, with a small reduction in 2015, when 31 species were observed. The density showed similar trends to richness, with the most significant increase in the period between 2012-2013, in which we identified a positive variation of 104%, while in the other two periods (2010-2012 and 2013-2015), increases in density varied at much lower rates (21 and 15%, respectively; Table 2).
Table 2. Floristic composition and density by species and ecological group of forest regeneration in a caíva system without animal access or mowing, between 2010 and 2015 (Canoinhas, Santa Catarina State, Southern Brazil).

Tabela 2. Composição florística, densidade por espécie e por grupo ecológico da regeneração florestal em uma área de caíva sem acesso dos animais ou da prática da roçada, entre 2010 e 2015 (Canoinhas, Santa Catarina, Sul do Brasil).

| SPECIES NAME (common name) | 2010 | 2012 | 2013 | 2015 |
|----------------------------|------|------|------|------|
| **Density (N.ha⁻¹)**       |      |      |      |      |
| **Pioneer**                |      |      |      |      |
| Allophylus edulis (vacuam) | 833  | 792  | 1542 | 1438 |
| Zanthoxylum rhoifolium (mamica-de-cadela) | 750  | 646  | 708  | 833  |
| Myrcia spinosa (guarani)   | 292  | 167  | 271  | 208  |
| Ocotea pabulara (canela-guacacá) | 250  | 375  | 1188 | 604  |
| Ilex theezans (congonha)   | 188  | 208  | 454  | 125  |
| Lonchocarpus spp. (timbó)  | 146  | 104  | 42   | 583  |
| Mimosa scabrella (braeatinga) | 125  | 104  | 188  | 167  |
| Curitiba prismaticà (carninha) | 104  | 125  | 250  | 750  |
| Annona spp. (aricuito-preto) | 83   | 21   | 104  | 292  |
| Cauana vernalis (cuvatã)   | 83   | 470  | 354  | 625  |
| Ilex paraguariensis A.St.-Hil. (erva-mate) | 83   | 21   | 0    | 83   |
| Vachellia caven (Molina) Seigler & Ebinger (espínilho) | 83   | 0    | 63   | 0    |
| Gymnanthes klotzschiana Müll.Arg. (branquinho) | 42   | 0    | 0    | 0    |
| Cedrela fissilis Vell. (cedro) | 42   | 104  | 104  | 354  |
| Erithroxylum deciduum A.St.-Hil. (marmeleiro) | 42   | 0    | 42   | 0    |
| Matayba elaeagnoides Radlk. (miguel-pintado) | 42   | 0    | 604  | 604  |
| Sapium glandulosum (leteiro) | 21   | 83   | 21   | 83   |
| Prunus brasiliensis (Cham. &Schldldl.) D.Dietr. (pessegueiro-brabo) | 21   | 21   | 83   | 0    |
| Cinnamomodendron dinisii Schwacke (pimenteira) | 21   | 0    | 42   | 0    |
| Podocarpus lambertii Klotzch ex Endl (pinheiro-bravo) | 21   | 0    | 0    | 0    |
| Eugenia uniflora L. (pitanga) | 21   | 21   | 0    | 83   |
| Aracária angustifolia (Bertol.) Kuntze (araucária) | 0    | 104  | 83   | 146  |
| Ocotea silvestris Vattimo-Gil (canela-preta) | 0    | 42   | 271  | 125  |
| Myrsine umbellata Mart. (capororoca) | 0    | 167  | 542  | 1021 |
| Campomanesia xanthocarpa (Mart.) O.Berg (guabiroba) | 0    | 42   | 42   | 83   |
| Casearia decandra Jacq. (guaçatunga-branca) | 0    | 188  | 42   | 333  |
| Ocotea porosa (Nees & Mart.) Barroso (imbui) | 0    | 21   | 21   | 0    |
| Guapira opposita (Vell.) Reitz (maria-mole) | 0    | 104  | 0    | 0    |
| Hovenia dulcis Thumb. (uva-japão) | 0    | 42   | 0    | 0    |
| Eugenia uvalha Cambess. (uvaia) | 0    | 63   | 0    | 0    |
| Annona neosalicifolia H. Rainer (aricuito-amarelo) | 0    | 0    | 42   | 0    |
| Schinus terebinthifolius Raddi (aroeteira) | 0    | 0    | 42   | 42   |
| Nectandra megapotamica (Spreng.) Mez (canela-imbui) | 0    | 0    | 63   | 21   |
| Dalbergia frutescens (Vell.) Britton | 0    | 0    | 42   | 0    |
| Machaerium paraguariense Hassl. (farinha-seca) | 0    | 0    | 42   | 42   |
| Casearia sylvestris Sw. (guaçatunga-preta) | 0    | 0    | 21   | 208  |
| Myrcia splendens (Sw.) DC. (guamirim-chorão) | 0    | 333  | 0    | 0    |
| Syagrus romanoffiana (Cham.) Glassman (jerivá) | 0    | 0    | 333  | 167  |
| Acosium lentiscifolium Schott (murta) | 0    | 0    | 21   | 0    |
| Picramnia excelsa Kuhl. ex Pirani (pau-amargo) | 0    | 0    | 42   | 83   |
| Trichilia sp. (trichilha) | 0    | 0    | 63   | 0    |
| Clethra scabra Pers. (carne-de-vaca) | 0    | 0    | 125  | 0    |
| Eugenia involucrata DC. (cerejeira) | 0    | 0    | 0    | 42   |
| Balfourodendron riedelianum (Engl.) Engl. (pau-marlim) | 0    | 0    | 0    | 42   |
| Ocotea odorifera (Vell.) Rohwer (canela-sasafrás) | 0    | 0    | 0    | 21   |
| Piptocarpa axillaris (Less.) Baker (vassourão-preto) | 0    | 0    | 0    | 21   |

**TOTAL**.ha⁻¹: 3292  4021  8104  9313

**ECOLOGICAL GROUPS**

| ECOLOGICAL GROUPS | 2010 | 2012 | 2013 | 2015 |
|-------------------|------|------|------|------|
| Late successional | 313  | 208  | 688  | 354  |
| Secondary         | 2854 | 3417 | 6625 | 7500 |
| Pioneer           | 125  | 402  | 792  | 1458 |
(N.ha\(^{-1}\)) = number of trees per hectare; superscript numbers refer to classification of the ten species with the highest density of individuals per year;
(N.ha\(^{-1}\)) = número de indivíduos arbóreos por hectare; números sobrescritos referem-se à classificação das dez espécies com maior densidade de indivíduos por ano.

Figure 3. Density (Nseedl.ha\(^{-1}\)) and richness (S) of forest species in the natural regeneration of a caíva system between 2010 and 2015 (Canoinhas, Santa Catarina State, Southern Brazil).

Figura 3. Densidade (Nseedl.ha\(^{-1}\)) e riqueza (S) de espécies florestais na regeneração natural em uma caíva entre 2010 e 2015 (Canoinhas, Santa Catarina, Sul do Brasil).

The absolute density of the species in the regeneration varied in relation to the initial community, although the same behavior was not observed for the relative density (Table 2). A species may maintain a stable absolute density during the study, but an increase or decrease in the density of other species may alter its relative density. Curiously, the species with the highest absolute density did not alter their relative density; *Allophylus edulis* maintained the highest density in all years (with a tendency to increased density), and *Zanthoxylum rhoifolium* remained as the third most dense. On the other hand, we observed an important variation in the population of several other species, consequently altering their relative abundance.

The concentration of height classes of the seedlings varied throughout the study, with most concentrated in the <0.5 m class in 2010. The variation in height became greater in 2013, where several individuals exceeded the adult threshold (1.5 m) and by 2015 several plants reached heights of 8 m (Figure 4). The tallest plants were those of the pioneer ecological group (predominantly, *Mimosa scabrella*).

Figure 4. Distribution of the number of individuals.ha\(^{-1}\) by height (cm) of the natural regeneration between 2010 and 2015 in caíva plots protected against animal grazing. Dashed line at 1.5 m = threshold above which plants are considered adults.

Figura 4. Distribuição do número de indivíduos.ha\(^{-1}\) por altura (cm) da regeneração natural entre 2010 e 2015 em parcelas de caíva protegidas contra pastojo animal. Linha tracejada a 1,5 m = limiar acima do qual as plantas são consideradas adultos.
Comparison between natural regeneration and forest diversity and structure

The diversity of shared species between regeneration and the adult population was stable for 12 species in all years, that is, between 30 and 42% of the diversity was found in both populations (Table 3).

The number of species unique to one component was always higher in the regeneration than adults. The adult population showed a more stable diversity, with a tendency for homogenization, since the number of exclusive species was zero between 2013 and 2015. In the regeneration, the diversity of species varied throughout the study, enabling us to observe a relatively large number of species not found in the years prior to 2015.

Table 3. Comparison of species diversity of adult population (tree) and natural regeneration (seedl) in different years. Parameters: richness (S), exclusive number of species (Excl), number of shared species (Sshared), and total number of species in each comparison (Stotal).

Tabela 3. Comparação da diversidade de espécies da população adulta (árvore) e da regeneração natural (seedl) em diferentes anos. Parâmetros: riqueza (S), número exclusivo de espécies (Excl), número de espécies compartilhadas (Sshared) e número de espécies totais em cada comparação (Stotal).

| YEAR COMPARISON | INDIVIDUAL YEAR PARAMETERS | COMPARISON SUMMARY |
|-----------------|---------------------------|---------------------|
| 1st term x 2nd term | S1 | Excl | S2 | Excl2 | Sshared | Stotal |
| Tree 2010 x Tree 2013 | 21 | 5 | 18 | 2 | 16 | 22 |
| Tree 2013 x Tree 2015 | 18 | 0 | 18 | 0 | 18 | 18 |
| Seedl2010 x Seedl 2012 | 21 | 9 | 23 | 9 | 12 | 32 |
| Seedl2012 x Seedl2013 | 23 | 5 | 37 | 19 | 18 | 42 |
| Seedl2013 x Seedl2015 | 37 | 5 | 31 | 8 | 23 | 45 |
| Seedl 2010 x Tree 2010 | 21 | 9 | 21 | 7 | 12 | 28 |
| Seedl 2013 x Tree 2013 | 37 | 25 | 18 | 3 | 12 | 40 |
| Seedl 2015 x Tree 2015 | 31 | 19 | 18 | 3 | 12 | 34 |

DISCUSSION

Species diversity and structure in caívas

The results for adult diversity (18-23 species) showed levels similar to those reported in the Santa Catarina Forest Inventory (SCFI; MEYER et al., 2013; plots), which confirms the important role of caívas in forest cover conservation in the state. The SCFI used sampling areas similar to those installed in this study (4000 and 4320 m², respectively), and included managed and unmanaged forests, which should be sufficient to capture wide variations in richness.

Previous research has shown that the productive focus of a caíva (greater amount of erva-mate production or higher animal load) is the main factor that affects the diversity of species, with previously observed variations among caívas of 18 to 42 species ha⁻¹ (HANISCH et al., 2010, PINOTTI et al., 2018).

The main productive focus of the studied caíva is erva-mate, which is economically valuable and a relevant component in the income of most small-scale properties in Southern Brazil. Erva-mate trees are traditionally harvested in three-year cycles and after several harvests (20-40 years), trees may require a radical pruning to increase yield (STUEPP et al., 2016). The results for 2013 show precisely the effects of this type of erva-mate management; the reduction in density reflects, in most cases, trees that were harvested (shifting to lower height classes) and dead trees that were removed (reducing density).

Another species that reflected the traditional management of caívas was Curitiba prismatica. Because it is a fast-growing species with a highly effective ability to disperse, sprout after cutting, and develop into dense clusters (LORENZI, 2014), its removal is a regular activity in the region and is seen as necessary to maintain the productive structure of the forest. Ilex theezans, which also showed a reduction in population, had a clustered distribution in the area (combined with its typically dense canopy) (LORENZI, 2014). Similar to C. prismatica, I. theezans is seen as an impediment to pasture development and erva-mate production. The lower levels of variation in density for other species may be related to less intensive interventions as well as natural mortality.

In the plots that were fenced off to protect against animal grazing and mowing, we observed a steady increase in the seedling population and an important increase in species diversity in relation to pre-fencing levels. Although several species showed fluctuations in their population over the six-year period, some species populations increased consistently among the regeneration, particularly A. edulis, C. prismatica, and Cupania vernalis. These secondary species are frequent in natural forests and tolerant to considerable shade levels.
(VIBRANS et al., 2011) Although most of the population increase is concentrated within secondary species, we also found a stable increase in pioneer and late successional species (Table 2). These results indicate a likely transition from initial stages of forest regeneration to more diverse and structurally complex stages over the short study period (six years).

The richness of regeneration found in this study indicates a high level of resilience of the caíva trees and confirms that they have sufficient material legacies (for example, seeds, remaining trees, soil nutrients) and information legacies (species with adaptation to disturbance) (JOHNSTONE et al., 2016) to maintain productive forest communities. However, studies that confirm the adequate amount of regeneration in forest remnants submitted to anthropogenic actions are still rare.

Finally, the occurrence of pioneer species among the regeneration with rapid growth (>1.50 m in height by 2013) that surpassed the regeneration/adult threshold, indicates that enough light exists for them to thrive. Furthermore, the fastest growing plants (>3 m by 2013), considered to be established as viable trees, were secondary species, indicating that the environmental conditions (especially light) are favoring secondary over pioneer species, again suggesting a positive trend in the development of a complex and healthy forest.

**Implications for conservation and caíva development**

The regeneration dynamics identified herein show that caívas can be successfully managed to guarantee long-term sustainability. This involves the introduction of silvicultural practices to manage the regeneration and adult population, maintain a consistent forest canopy, and increase species diversity (favoring species not found in the forest canopy). Although the management of regeneration can prioritize secondary and late successional species due to their longer life cycles, strategies can also take advantage of rapidly growing pioneer species as a source of firewood to be consumed locally. This, in turn, provides economic diversity alternatives, which has been suggested as a path for sustainable rural development (VIEIRA et al., 2009). Additionally, appropriate silvicultural practices can take advantage of a species’ inherent characteristics and create opportunities for local or commodity consumption. In this context, even C. prismaticus – a species perceived as a problem – could be managed to produce tool shanks, an end use for which the species has been traditionally employed in the region.

Our results indicate a need to implement management practices that will maintain the tree cover in the long-term, which can be achieved by taking advantage of the system’s inherent regeneration potential. Caívas have sufficient material legacies (e.g., seeds, remnant trees, soil nutrients) and information legacies (species with traits suited to disturbances) to maintain productive but diverse forest communities; as such, caívas are forests with relevant ecological memory (JOHNSTONE et al., 2016) that are capable of rapid recovery. Therefore, they play an important role in regional conservation (LACERDA 2016). The presence of species in the regeneration plots that were not found in the adult tree population is significant (48% more species in 2015 in relation to initial levels; Table 2). Although this result can be partially attributed to neighboring trees not included in the study area, the diversity of species (which are mainly dispersed by zoorhory) may be related to the movement of birds and other animals across the landscape (COLORADO et al., 2018). Our results indicate that in areas with caívas located within relatively short distances from each other (<1 km), anthropogenic forest fragmentation has not impeded successful seed dispersion for trees species.

As a silvopastoral agroforestry system, caívas need to be recognized for their sociocultural and environmental benefits. Currently, income generation in caívas is constrained by low levels of animal production, erva-mate price fluctuation, and legal restrictions on forest management that have put the continuity of the system at risk (MELLO and PERONNI, 2015; HANISCH et al., 2016). Small-scale farmers are facing mounting pressure to transition towards monoculture plantations, such as commercial forests (pine) or annual crops (soy and corn), with the consequent losses in cultural and environmental benefits.

Along with the implementation of management practices that guarantee the long-term health of caíva forests, the adoption of techniques to improve pastures has also been cited as a vital step for their sustainability (HANISCH et al., 2016). The introduction of techniques widely used in silvopastoral systems has helped to improve animal productivity, such as pasture rotation, control of stocking rate, and introduction of alternative pasture species (HANISCH et al., 2016). Additionally, economic incentives, access to credit, and the establishment of payment for ecosystem services (PES) could help to strengthen the social and economic capital of caívas. Finally, it is important to emphasize that the improvement of these agroforestry systems and development of silvicultural practices must be supported through the direct involvement of communities and farmers. It is also necessary for policy-makers to include small-scale farming initiatives in government policies, representing a paradigm shift from the current focus on large-scale production of agricultural commodities.
CONCLUSIONS

- Forest management in the caíva modified the population structure mostly through the reduction in the density of a few adult tree species, particularly Ilex paraguariensis and Curitiba prismatica.
- Without the presence of animals and the practice of mowing, the caíva presents significant resilience for forest regeneration, despite the extractive use of these remnants over a long period of time;
- The forest richness was 21 species in the adult population and 37 in the forest regeneration, with only one exotic species, indicating the contribution of caívas to the conservation of species typical of the Araucaria Forest biome;
- Several species not found in the adult population were found in the regeneration population, demonstrating the presence of effective seed dispersal agents;
- After six years of isolation in the plots, a density of more than 8000 seedlings.ha⁻¹ was found, confirming that this practice can be an important strategy for the management of these areas for environmental conservation.

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