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PIGS, FORESTS, AND INSTITUTIONAL TIPPING POINTS

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ABSTRACT

PIGS, FORESTS, AND INSTITUTIONAL TIPPING POINTS

Flavia Camargo de Oliveira

In southern Brazil, a traditional farming system called *faxinal* has also worked to preserve forests. Under pressures for intensified production, some communities have transitioned into a land-use system governed exclusively by a private property regime, while others have resisted such pressures and still have the main feature of the *faxinal* as a communal area, covered mainly by forest, used for livestock farming. In this research I ask two questions: What factors favor a *faxinal* to resist pressures to abandon the model and move towards a more conventional, private property model? Do traditional *faxinal* do a better job preserving forest than places where the *faxinal* model has been abandoned or never even existed? In chapter 1, I used a social-ecological resilience framework and the literature on common-poll resource (CPR) governance to analyze data on local institutions and land management practices communities of *faxinal*. I described (1) local institutional arrangements and cooperation mechanisms that foster forest conservation in the *faxinal*, (2) internal and external challenges to cooperation and rule enforcement, and (3) ways in which the system copes with the disturbances and adapt. In chapter 2, I move to landscape scale of analysis to look at changes in forest cover over time in communities of *faxinal* across a large geographical

range. Here I demonstrated that the *faxinal* have worked for securing forest cover. However, the high rates of deforestation in the region are an important threat for both the local forest and the *faxinal* and I recommend conservation strategies to focus on supporting this system's institutional arrangements and land management strategies that foster forest conservation. Finally, on chapter 3 I scale-down to the forest plot to look at the effect of the local governance strategies of the *faxinal* on forest diversity and resilience. My results showed that the *faxinal* traditional governance translates into higher diversity, especially in the forest regenerative strata, and into the maintenance of forest fragments that have key characteristics presented in the literature as features that define the structure and composition of the local forest.

DEDICATION

To my mom, who always had my back.

To all the communities of faxinal, with the hope that this work can serve them in securing rights and land, and rights to land.

ACKNOWLEDGEMENTS

This work is a result of many minds, hearts, and hands working together. I am grateful to everyone who helped me make this happen. First, I want to thank all the families in the communities that I visited and that received me in their homes as if I was part of their families. I am forever changed by them, and I hope that my work can help them with securing their rights to land and to the recognition of their collective identity and territories. Especial thanks to D. Iracema, Rosa, and D. Maria, these strong and sweet women that I had the honor to meet. I also want to thank my incredibly supportive committee at UCSC and UFSC. First, my advisor, Erika Zavaleta, for this learning and growth experience that you made possible for me, for believing, respecting, and encouraging my ideas all along the way, thank you. I learned a great deal from your example. Carol Shennan, Andy Szasz, and Nivaldo Peroni, you have also been the most amazing mentors. Your encouragement, friendship, and example had a great impact on me and kept me going until the end.

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CHAPTER 1

Local responses to global changes affecting institutional tipping points in a traditional forest management system from Southern Brazil

ABSTRACT

This study is a case of common-pool resource (CPR) governance and resistance against and adaptation to the homogenizing steamroller effect of capitalist modernization on traditional cultural forms and land-use strategies. I investigated local institutions that affect forest conservation in a traditional farming system from Southern Brazil called *faxinal* where land has been historically managed as a common good of collective use. The advance of logging companies and large-scale agriculture in the region has imposed social-ecological changes on the communities' relationship with the collective use of the land, ultimately affecting the local forest. I am asking "What favors a *faxinal* to resist the pressures to abandon its collective land-use model and move towards a more conventional, private property model?" I used a social-ecological system (SES) resilience framework that I built based on the CPR governance and SES resilience literature to describe and analyze my explanatory variables. To account for differences in local responses and adaptations to pressures, I focused on two very distinct municipalities in terms of contextual descriptors (e.g., history of land occupation, cultural background, geographical location, among others). To understand the factors that explain changes in forest management approaches, I examined (1) the rules, norms and traditions underlying the system's collective land-use practices directly affecting forest conservation, (2) the disturbances that directly affect the local institutions (e.g., historical land disputes, conflicts within communities, among others), and (3) the system's adaptations to cope with disturbances (e.g., grassroots organization, and partnerships with public universities and local governments). The social-ecological framework that I used was a helpful tool to map the institutional arrangements of the *faxinal* and to analyze how they evolved over time under different types of pressures. Finally, the *faxinal* has secured the maintenance of forest cover in the region and now, the fact that forest has been conserved in the *faxinal* is helping local communities to secure their rights to land and resources.

Keywords: Brazil, common-pool resource, *faxinal*, forest conservation, global changes, governance, institutions, resilience, social-ecological system.

INTRODUCTION

The tragedy of the commons assumed that all common-pool resources (CPRs) are embedded in a deficient incentive structure that cannot exclude free riders and that presents no impediments for harvesting resources until exhaustion leaving resource users with no incentives to sustainably manage CPRs (Pennington 2012). The work of Ostrom (1990) though, demonstrated how the interplay between incentives and institutions in CPR governance are more complex than economists had traditionally thought and that resource users can develop mechanisms that allow the sustainable management of CPRs (Ostrom 1990, Pennington 2012, Tarko 2012).

In Brazil, stories of good governance of CPRs can be found throughout the country as part of the livelihood strategies of traditional and Indigenous communities (for examples, please refer to Baldauf and Reis 2010, Baldauf et al. 2007, Oliveira and Hanazaki 2011, Castello et al. 2011, Sattler et al. 2015, IPBES 2019). Brazil's National Policy for Sustainable Development of Traditional Peoples and Communities (Brasil 2007) defines traditional communities in terms of, among other criteria, their low impact management techniques. This provides traditional communities with bargaining power within the conservation debate and with regards to access to land and resources, empowering these communities as stewards of the resources their livelihoods depend on. The dispute around this narrative, however, is highly controversial and playing a crucial role in this debate is the compilation of empirical evidence on whether traditional management practices are viable alternatives to deal with current rapid social-environmental changes. This debate has important implications for conservation of natural resources in the country, especially considering that traditional communities historically lived in areas that are now highly regarded for conservation.

In this study I investigated local institutions (i.e., rules, norms, traditions) that affect forest conservation in a traditional farming and forest management system from Southern Brazil called *faxinal* and I focused on identifying local differences in how communities respond, resist, and adapt to pressures. A main characteristic of the *faxinal* is the communal small-scale livestock farming in an area historically governed by social practices that discouraged the removal of forest (Figure S1.1 and S1.2) (Chang 1988, Sahr 2008, Bertussi 2012, Hauresko 2012, Correia and Gomes 2015). For this reason, these communities have been able to secure forest cover in areas that otherwise would most likely have transformed into soybean monocultures and reforestation with exotic species for timber and paper production.

The forest within which the *faxinal* is located – the Araucaria Mixed Forest – has been highly degraded since early 1900's, having less than one percent of its original cover left as primary forest and approximately 20-25% as secondary forest (Castella and Britez 2004, Lacerda 2016). The main reason for this historical degradation was the arrival of logging companies and large-scale agriculture, which also imposed social-ecological changes on the *faxinal* (Schuster 2010). The fact that the identity of the *faxinal* is intrinsically linked to collective land management practices that allow forest conservation has been a main asset used by these communities in their fight for land and resources. However, under pressures for intensified production, some communities have transitioned into a land-use system governed exclusively by a private property regime. As the system changes, its ability to persist and to effectively conserve forest is questioned.

My research focuses on the state of Paraná, which is the only state in Brazil where the system has persisted and where recent debates about the legislation pertaining to the *faxinal* (e.g., discussions on whether transforming *faxinais* (plural) in protected areas is the best practice for preserving forest fragments and help communities) might be imposing significant changes in *faxinal* institutions. Also, for the past 30 years, Paraná has had the highest rates of deforestation for the Araucaria Forest (SOS Mata Atlântica 2016) and the main region where this deforestation has happened overlaps with the area where *faxinais* exist. This makes these communities potentially both vulnerable and of heightened importance if they are protecting remaining forest areas. I am addressing the question "What factors favor a *faxinal* to resist pressures to abandon the model and move towards a more conventional, private property model?" To answer this question, I used a social-ecological system (SES) resilience framework to examine local institutions that affect forest conservation in the *faxinal* and how they have resisted and adapted to pressures over time.

Social-ecological system resilience framework

The SES approach proposed by Ostrom (2007, 2012) to investigate successful CPR governance focuses on the decomposable nature of complex systems and facilitates a more detailed understanding of interactions between the various subparts of a SES, such as its resource users and institutions. While Ostrom's work on CPR focused primarily on the institutional arrangements of CPR governance systems (Lara 2015), the SES resilience literature that emerged from that work engages more directly with resource management. In fact, a major novelty that the SES framework brought to the studies on sustainable natural resources management is the explicit connection it makes between resource users and institutions (Anderies et al. 2004).

Ostrom's SES framework is used to diagnose an outcome of a system (e.g., forest degradation or preservation) and it conceptualizes a CPR system as a multi-tier system where its main components (i.e., resource system, resource unit, governance system, and users) are decomposed in sub-tiers (i.e., location, economic value resources, government organizations, number of users – to cite a few) (Ostrom 2007). However, not necessarily all the second-tier variables proposed by Ostrom will play a role in generating an outcome of interest. Furthermore, each sub-tier can be further decomposed and there is a lot of effort to improve the framework by discussing, testing, and expanding its second-tier variables (Ostrom et al. 2014).

To build my SES resilience framework for the *faxinal* and guide my analysis, I used Ostrom's conceptual multi-tier CPR system and the core concepts that define resilience (i.e., disturbance, adaptation, and tipping points) to select the components of the *faxinal* that affect my main outcome of interest – the resilience of local institutions supporting forest conservation in the *faxinal*. The resilience thinking makes sense in the current context of rapid changes in SESs and loss of biocultural diversity and an integrative SES resilience analysis can guide researchers in understanding how these systems deal with uncertainties and disturbances and why some continue existing while others collapse (Holling et al. 2002, Berkes et al. 2003, Ostrom et al. 2014).

METHODS

Data collection

My research involved a preliminary study followed by an in-depth study. In the preliminary phase, I identified variables affecting local institutions that rule collective land management and forest conservation in the *faxinal* and used this information to build my SES Resilience framework that guided my in-depth data collection and analysis during the second phase of my research. In the first phase, I conducted preliminary fieldwork during the summers of 2014, 2015 and 2016 to visit local communities, local government institutions, and research centers in public universities. I visited 34 communities located in 11 municipalities and conducted informal interviews with community leaders (n=19), community households (n=47), local government agents (n=5), and local researchers (n = 5) and participated in government and community meetings. The communities were sampled from a database listing 227 *faxinais* in Paraná (Souza 2009) and selected based on contextual factors that influence forest conservation and that are represented by contrasting differences regarding geographic location, cultural background, population density, area sizes, the main agricultural and forest commodities produced in each region, and whether a community was registered as an ARESUR (i.e., a category of protected area created specifically for the *faxinais*). These factors were defined based on the data collection forms developed by the International Forestry Resources and

Institutions (IFRI 2016), which is a research network founded by Elinor Ostrom that investigates how governance arrangements shape forest outcomes.

In this preliminary screening, I identified relevant variables that affect local institutions underlying collective land management practices and forest conservation. The data was gathered through visual assessments of the landscape and informal interviews with local community leaders, local residents (household), government agents, and local researchers working with the *faxinal* when I asked questions on socioeconomic data (e.g., size of the communities, number of families, farm-/non-farm-based and forest-/non-forest-based economic activities) and information on agricultural practices (e.g., size of farmed area, crops grown, soil management practices), forest management practices (e.g., size of managed forests, forest products managed), community rules regulating CPR use, and historical conflicts in the field sites.

Based on findings from this preliminary study, I used a nonprobability case control sampling (Bernard 2011) to select six *faxinais*, located in two municipalities to collect in-depth data. I focused on the municipalities of Prudentópolis (n=3) and Pinhão (n=3) (Figure 1.1) because they span a range of variables identified as key factors explaining differences between communities of *faxinal* and differences in forest cover change over time. These variables include: (1) the main pressures suffered by the *faxinal* system, (2) distinct cultural backgrounds, (3) different soil types and related land-use histories. These differences are described in detail in the results section. The communities located in Pinhão and Prudentópolis are represented hereby by the codes PIN1, PIN2, and PIN3 and PRU1, PRU2, PRU3, respectively. Relevant socio-economic descriptors for Pinhão and Prudentópolis and their communities (Table S1.1) show that main differences between these sites are that Prudentópolis and its communities are more densely populated than the ones in Pinhão and that communities in Prudentópolis are smaller and, in general, closer to urban areas.

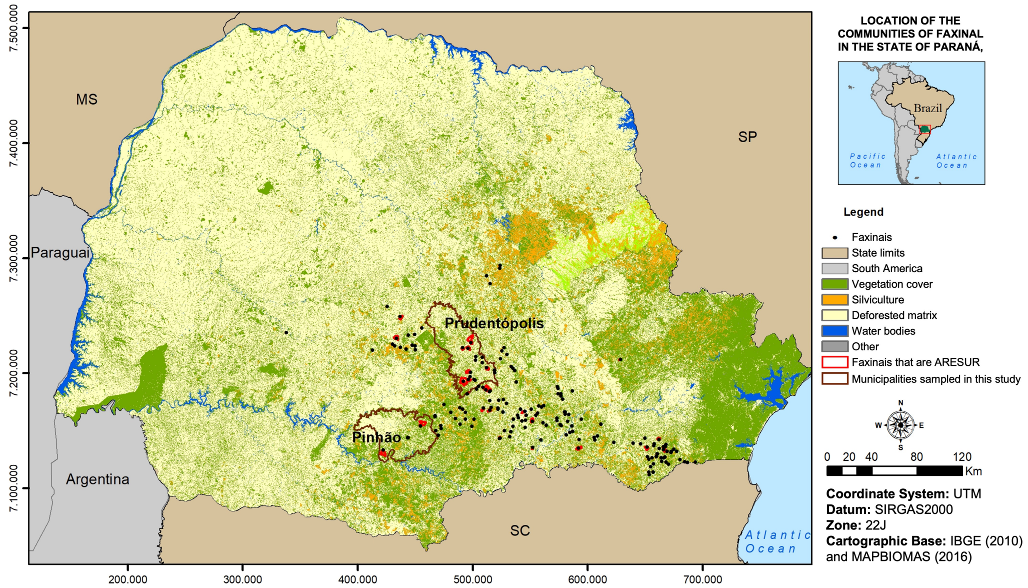

Figure 1.1. Map of field site showing (1) the municipalities sampled in this study, Prudentópolis and Pinhão, (2) the *faxinais* inventoried by Souza (2009) for the state of Paraná, Brazil, and (3) the *faxinais* that are considered ARESURs or that are in the process of becoming one (in red). Not all the 227 communities inventoried by Souza (2009) had their geographic location available to be displayed in the map, however the geographic range of the area occupied by *faxinais* is accurate.

The variables identified in my preliminary study were used to build a SES resilience framework to guide data collection on the *faxinal* (Figure 1.2). In the context of the resilience thinking, these variables were identified in terms of disturbances, adaptations, and outcomes. The outcomes of interest in this study are the local institutions underlying the *faxinal*'s collective land-use system that support the maintenance of the local forest.

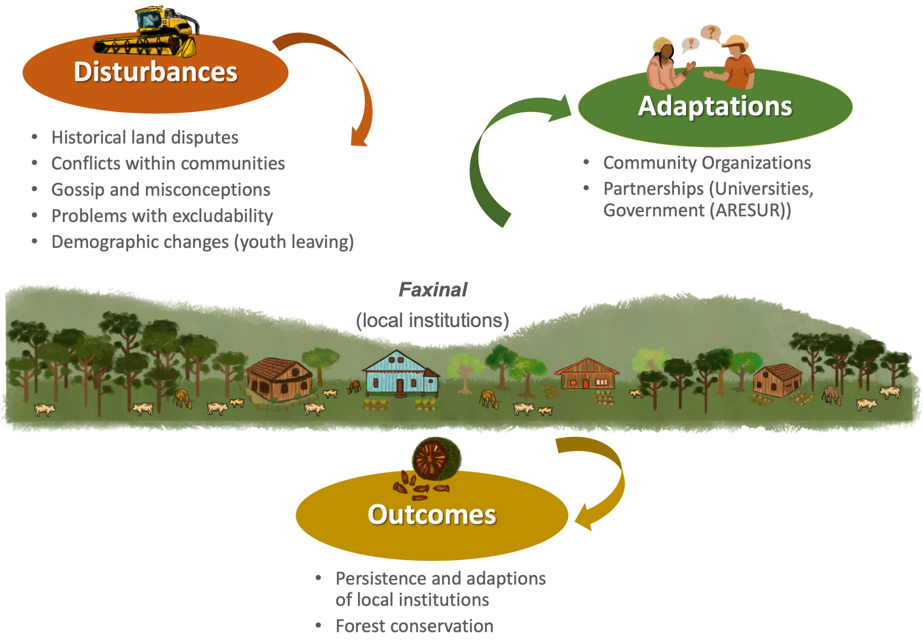

Figure 1.2. SES resilience framework for the *faxinal* with a focus on variables identified in a preliminary study and that represent disturbances suffered by the system, adaptations that allow the system to cope with the disturbances, and the outcomes of interest that are represented by the local institutions supporting the collective land-use in the *faxinal* and the maintenance of the local forest.

For the in-depth study, I collected data using groups interviews[1] (n=6) in all six communities of *faxinal* in Prudentópolis (n=3) and Pinhão (n=3), semi-structured interviews with local leaders (n=6) of the farmers' associations in each community, guided walks, and direct observation of community meetings, management of natural resources (e.g., harvesting of forest products and management of livestock) and other cultural activities (e.g., religious rituals). For the group interviews, I invited community members using a few strategies that included (1) going to their houses, introducing myself and the research and

[1] The group interviews were also used for introducing myself and my research to the community and for asking for their permission to collect data, in accordance with the UCSC IRB protocols.

inviting them in person, (2) asking community members that I had already met to invite others, (3) asking community leaders to invite people during their community meetings. For collecting data during group interviews I used maps of the communities printed out in large scale to serve as visual aid and built a timeline with participants while asking questions about the history of the community and of the conflicts around land-use, the current use and the state of the forest fragments, and other contextual information.

During the guided walks, I conducted informal interviews with community members while observing and describing the landscape and the community activities. This method allowed for community members to be stimulated by the surrounding landscape and by their interactions with other people, which prompted them to provide information about the history and dynamic of resource management, and changes in land-uses in the *faxinal*, that were not mentioned during interviews conducted indoors. In addition, I conducted informal interviews with local researchers (n=3) studying the *faxinal* and with local government agents (n=3). I spent an average of three weeks on each community over the course of 12 months in 2017 and 2018. The interviews were also built based on the IFRI (2016) forms and followed the University of California Santa Cruz (UCSC) IRB requirements for this type of research, including proper informed consent.

Data analysis

I used the SES resilience framework built for the *faxinal* as guidance to code my data according to institutional and collective action (cooperation) variables affecting forest conservation and to describe conditions that push for institutional tipping points. I used grounded theory to identify emergent themes that explain: (1) how local institutions underlying forest conservation work in the *faxinal*, (2) whether these institutions and their related management strategies are changing, (3) why they are changing, and (4) how they might be adapting to maintain the traditional core structure of the *faxinal* system represented by a collective territory, covered mainly by forest. The data presented in this chapter is mainly descriptive.

RESULTS

The SES resilience framework developed to study the *faxinal* provided valuable insights on a set of variables that explain (1) how local institutions and rule compliance have supported forest maintenance in communities, (2) how these institutions have been challenged over the years by local and global threats, and (3) how the *faxinal* has been coping with threats and which are some local responses of the *faxinal* to global changes (Figure 1.3). I identified cooperation mechanisms that represent core characteristics of the *faxinal* and that foster forest conservation. They are represented by institutional and collective action structures of the system including economic incentives, cultural traditions, and social control reinforcing local norms. I also documented threats that have been challenging the *faxinal* and its ability to preserve forest. Those include land disputes with a logging company in Pinhão, which lead to the displacement of families, and internal conflicts between community members in both Pinhão and Prudentópolis. Finally, I described mechanisms of resistance and adaptation that work for securing the rights of the people living in *faxinais* and play a key role in supporting this system.

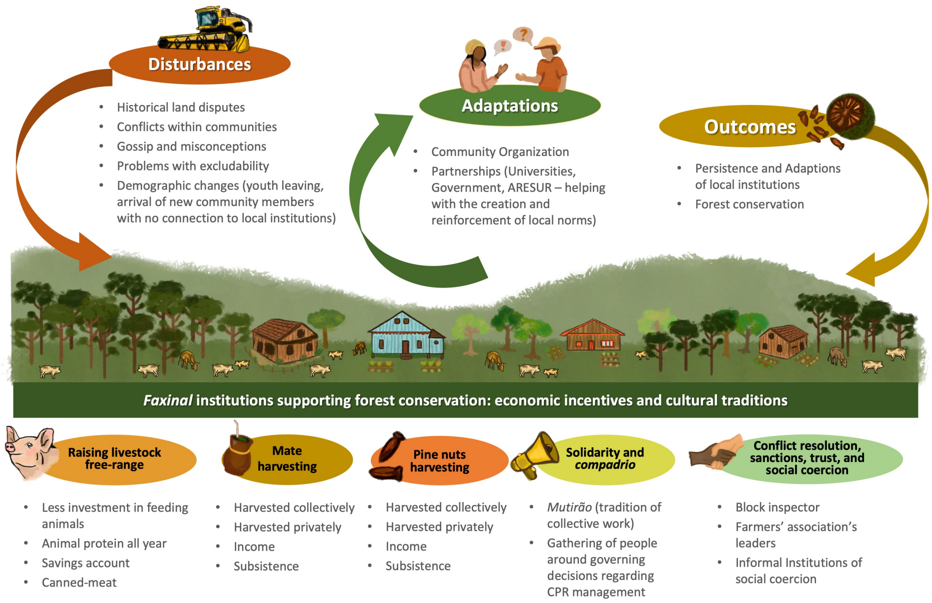

Figure 1.3. Diagram illustrating the data collected and coded according to the variables defined in the SES resilience framework developed in this research. The top of the figure displays the disturbances and adaptations identified during data collection and the outcomes defined for this SES resilience analysis. The bottom of the figure displays the institutions supporting forest conservation in the *faxinal*.

Cooperation mechanisms of the *faxinal* supporting this system and its forest: economic incentives and cultural traditions

Economic incentives and cultural traditions of raising livestock free-range

Raising free-range livestock in the communal area of the *faxinal* reduces the investment a family must make to feed their animals. The main livestock raised in the *faxinal* are pigs, cattle, chickens, and horses. Goats and sheep are also present in some communities, but in much lower numbers. The pigs are the main livestock of the *faxinal*. Traditionally, families would raise them not only for the meat, but they would also use pork fat to burn as fuel for lanterns, when electricity was not available, and to preserve the meat. The pork meat preserved in fat is called *carne-de-lata* (canned-meat) and it can last for over a year outside the refrigerator. This preservation technique is a cultural tradition still carried out by local families as *carne-de-lata* is considered a delicacy in the *faxinal*. The chickens are raised for the meat and eggs, the cattle are raised for the meat and milk, and the horses are raised mostly for leisure, but in some cases, horses are also use for farming labor. Pigs, cattle, and horses spend the day wandering around the *faxinal* collective area where they exercise and feed from forest resources and grass. According to interviewees, these animals feed mainly from pine nuts from the *Araucaria angustifolia* (Bertol.) Kuntze tree (hereby Araucaria tree) and fruits and leaves from various tree species. At the end of the day, they return to their owners where they are fed corn and sometimes silage, twice daily (morning and evening). The livestock provides the local families with animal protein throughout the year and are also considered a kind of "savings account" as they can sell the animals when they need the cash. If the families had to switch to a confined livestock system, they would have to reduce the number of animals they raise and that would have a considerable impact on the household economy.

Economic incentives and cultural traditions of harvesting mate and pine nuts

These communities' economies and subsistence have also historically relied on the collective use of their forests for the harvesting of *erva-mate* (i.e., the *mate* tea from the tree species *Ilex paraguariensis* A. St.-Hil.) and the harvesting of pine nuts from the Araucaria tree. Traditionally, *erva-mate* has been managed in the understory of forest fragments collectively used in the *faxinal*, and that is still the case for the communities visited in Pinhão. In Prudentópolis, though families have been either managing *erva-mate* in forested areas they enclosed inside the *faxinal*, reducing the forested areas available for the communities' livestock, or planting monocultures of mate tree in their agricultural areas outside the *faxinal*. Yet, in both the private and collective systems of harvesting *erva-mate* this plant is an important source of income for the families, and it is sold to companies that will roast the *erva-mate* leaves and sell the final product. In the case of the pine nuts from the Araucaria tree, in Prudentópolis this forest resource is only harvested for the household consumption, while in Pinhão the pine nuts are also a source of income for the families. The harvesting of the pine nuts for income is not usually done collectively. In general, families will harvest them in the areas for which they have land titles or in the area claimed as their property and, for the most part, people respect this arrangement. However, there has been violent conflicts involving community members that violated the agreement. People that harvest pine nuts only for household consumption can do it anywhere within the *faxinal*, both in Prudentópolis and Pinhão.

Solidarity and the compadrio system

Solidarity and social coercion support cooperation mechanisms in the *faxinal* system. In the *faxinal* it prevails a combination of both private and communal land tenure and historically the system has been occupied by both families that have land titles or that have occupied a piece of land for many generations, thus having legal rights over that land, and also by families that do not have titles or rights to properties inside the *faxinal*, but that were welcomed in a community and allowed to settle and raise their animals collectively with the rest of the community members. The so called *mutirões* are also a common tradition of collective use and solidarity in the *faxinal*. In the countryside of Brazil, *mutirão* is the name given to collective working approaches that engage members of a community on achieving a specific goal. This goal could be a project that will benefit the entire community (e.g., building fences to demarcate the boundaries of the *faxinal*) or that will benefit just one family, who will later engage in *mutirões* for the benefit of other families. The *mutirão* for labor that benefits the whole community and that counts on community mobilization so that is mandatory for all community members to engage exists only in PIN1 and PIN3, it is totally absent in PIN2, and happens to some degree in Prudentópolis, but most of the community members do not engage and it is not mandatory in this municipality.

The *compadrio* system is defined by the relationship between godparents and godchildren and these children's parents. It exists throughout Brazil, mainly in peasant communities (Arantes 2011). The *compadrio* system aggregates a lot of families inside a community and as a young man from a *faxinal* community from Pinhão stated "(…) in the end everybody is related [through the *compadrio* system]." The families involved in these kindship ties respect each other and support each other in political disputes inside the community. Consequently, if most of the people defend the *faxinal*'s traditional norms, this system is more likely to resist to social, political, and economic forces pushing for changes in the land-use dynamics. Alfredo Wagner Berno de Almeida, a well-known Brazilian anthropologist that studies traditional and indigenous communities in Brazil and their mechanisms of resistance to modernization, theorizes that the mechanisms of solidarity and social control that exist in these communities challenge the positivist perspective of the evolutionary theory that predicts that these systems would be naturally replaced by "progress", which in rural areas is mainly represented by the advance of the agrobusiness industry (Almeida 2008).

Conflict resolution, sanctions, trust on local institutions, and social coercion

In the past, community members could apply for the position of *inspetor de quarteirão*, which can be roughly translated as the "block inspector", who would mediate acceptable behavior, mobilize people around a common project, settle agreements when there was a conflict between community members and applied sanctions. The block inspector position was formalized through the local city hall and the work was voluntary. According to the people I interviewed in both municipalities, the last time the communities had a block inspector was approximately 30 to 40 years ago. The block inspector was always a man, and he was considered almost as a local police force. Whenever he was not able to resolve a conflict, he would take the people involved in the conflict to the local police chief. Nowadays, community members try to settle problems through the local farmers' associations during community meetings and with the help of local leaders, such as the president of the farmers' association or the local representatives of *faxinal* state-level grassroots association named 'Association of the People of the Faxinal' (APF).

Nowadays, sanctions for violations of rules and norms regarding the collective use of the *faxinal* are, for the most part, applied by external forces such as the State and Municipal Secretaries of Environmental and they are applied to the whole community. This is the case for *faxinais* that are officially recognized as an ARESUR (acronym in Portuguese for Special Area of Regulated Use). The ARESUR is a state government attempt to support the *faxinal* system and preserve their remaining forest. The state of Paraná passed a decree in 1997 (IAP 1997) that recognizes and values the collective territory of the *faxinal* and regulates the creation of ARESURs. The *faxinais* that are ARESURs qualify to receive a portion of the reimbursement coming from the ICMS Ecológico (Green Value Added Tax), a tax revenue sharing scheme that aims to incentivize biodiversity conservation by reimbursing municipalities depending on the extent of their territory that has been designated as protected areas (Moro and Lima 2012). For an ARESUR to be created, community members must design a "community agreement" where they establish the resource use rules to be followed in the *faxinal*. These rules must comply with the ARESUR decree statement that the *faxinal* conserves forest and other natural resources. Rules will vary across different communities, but in general they regulate the activities that directly affect the conservation of natural resources, such as the number of animals each family can raise in the community. Violations of this agreements are assessed through an annual evaluation run by the environmental government authority in charge and when there is violation of the community agreement the *faxinal* will not qualify to receive their share of the ICMS Ecológico for the following year. Sanctions for illegal deforestation and other environmental violations according to the Brazilian Federal Constitution are also applied by the state.

The ability of a community to resolve their conflicts will largely depend on whether the president of the farmers' association and the APF representatives are trusted and respected among most of the community members and, thus, can engage people in community meetings and activities through this local institution. This mechanism of cooperation for mobilizing people towards common goals in the *faxinal* is strong in PIN1 and PIN3, and absent in PIN2 and, where internal conflicts compromised the *faxinal* institutions. Communities in Prudentópolis have been struggling with this as well due to internal conflicts of interest and communication problems. Trust issues, internal conflicts and communication problems are described in detail in the next section.

Conflict resolution will also depend on whether most of the families in a *faxinal* have been living there for many generations and are used to and agree with the informal and formal rules of a community. In a more informal setting, social coercion reinforcing local norms happens when people will control each other's behaviors. For example, families living in the *faxinal* have historically agreed that the *faxinal* should not be used for purposes that require cutting the forest down. However, the data I collected in group interviews and in the interviews with community leaders shows that this informal rule is not a consensus within communities. Technically, families that hold land titles can fence out their properties inside the *faxinal* and promote land-uses that will not include and benefit the rest of the community. Yet, many families will not do that because they do not want to go against their neighbors and relatives. This mechanism of social coercion will also influence new community members that do not want to start off with a bad foot with their new neighbors. The benefit of being able to count on your new neighbors might be greater than the benefit of promoting a land-use that goes against traditional rules.

Mechanisms threatening the *faxinal* and its forest

Land dispute with a logging company in the municipality of Pinhão

The logging company João José Zattar S.A. arrived in the municipality of Pinhão in late 1940's and severely transformed the landscape and the lives of the local communities. Since then, the company has accumulated 1/3 of Pinhão's territory. This happened largely through the process of *grilagem*, which is the grabbing *of* land *by* fraud*,* violence, abuse of power and corruption. The process of land grabbing and the violence towards local communities performed by Zattar is well documented by anthropologists and social scientists that worked in the region (Souza 2009, Ayoub 2013, Salles 2013, Correia and Gomes 2015, Ramos and Silva 2016). During the interviews I conducted in the *faxinais* in *Pinhão* this was a major topic that came up in almost every question I asked, which shows how this company's activities largely affected these communities' livelihoods. The changes in the landscape that affected local people's lives span from reduced communal territory for the communities' livestock and for the harvesting of *erva-mate* and pine nuts to the opening of large roads in the middle of communal areas leading to many events of livestock being struck and killed by Zattar's large logging trucks.

Interviewees reported that the company arrived in their communities offering jobs and offering to build grocery stores and drugstores nearby the communities to facilitate their access to these services. According to an interviewee "(…) Zattar attracted people with these offers in the beginning, but later they started to steal the lands of the families." Interviewees also stated that the events of running over people's livestock started in the 1970's. These running over incidents would happen frequently and they eventually led many families to confine and/or reduce their herds and give up on the *faxinal* lifestyle completely. Here is a statement made by a community member that participated in a group interview in Pinhão, in the English translation from the original Brazilian Portuguese transcript:

> "I used to see animals being run-over all the time (…), I used to see this on that road, dead horses on that road, do you remember, *compadre*? Cows, pigs, every time you went on the road you would see a dead pig, people's chicken. God. (…) [Cattle-guard] was something we had in the old days, right when this road was built, nobody had fences [surrounding in their properties]. When Zattar[2] built this road we had cattle-guards everywhere [to contain the animals], but we only had cattle-guards on the big roads, you know. (…) Right over there beyond the local shop there is a place where you can see that we had a cattle-guard."

Then another community member added the following:

> "But as time passed people started to fence out their lands alongside of the road, on the edge of their properties. The Zattar company started to mess with us, they started enclosing [land], then the animals would not go on the road and people removed the cattle-guards."

According to the interviews, in the 1990's the company's *jagunços* (i.e., hitmen or bandits) started to violently threaten and kill people who would refuse to leave their properties and hand it to the company. Here is what one of the interviewees reported:

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[2] João José Zattar was the owner of the Zattar logging company and the local families call him Zattar.

"I remember that when the killings of settlers started, they started to kill, you know, (…) that's when the mayor stepped in and started to arrest the hitmen. It was around that time, 1990, 1995."

When I asked about whether the company holds land title for the territories they claim to own, an interviewee stated the following:

"They say they do, you know. But other people say that they do not have it."

Interviewees also reported that in the 1980's and 1990's the company had police force working for them and that there was even a jail building in their property where people would be arrested and sometimes get bit up by a local inspector that worked for Zattar. According to the interviewees and as reported in the literature describing these events (Porto 2013), the land grabbing process performed by Zattar involved exploiting people's *illiteracy* and lack of legal documents to fool them into sign papers presented as contracts for selling Araucaria trees to the company, but people were actually signing contracts that entitled Zattar to their properties. These events of fooling illiterate people to sign fraudulent contracts in favor of the Zattar company happened from the 1950's until the 1980's (Ayoub 2013, Porto 2013).

Internal conflicts

Different land management strategies driven by communal and private uses of the land are co-occurring within the *faxinal*. This scenario is a direct result of conflicts of interest between families living in the same community and it is more common in Prudentópolis than in Pinhão. While some people believe it is best to leave all forest fragments standing and as open-access areas to all community members, so the livestock can wander freely around the *faxinal*, others prefer to fence out their properties, so they can implement other types of land-use (e.g., *erva-mate* plantations, soybean, and tobacco monocultures, etc.) and prevent the livestock to trample their plantations. These conflicts have divided community members into groups, the ones in favor of the *faxinal* and the ones against the *faxinal*. In Prudentópolis this divide was strong in all three communities. In Pinhão, these conflicts are an issue only in PIN2 where they have been, for many decades, splitting this community in several pockets of smaller *faxinais*. PIN2 was also the only community in both municipalities where community members organized to vote against this *faxinal* becoming an ARESUR.

Community members in Prudentópolis also reported stories of livestock being poisoned inside the *faxinal*. People that defend the persistence of *faxinal* accuse the ones that are against it of poisoning the animals, especially the pigs. There are also stories of people using pesticides in the forest fragments in the *faxinal*, which might be preventing forest regeneration and keeping these fragments relatively clear. According to the stories reported during the interviews, these incidents are a result of people being angry that someone else's animal destroyed their plantations, but also of people trying to force a change in the system so that they can implement land-uses the require deforestation inside the *faxinal*. The killing of livestock is a traditional response of local people to when a neighbor's animal enters their areas and damages their plantations. In the past, this kind of issue was resolved by the block inspector who would mediate an agreement between the two parties to repair the damage caused by the animal.

Gossip and misconceptions

Cooperation and rule enforcement are challenged by misconceptions and gossip about the activities carried out by the leaders at the communities' farmers' associations and by how the Green Value Added Tax that is disbursed to the communities of *faxinal* that are now ARESURs. It became clear during the interviews that community members, including community leaders, do not understand how this tax revenue sharing scheme works, which misguides them in believing that either the government or the community leaders, who are the ones dealing directly with the government in this transaction, are fooling the entire community. In fact, there were situations in which either corruption or bad management at the level of municipal governments resulted in some communities not receiving the entirety of their tax revenue share for a few years. In addition, since the state decree regulating the ARESURs was passed, in 1997, there has been many adjustments on the logistics of how to disburse the funds to the communities and this has resulted in some communities not receiving any resources during entire years. As stated throughout the literature on CPR governance, the building of trust is central for assuring high adherence to rules (Ostrom 1990, Pennington 2012). Once community members start to distrust the process and the people sustaining the ARESUR scheme, they do not feel obligated to follow the rules design in the community agreement regarding the governance of CPRs in the ARESUR.

Problems of excludability

Community members claim that people who does not live in the *faxinal* usually respect the boundaries of the communities when it comes to harvesting pine nuts and *erva-mate*. Yet, there are problems with horses that are left in the *faxinal* by outsiders. These horses end up consuming forest resources and pasture and when they die, they contaminate the water bodies. It is common that nobody comes back to claim these horses. This situation is relatively novel and is a result of horses not being as important for farm work as they used to be and, thus, feeding and taking care of them can be considered a burden. There have also been issues with people that disrespected the claim of a community member on a specific Araucaria tree leading to violent disputes around who can harvest the pine nuts of a specific tree. Disputes around Araucaria trees are not common, though, and the cases reported in the interviews seemed to be isolated and only happening in Pinhão. The problems with the horses, on the other hand, have been used to support the argument of those who believe that the collective land-use dynamic of the *faxinal* does not work and should end.

Demographic changes

Demographic changes are also transforming the land-use dynamics in the *faxinal*. Once the youth migrate to urban areas looking for education and job opportunities the chances that the areas occupied by their families will be sold to outsiders increase. In general, new community members are not interested in perpetuating the collective land-use dynamic of the *faxinal* and will join the ones standing against this system. In some cases, people that graduate from college and follow an academic career will come back to contribute with the *faxinais*' grassroots projects, but that is not at all the most common choice of those who decide to leave the *faxinal*. Also, community members reported several conflicts with new people moving into the *faxinal* that do not relate to the *faxinal* traditions and institutions and impose a different approach to resource and land management. This dynamic is evident in both municipalities, but in PIN2 the demographic changes caused by the arrival of new people have transformed the landscape more profoundly and now this community is divided in several small pockets of *faxinal* surrounded by other land-uses including large-scale pasture systems and soybean monocultures. The arrival of new people in PIN1 and PIN3 happened in a much smaller scale than in PIN2 and did not disrupt the *faxinal* system and the *faxinais* in Prudentópolis have been dealing with disruptions caused by new dwellers, but the internal conflicts in these communities are, for the most part, happening between families that have been there for generations.

Mechanisms of resistance and/or adaptation

The faxinal grassroots organization and government institutions

To cope with the social-ecological and political changes that have affected the *faxinal* over the years, communities have organized as a grassroots association, the APF. The APF was created in 2005 to support *faxinais* to secure legal rights to their ethnic recognition as traditional communities and to the recognition to their collective territories (Souza 2010). This grassroots institution was fundamental for pushing for the constitutional recognition and legislation at state and municipal levels, including the State Law Nº 15.673/2007 that recognizes the collective identity of the *faxinalenses* (i.e., people that live in the *faxinais*) and their identity as traditional communities. The APF also played a major role in pushing for legal recognition of the community agreements designed community members for the process of creating an ARESUR (Dallagnol 2018). In this sense, the ARESUR, with its ICMS Ecológico, monitoring of CPR governance and sanctions for the violations of the community agreements, are also considered in this analysis as a mechanism of adaptation of the *faxinal* system to cope with disturbances.

The APF is less active in PIN2 where personal conflicts involving the family of the local representative of the APF in the region, escalated to political disputes that lead to most of the community that participated in the voting process for the recognition of PIN2 as an ARESUR to decide against it. The APF has more influence in all other communities, but especially in PIN1 and PIN2 where they have helped research groups from a local university to organize workshops where communities can learn about relevant legislation affecting their livelihoods and are trained to navigate bureaucratic processes to access resources and claim their rights. At a state level, the APF organizes meetings with representatives of communities where they address the main problems faced by each community and debate about strategies to strengthen the *faxinal* system (Souza 2009). For instance, during their second state-wide meeting, in 2007, they decided to map the *faxinais* in Paraná using the social cartography approach (Sletto et al. 2020) by which communities map their territories according to their own perspectives. The social cartography approach allows communities to reinforce their local identities and resource governance and to contest narratives that marginalize them (Sletto et al. 2020). The map built by PIN1 and PIN3 (Projeto Nova Cartografia Social Dos Povos e Comunidades Tradicionais do Brasil – Série Faxinalenses do Sul do Brasil, Faxinalenses no Setor Centro, Paraná 2008), for example, includes information about the scenario of land grabbing and violence they have to fight against.

The partnership with universities

Two research groups from the Federal University of Paraná (UFPR) have been supporting the APF in their legal battles for securing the rights of the *faxinalenses*. These groups are based in the Geography and Sociology departments of UFPR, and they gather undergraduate and graduate students and professors from these departments who organize meetings and workshops in *faxinais* to bring information about the legislation affecting these communities and to discuss about the Green Value Added Tax budget available for the communities. As described earlier in this paper, the misconceptions about how the Green Value Added Tax is disbursed to the *faxinais* has affected trust and rule compliance at the community level and has led community members to stand against the *faxinal* system. In addition, because communities are often oblivious to the paperwork and bureaucracy that they need to navigate through in order to access the full amount of resources offered to them in this budget, they ended up losing access to part of these resources over the years. In this context, the partnerships with these research groups have been essential for building group cohesion. However, due to budget and human resources limitations they cannot work with all the communities of *faxinal*. The communities in Prudentópolis, for instance, are not included in their agenda and the conflicts between community members that result from the spreading of misconceptions about the Green Value Added Tax budget and how it is disbursed seem to be escalating over the years in Prudentópolis. A testimony to that is the increase in the soybean and tobacco cultivated areas inside the communities over time as well as the increase in the number of families enclosing their properties. In Pinhão, this is the case only for PIN2, where internal conflicts have escalated and pushed this community away from participating on initiatives to strengthen the *faxinal* institutions.

DISCUSSION

Even though core institutional characteristics of the *faxinal* that are the support of this system's collective land management choices favoring forest cover maintenance are still in place in all the communities included in my in-depth study, there is much variation in the types of disturbances faced by communities and in their choices for how to cope with these disturbances. There is also variation on the resources and partnerships available for communities to cope with disturbances and that can affect how the *faxinal* system will evolve in each community.

The communities of Prudentópolis and Pinhão have historical similarities in terms of how the governance of their collective territories was originally organized and worked for preserving forest fragments through time. This shows that core features of the *faxinal* system have been maintained over time across different geographical locations. For example, the collective use of the standing forest in the *faxinal* is secured by economic incentives and cultural traditions related to raising livestock free-range in the collective area, mainly the pigs, in both municipalities. Other traditions supporting the maintenance of standing forest in the *faxinal* are the harvesting of Araucaria pine nuts and of *erva-mate* for subsistence and income. These cultural traditions are stronger in Pinhão, as communities in Prudentópolis no longer rely on the pine nuts for income generation and are implementing other management strategies for the *erva-mate* that do not involve the collective governance of the *faxinal* forest. The first is due also to the fact that Araucaria trees are much rarer in the communities of

Prudentópolis, as stated in interviews and observed in field visits. The *compadrio* system in another example of tradition that exists in all communities, and it is an important cooperation mechanism to gather people around collective-action interests. On the other hand, the *mutirão* for labor benefiting the entire community has been compromised in PIN2 and in communities of Prudentópolis, but it is still an important mechanism to engage people around collective-action interests in PIN1 and PIN3.

Differences between communities also showed in terms of the main challenges faced by the *faxinal* in the two municipalities, the most important of them being related to the land disputes between communities in Pinhão and a logging company that has accumulated land through the process of *grilagem*. My data suggests that internal conflicts and demographic changes seem to have challenged PIN2 more than the other communities. Some particularities of this *faxinal* that might help explain this are: (1) the historical conflicts between two families that escalated to political disputes and community mobilization against the *faxinal* land management strategies, and (2) the fact that this community has a much larger area size (3-11 times larger than the others) and a larger number of families, approximately 400, when compared to the other five communities that have 30-180 families. The literature describes the history of land occupation in this community as a process where different types of conflicts overlapped over decades, including conflicts with the Zattar logging company. This contributed to the divide found among residents and to a high influx of new residents that brought different land management strategies to the community, weakening the collective territory that is the *faxinal* (Correia 2020).

My data also showed main institutional differences between communities regarding how they have been responding to the pressures for the enclosure of their collective territories. While PIN1 and PIN3 are highly mobilized for collective CPR governance of the *faxinal*, internal conflicts leading to the divide between community members is prominent in the three *faxinais* from Prudentópolis and in PIN2. These four communities share two main characteristics that can play a role in undermining collective-action initiatives and promote conflict. First, they have the highest population density (number of people per km^2) of all six communities studied, with PIN2 being six times more densely populated than PIN1 and PIN3 and the three communities in Prudentópolis being nine to 22 times more densely populated than PIN1 and PIN3. One of the variables listed by Ostrom (1990) that can affect CPR governance is a great number of resource users managing a resource unit. Even though this situation does necessarily impede cooperation, more populous communities may run into conflicts regarding the devise of costs, resource use monitoring, and reinforcement of rules (Dietz et al. 2002). Secondly, these four communities do not participate in the workshops organized by the university's research groups in partnership with the APF. These workshops gather communities and help people build a common language and understating of the social, economic, and political processes that affect them. Good communication allows for the development of social situations of cooperation and collaboration that support sustainable governance of CPRs (Ostrom 1990, Ostrom et al. 2012, Anderies and Janssen 2016) and the lack of it can push communities towards the scenario described by the tragedy of commons.

Good governance of CPRs relies on many parts of a system working together and a main requirement is the existence of a long tradition of shared norms of behavior and a high level of trust (Ghate et al. 2013). My data on cooperation mechanisms supporting the *faxinal* shows how tradition and trust is maintained by the system's collective activities (e.g., the cultural traditions around the free-range livestock farming, and the *mutirões* for the harvesting of *erva-mate* and for other community activities), and by other institutions including mechanisms of social cohesion and of social coercion. Solidarity and the *compadrio* system are very persistent traditions in the *faxinal* and are main foundations of this system (Sahr 2008, Correia 2020). Thus, the importance of these institutions for the resilience of the *faxinal* should not be overlooked.

The comparison of two municipalities with striking differences in their socio-political and land occupation histories illustrated how the *faxinal* serves as a strategy for securing local livelihoods in all communities and for securing land in the communities that struggle with land disputes. Maintaining standing forest has been instrumental for sustaining the *faxinal* for more than a century and now, the fact that forest cover has been maintained in communities of Pinhão, is serving them in their legal battles for securing their rights to land and resources and this is of great importance for PIN1 and PIN3. This makes forest conservation a priority for the *faxinal* system in this communities. In PIN1 and PIN3, communities have been using technical and scientific arguments showing that the *faxinal* promotes forest conservation as bargaining power within the Brazilian society in their legal strategies to secure land rights.

CONCLUSION

Given the world's current rapid environmental degradation it is crucial to have institutions that work for preserving natural resources. In my study I joined the effort of using the SES, the CPR governance, and the resilience literature to build a framework that can guide scholars across disciplines to collect data in a consistent way and generate general explanations about successful institutional arrangements for CPR governance. The methodological approach I used in this chapter included running a preliminary study guided by the theory on SES resilience and CPR governance to select explanatory variables that relate to a specific outcome of sustainable CPR governance. This approach was efficient to map institutional arrangements that structure incentives and property rights that influence forest management decisions in the *faxinal*, ways in which different communities will deal with disturbances, and the adaptation paths they will choose. Also, the comparison of communities from municipalities with striking contextual differences made explicit how institutional arrangements of a SES will evolve over time under different types of social and ecological pressures. Finally, these findings also reinforce Ostrom's message that good self-governance of CPRs is possible, but that it relies on many factors working together including good communication, long tradition of shared norms of behavior, and a high level of trust. However, depending on the types of conflicts that challenge a SES, communities might need to partner with external forces (e.g., local government and public universities, in the case of the *faxinal*) that can help them to cope with disturbances.

CHAPTER 2

The effect of a traditional land-use system on forest cover in Southern Brazil

ABSTRACT

Local and traditional land stewardship and management is found all over Brazil supporting communities' livelihood strategies and preserving biodiversity. In this study, I looked at forest cover dynamics in a traditional land-use system from Southern Brazil, called *faxinal*, that involves the collective use of forest for subsistence and income and for that, they have maintained forest standing. Considering this system's potential for promoting forest conservation, I asked the following questions: (1) Is the percentage of forest cover in *faxinais* higher than in their surrounding areas? (2) Is forest cover declining more slowing in *faxinais* than outside? and (3) Does the *faxinal* area matter for forest cover percentage? I sampled 29 *faxinais* (plural) with different areas (small, medium, and large) across a large geographical range and used remote sensing methods for calculating forest cover percentage and changes over time (1985-2017) inside communities and in buffer areas and a mixed-effects model approach to analyze the data. I found that (1) forest cover percentage increases as area increases inside the *faxinais*, but not in their buffers, (2) medium size *faxinais* have higher forest cover percentage compared to their buffers, (3) forest cover has been declining both inside

communities and in buffers in the period analyzed. I discuss this data in the context of the debates on the role of local livelihoods and of the land-sparing and land-sharing approaches for promoting conservation.

Keywords: traditional stewardship, subtropical forest, Araucaria Mixed Forest, *faxinal*, local communities, landscape ecology, land-sharing, land-sparing, forest conservation

INTRODUCTION

The land sharing *versus* land sparing debate has been diving opinions among scientists and land managers for decades (Phalan et al. 2011, Kremen 2105, Kremen and Merenlender 2018, Phalan 2018). Global environmental conservation strategies were, for a while, mainly oriented by the idea of "wilderness" (Mittermeier et al. 2008), focusing on land sparing and placing highest priority on relatively large areas least altered by human activity. There are two main problems with that idea. First, advances in the field of landscape ecology and community assembly have shown us that biodiversity conservation will involve more than just setting large untouchable areas aside (Wu 2009). For instance, the equilibrium and ecologic stability assumptions underlying the idea of conserving biological species in untouchable areas are now known to be unrealistic as ecosystems are ever-changing systems and important factors influencing species interaction and diversity patterns in the real world are completely ignored by this perspective, such as spatial elements, explicit lags, thresholds, limits, and nonlinearities (Holling 1973, Wu 2009). Secondly, a lot of the biodiversity of the world is located in areas actually used by humans (Alcorn 1996, WWF 2002, Chazdon et al. 2009a) and researchers and land managers have to think of ways to account for the human component of biodiversity conservation. In this sense, considering that the land sharing strategy is part of the reality of conservation biology, an important question to ask is – how are the managed landscapes working for biological conservation?

For tropical forests around the world, traditional and Indigenous land stewardship is part of conservation strategies. In Brazil, the creation of categories of protected areas that respect traditional and Indigenous tenure and resource use has been an important ally for biodiversity conservation. In fact, extractive and Indigenous reserves in Brazil, for instance, have been way more effective in containing deforestation in expanding frontier regions than inhabited protected areas (Schwartzman et al. 2000). Also, in addition to securing natural habitats, these conservation strategies secure local livelihoods that depend directly on the local natural resources.

Local and traditional forms of natural resources governance can be found throughout Brazil as part of the livelihood strategies of traditional communities. These communities have their rights of reproducing cultural practices through means of resource management and use recognized by the Brazilian legislation (Brasil 2007). Moreover, Brazil's National Policy for Sustainable Development of Traditional Peoples and Communities (Brasil 2007) defines traditional communities in terms of, among other criteria, their low impact management techniques. This has served as a powerful discourse for empowering traditional communities as stewards of the resources their livelihoods depend on. The dispute around this narrative, however, is highly controversial. Playing a crucial role in this debate is the compilation of empirical evidence showing whether specific types of traditional management practices are viable alternatives to deal with current rapid socio-environmental changes.

The *faxinal* is a traditional land management system from Southern Brazil, located in the state of Paraná (Figure 2.1), that involves raising livestock free range in a forested area used collectively (Chang 1988, Sahr 2008, Bertussi 2012, Hauresko 2012, Correia and Gomes 2015). In addition to their livestock farming, community members rely on the collective area for the harvesting of non-timber forest products (NTFP), mainly the *erva-mate* (i.e., leaves extracted from the tree *Ilex paraguariensis* A. St.-Hil. for making a traditional tea-like hot beverage) and the *pinhão* (i.e., pine nuts from the pine tree *Araucaria angustifolia* (Bertol.) Kuntze), for both subsistence and income generation. Most of the families also maintain agricultural parcels outside the *faxinal* area where they grow agricultural commodities such as soybean and tobacco as well as black beans, for both subsistence and income generation, and other subsistence crops (e.g., cassava, corn, rice, potatoes, pumpkins, etc.). A clear rule in the *faxinal* that is defined by local social norms is that the removal of forest cover is not allowed as their livelihoods rely on the standing forest for feeding the livestock and for managing NTPF (please, refer to chapter 1 for details).

The local forest managed by the communities of *faxinal* is a conifer subtropical forest called Araucaria Mixed Forest (AMF). The deforestation in this forest is high and it has been going on since early 1900's mainly driven by the intensification of land-use, especially by the conversion of forested areas into large-scale logging and monoculture agriculture. The fact that the *faxinal* sustains a type of land-use that allows for forest cover maintenance is taken as evidence that the *faxinal* has been an ally for protecting the AMF, especially when compared to the commodity monoculture land-use that is virtually everywhere else in the region.

In this chapter, I joined researchers at the Center for Ecology and Environmental Monitoring (NEMA) from the Federal University of Vale do São Francisco (UNIVASF) and from the Human Ecology and Ethnobotany Lab (ECOHE) from the Federal University of Santa Catarina (UFSC) to test the idea that the *faxinal* is working for conserving the AMF in the region when compared to the surrounding landscape dominated by large-scale commodity agriculture and logging and where the forested areas are mostly preserved through land sparing strategies mainly guided by the Brazilian Forest Code, the country's main legal instrument for regulating land-use on private rural lands. The Forest Code determines that landowners must set aside a percentage of the natural habitats in their properties for conservation. Here I asked the following questions: (1) Is the percentage of forest cover in *faxinais* higher than in their surrounding areas? (2) Is forest cover declining more slowing in *faxinais* than outside? and (3) Does the *faxinal* area matter for forest cover percentage?

METHODS

I sampled all the *faxinais* (n = 29) (Figure 2.1) in the state of Paraná that have their perimeters defined and made available by the Institute of Land, Cartography and Geosciences of the state government of Paraná (ITCG for the acronym in Portuguese). I selected a buffer of 1 km around each community to serve as the area used to compare the forest cover status and changes over time inside the communities with the areas surrounding them (Figure 2.2). There are six *faxinais* in the sample that are adjacent to their neighbor *faxinal* and thus, they had to be considered as one community with one buffer zone surrounding both *faxinais*, and because of this methodological adjustment, my final sample accounts for 26 areas of *faxinal*.

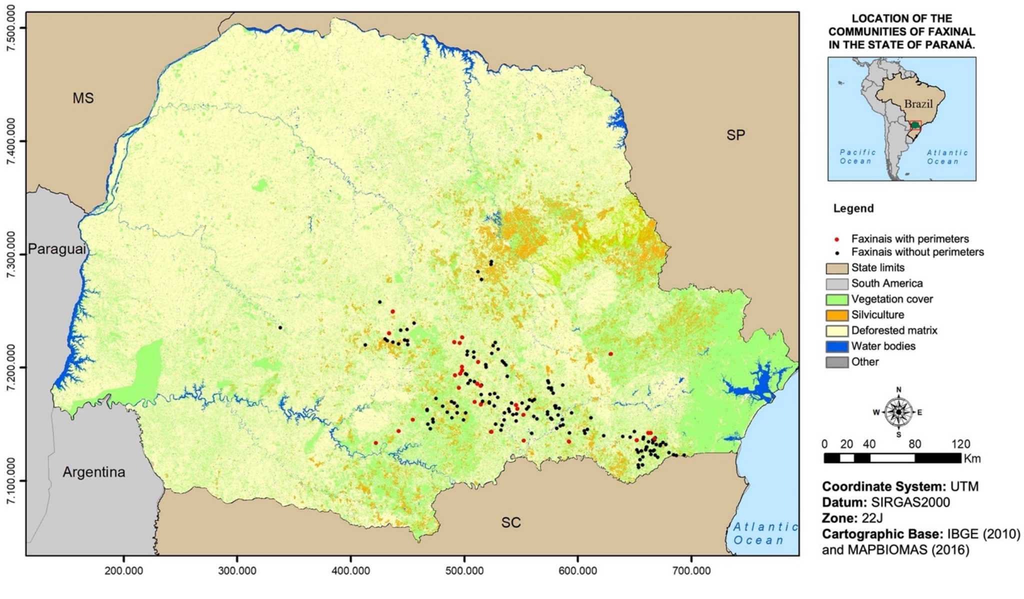

Figure 2.1. Location of all the *faxinais* in the state of Paraná, Southern Brazil, for which the geographic location is available (black and red dots) and of the 29 *faxinais* for which the perimeter is available and that are included in this study (red dots).

For the analysis of changes in forest cover over time, I focused on the 30-years period between 1985-2017 because a study published by the SOS Mata Atlântica (2016) showed that the state of Paraná was the leader in deforestation rates in the Atlantic Forest Biome – where the AMF is located – in Brazil for that period. Also, according to the study, the main region where this deforestation happened in Paraná overlaps with the region where the communities of *faxinal* are located (SOS Mata Atlântica 2016).

To look at changes in forest cover over time I used the land-use and land-cover classification data made available by MapBiomas, a Brazilian annual land-use and land-cover opensource monitoring initiative (MapBiomas 2021). My research partners at NEMA quantified forest cover changes within each *faxinal* and in their surrounding areas over the 1985–2017 period using the MapBiomas data on their category "forest cover" ("formação florestal" for the name in Portuguese) for our study region. I compared data on alternate years and my final sample has a total of 17 years analyzed. The 17 GeoTIFF files (for all 17 years) downloaded from the MapBiomas (2021) platform were converted to shapefiles and the areas within and surrounding (1 km buffer) the *faxinais* were selected for the 26 *faxinais* included in my sample (Figure 2.2). Finally, the research at NEMA used ArcGIS to calculate the total area for the "forest cover" category for each of the selected areas (i.e., inside *faxinais* and in buffers) to generate the percentage values for forest cover for each of the 17 years analyzed between 1985-2017.

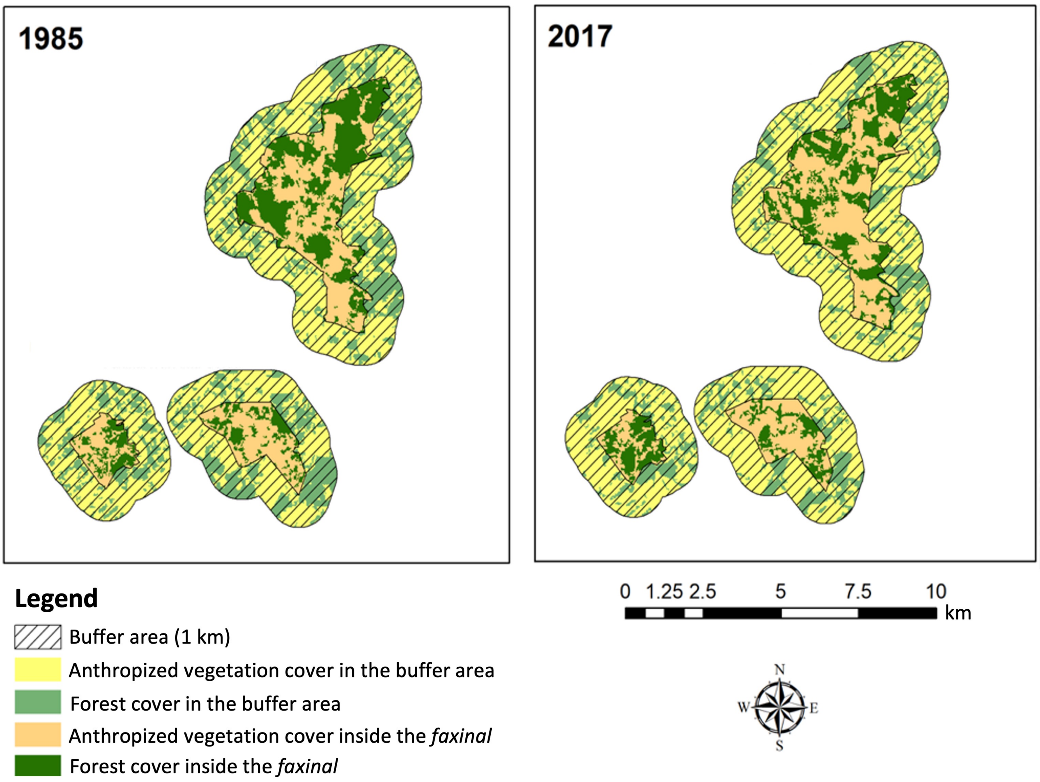

Figure 2.2. Figure showing how the data retrieved from the MapBiomas platform was used to calculate the forest cover and the anthropized vegetation cover inside the *faxinais* included in this study and in theirs buffers. The figure on the left shows an example of the land-cover for 1985 and the figure on the right shows the land-cover status for the same area in 2017.

Data analysis

The area (ha) of each *faxinal* was categorized in small, medium, and large according to the values of variable quantiles. *Faxinais* with areas larger than the third quantile (75% of all values) were considered as large, the ones with areas smaller than the first quantile (25% of the values), were considered as small, and areas in between were categorized as medium. The small (n = 6), medium (n = 14), and large (n = 6) *faxinais* in the sample have areas ranging between 30.8–166.1 ha, 202–807.6 ha, and 1,088–3,325.2 ha, respectively (Table 2.1).

Table 2.1. Sample size (number of *faxinais*) and area range (ha) for the three *faxinal* area categories (small, medium, and large).

	Faxinal* area categories		
	small	**medium**	**large**
Number of *faxinais*	6	14	6
Area range (ha)	30.8 – 166.1	202 – 807.6	1,088 – 3,325.2

*Categories were defined according to the values of variable quantiles

All my statistical analyses were run in collaboration with my research partner from ECOHE. We built mixed effects models with a Beta distribution using forest cover proportion as the response variable for testing my two hypotheses. We treated *faxinal* area (small, medium, and large), the location of the forest cover measures (i.e., inside *faxinais versus* buffers), and the different years in which the measures of forest cover were taken as fixed effects. Fixed effects also included interaction between area and year to account for different relations between forest cover and year for each area category (small, medium, and large). An interaction between location of the forest cover measures and area categories was added to the fixed effects to check if forest cover increases along the area categories for both locations (inside *faxinais versus* buffers). When significant differences were detected, a Tukey test was applied to check for significant pair-wise interactions. To account for repeated measures (i.e., forest cover measures over the years), we specified the years within each *faxinal* as a random slope. Model selection was based on the Akaike Information Criterion

(AIC) (Zuur et al. 2009) and the final model was validated by a graphical analysis of randomized quantile residuals (Dunn and Smyth 1996, Gelman and Hill 2006). All analyses were run in the R environment (R Core Team 2021) using the "glmmTMB" (Brooks et al. 2017) for the mixed effects model, "DHARMa" for model validation (Hartig 2021), and "lsmeans" to contrast analyses (Lenth 2016). All graphs were drawn in R using packages 'ggplot2' and 'ggeffects' (Wickham 2016, Lüdecke 2018). The final model selected is the following:

forest cover % ~ area * year + location * area + (0 + year | faxinal)

To further explore and visualize the changes in forest cover over time inside the *faxinais* and in the buffers we applied a paired t-test to compare forest cover between 1985 (first year of sample) and 2017 (last year of sample) within *faxinais*, and around *faxinais* (Zar 2010). The response variable was tested for normality using Kolmogorov-Smirnov (within: D = 0.0932, p-value = 0.756; around: D = 0.943, p-value = 0.707), and homogeneity of variances between years with Fligner-Killen test (within: χ^2 = 0.677, p-value = 0.410; around: χ^2 = 0.090, p-value = 0.764).

RESULTS

Effect of area and location (inside *faxinal versus* buffer) on forest cover

Here I am answering my first and third questions: Is the percentage of forest cover in *faxinais* higher than in their surrounding areas? Does the *faxinal* area matter for forest cover percentage? I found an effect of the interaction of location (inside *faxinal versus* buffer) and area on forest cover percentage. Forest cover differs between area categories in a joint effect with location. For instance, forest cover increases from small to medium *faxinais* inside communities, but it decreases in the buffers. In summary, small *faxinais* differ from medium and from large ones, respectively, in their effect on forest cover relative to surroundings (Table 2.2). Confidence intervals show that a clear difference is found for forest cover percentage between medium *faxinais* and their buffers, but not for small and large *faxinais* (Figure 2.3).

Effect of time on forest cover

Here I am answering my second question – Is forest cover declining more slowing in *faxinais* than outside? I found an effect of the interaction of *faxinal* area and year on the percentage of forest cover, showing a decline in forest cover over time in medium (est. = - 0.0124, p = 2.42e-09) and large (est. = - 0.0128, p = 7.72e-05) *faxinais*. For small *faxinais* forest cover did not vary along years (p = 0.92) (Table 2.3, Figure 2.4). Figure 2.4 shows forest cover status over time, but the analysis does not separate the areas inside the *faxinais* and their buffers as the model could not account for that. The total decline of forest cover both inside the *faxinais* and in their buffers between the first (1985) and last (2017) years of my sample is displayed in Figure 2.5.

Table 2.2. Outcome of the Tukey analysis applied on the interaction between location (inside *faxinais versus* buffer) and area (small, medium, and large). The p-values < 0.05 indicate significant differences between sizes in the effect of the *faxinais* on forest cover.

Location *versus area*	**tukey**	**estimate**	**SE**	**df t.ratio**	**p.value**
buffer x inside *faxinal* small x medium	0.7908	0.0781	873	10.127	<.0001
buffer x inside *faxinal* small x large	0.7709	0.0923	873	8.354	<.0001
buffer x inside *faxinal* medium x large	-0.0199	0.0760	873	-0.262	0.7932

Table 2.3. Effect of area on forest cover change over time.

	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
Intercept: small	0.1297295	6.5021698	0.020	0.98408
Slope: small	-0.0003058	0.0032520	-0.094	0.92507
Intercept: medium	24.30	4.174	5.822	5.81e-09 ***
Slope: medium	-1.246e-02	2.088e-03	-5.967	2.42e-09 ***
Intercept: large	25.67	6.496	3.952	7.76e-05 ***
Slope: large	-1.284e-02	3.249e-03	-3.953	7.72e-05 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

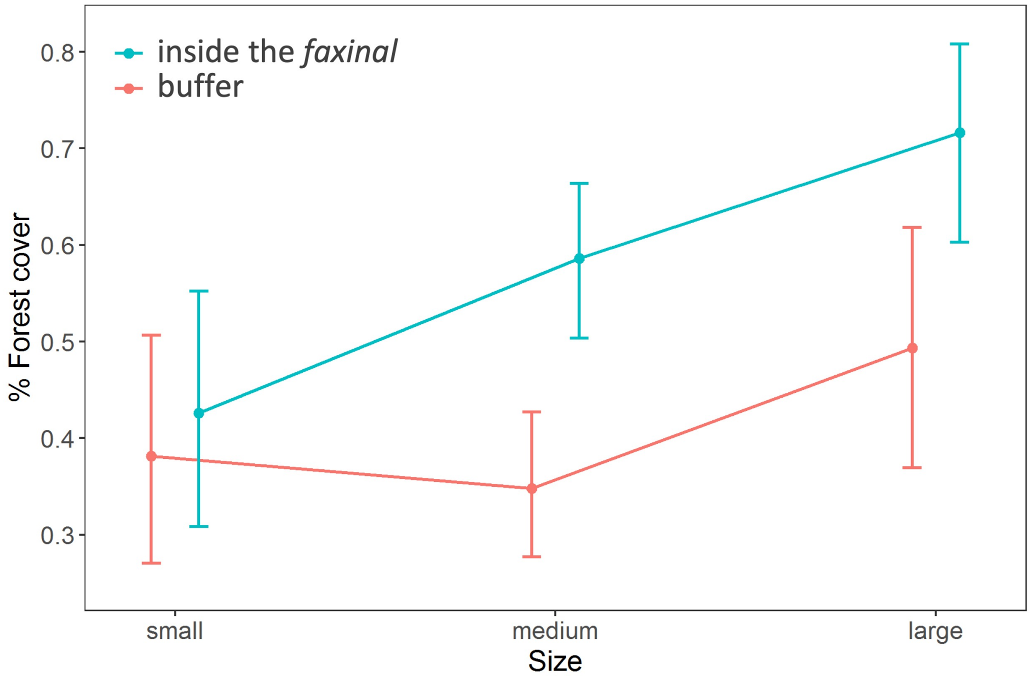

Figure 2.3. Effect of the interaction of *faxinal* area (small, medium, and large) and location (inside *faxinal versus* buffer) on forest cover measure. Small *faxinais* differ from medium and from large *faxinais*, respectively, in their effect on forest cover relative to surroundings. Bars = 95% C.I.

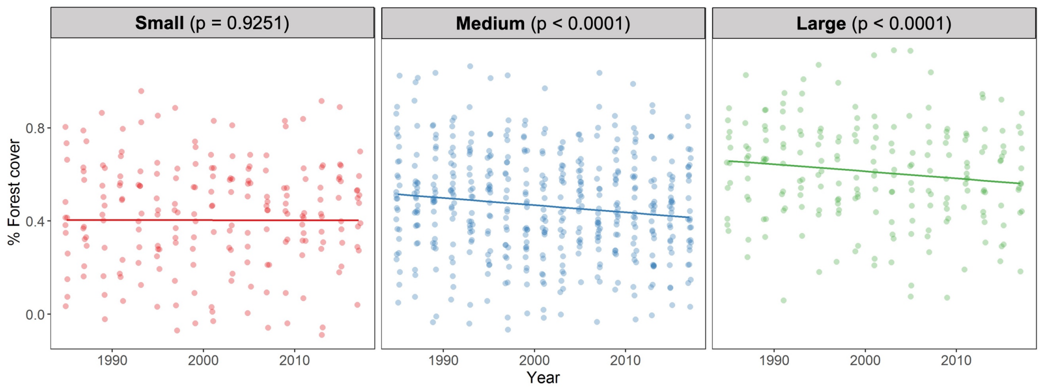

Figure 2.4. Forest cover status over time for the *faxinais* and their buffers (values aggregated) and for each area category (small, medium, and large). For the small *faxinais*, forest cover inside the communities and in their buffers is maintained through time ($p = 0.9251$), and for the medium ($p < 0.0001$) and large ($p < 0.0001$) *faxinais*, forest cover inside the communities and in their buffers is decreasing through time.

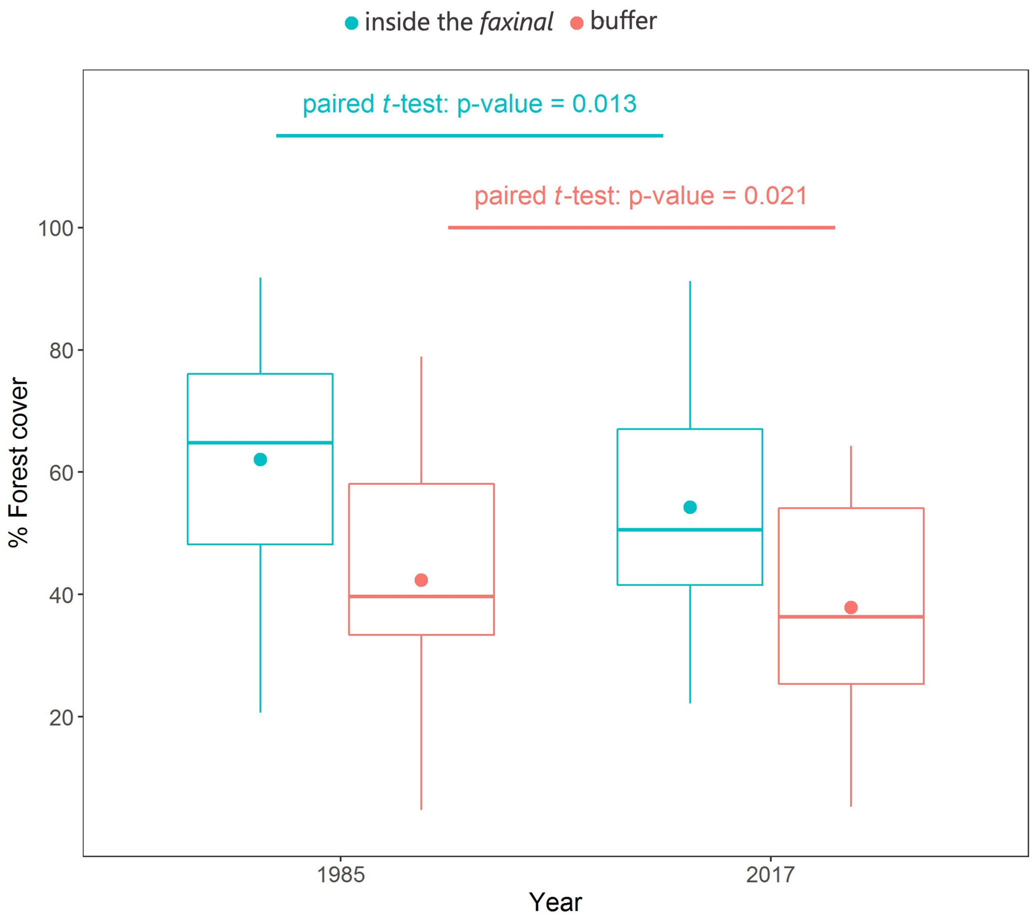

Figure 2.5. Effect of location (inside the *faxinal versus* buffer) and year on percentage of forest cover. Forest cover declined from 1985 to 2017 both inside the *faxinais* (p = 0.013) and in their buffers (p = 0.021).

DISCUSSION

My results showed that forest cover percentage will increase as area increases inside the *faxinais*, but the same effect was not found for their surrounding areas. In the buffers, forest cover decreased from small to medium areas and then increased from medium to large ones, but in general those changes were not significant. Also, medium size *faxinais* have higher forest cover percentage compared to their buffers. This difference did not show for small and large communities. Results from the effect of time on forest cover percentage show that forest cover has been declining both inside the communities and in their buffers in the 30-years period analyzed (1985-2017) for medium and large *faxinais* and the rate of the decline is similar for both inside the *faxinais* and in their buffers. On the other hand, in small *faxinais* forest cover is being maintained over time both inside the communities and in surrounding areas.

The fact that, in general, the percentage of forest cover was higher in the communities when compared to their surroundings corroborates the findings of other researchers that showed that traditional and Indigenous territories work for containing deforestation driven by the advancement of the agro-industrial frontier (Fa et al. 2020). Characteristics found for these traditional social-ecological systems and that can contribute with the conservation and sustainable management of their natural habitats include a collective land-use and property rights and the fact that their livelihoods rely on the management of local natural resources for both subsistence and income (Ostrom 1990, Fa et al. 2020). In addition, this communities will also physically block extractive activities. All the situations described above are true for communities of *faxinal*. There are communities, for example, that have been involved in land disputes with a logging company for decades and their efforts have been, for the most part, successful in blocking this industrial logging activity in their region (Souza 2009, Ayoub 2013, Porto 2013, Salles 2013, Correia and Gomes 2015, Ramos and Silva 2016).

When looking at the effect of area on the percentage of forest cover, one could assume that higher population densities are pushing for the over-use of resources and deforestation in small *faxinais*, as my analyses demonstrated that the proportion of forest cover in small communities does not differ from its buffer. However, the literature on human-environment interactions have moved beyond simplistic assumptions like that and now we know the importance of other contextual factors, such as local institutional-arrangements, in mediating whether variables like population density, area size, poverty, among others, will in fact play a role in resource management and changes in land-cover (Ostrom 1990, VanWey et al. 2005). In this sense, even though population density could be playing a role in the case of the small communities, the social dynamics on the ground cannot be overlooked.

For the case of the *faxinal* system, contextual variables that can affect forest cover in communities of all sizes are described in the first chapter of this dissertation and include, for instance, the fact that the *faxinal* has a hybrid tenure system with a combination of both private and communal land tenure that allows for a dynamic that is currently happening in some communities, where local residents are selling their properties to outsiders that have no connection to the *faxinal* system and its rules for the collective use of the forest. The new residents will not necessarily respect local rules and could replace part of the forest in their new properties with other types of land-uses, such as soybean monocultures. Conflicts of interest between community members also play a major role in the land management decisions in the *faxinal* and are pushing for changes in land-cover in this system. Thus, it is possible that changes in forest cover are happening more intensely in some communities not because they are overpopulated, but because they now have less families committed to the *faxinal* system and to its social dynamics that work for forest conservation. These conflict dynamics are happening at a larger scale in the *faxinais* across Paraná and could be pushing for changes in forest cover over time at a regional level.

In the case of the large *faxinais*, the fact that my analyses did not show difference in the proportion of forest cover between inside the communities and their surrounding areas might be explained by the fact that three out of the six large *faxinais* in my sample are nearby protected areas, including the Environmental Protection Area (APA) of Guarapuava (Área de Proteção Ambiental de Guarapuava, for the name in Portuguese) (Instituto Socioambiental 2021) and the Wildlife Refuge of Pinhão (Refúgio da Vida Silvestre de Pinhão, for the name in Portuguese) (Instituto Água e Terra 2021). In this sense, this could be showing a combined effect of the land sparing and land sharing approaches for forest conservation in the region.

Conservation strategies that combine both approaches can help mitigate a main problem of the land sparing approach, which is related with the quality the of the matrix surrounding the natural habitat patches and that will depend on the intensity of the management at the farm plot level in this matrix. Intensity of management can cause great regime shifts in ecosystems, which might require a lot of effort to recover. Just to give an example, the excess of nutrients surplus released by intensive agricultural management into water bodies can lead to an increased concentration of these nutrients in aquatic systems and to intense regime shifts in food webs and entire ecosystem dynamics (Elser and Bennett

2011). Intensive land management can also reduce the availability of alternative habitats, seasonal resources, and steppingstone resources for migrating species or for species living in surrounding forest patches (Schellas and Greenberg 1996). In addition, there is plenty of evidence (Kibblewhite et al. 2008, Parikh and James 2012) that agricultural intensification mines the resilience of the soil in the long term by promoting and enhancing erosion, nutrient depletion, destruction of soil structure and thus, its ability to hold water and nutrients over time, which also leads to the destruction of habitats for many species and reduces the overall ecosystem functionality in the area. In this sense, and in the context of biodiversity conservation, it is relevant to think of the role of a diversity of land management and conservation strategies working together at a landscape scale for generating more effective conservation outcomes, which can also benefit agricultural production by providing ecosystem functions such as biological control, pollination services, reduced soil erosion and runoff, and nutrient cycling.

Finally, when looking at the effect of time on forest cover proportion, the data showed that deforestation increased in the 30-years period analyzed at similar rates for both inside and outside the *faxinais* and thus, it has followed the deforestation pattern described for the AMF for that period by SOS Mata Atlântica (2016). The fact that in general, *faxinal* still secures higher forest cover than their surrounding areas (Figures 2.3 and 2.5) though, might indicate that the *faxinal* land-sharing strategy historically has worked better for maintaining the AMF cover in their region, when compared to land-sparing conservation strategies happening in the buffers, including the protected areas nearby larger *faxinais* and the natural habitats secured by the Brazilian Forest Code in private properties. My data suggests that this is especially relevant for the medium size *faxinais*, which were the most numerous in my sample and thus, will have forest conservation outcomes across a larger geographical range than the small and larger communities included in this study. However, as deforestation is happening at similar rates inside and outside the *faxinais* an important conservation strategy for the AMF in the areas where communities of *faxinal* are located is supporting and strengthening this system's land management strategies and institutions underlying forest cover maintenance.

CONCLUSION

The land sparing and land sharing conservation approaches can work together to foster the conservation of the AMF in Paraná. These strategies will depend on contextual variables, like described for the changing social dynamics of the *faxinal* system, and they also might have different effects at different scales. For instance, for the areas where medium *faxinais* exist, the land sparing strategy, supported mainly by the conservation promoted by the Brazilian Forest Code, seems to not be generating the same forest cover maintenance benefit as does the *faxinal* land sharing strategy. In this sense, supporting these communities' land management strategies is of great importance for the conservation of the AMF in the region.

CHAPTER 3

An approach to measure the effect of local governance on forest resilience and diversity in the Araucaria Mixed Forest, Southern Brazil

ABSTRACT

Forest cover loses around the world have dramatically accelerated mainly driven by land-use intensification and there is an urge to investigate and reinforce land-use systems that go on the other direction and conserve forests. The *faxinal* is a traditional land management system from Southern Brazil that has been keeping forest standing while supporting local livelihoods. The Araucaria Mixed Forest (AMF) managed in the *faxinal* is highly degraded throughout the region and its existence depends strongly on supporting conservation strategies that are already in place and working. Considering the potential for the *faxinal* to conserve the AMF, I investigated the effect of the natural resources' governance of the *faxinal* on the local forest diversity and resilience. I found that communities with more traditional governance present higher diversity, especially in the regenerative forest strata. Also, main differences in forest composition were found across regional scales when comparing different municipalities, but different management strategies in the *faxinal* can also drive differences in composition with communities that rely more intensely on the harvesting of non-timber forest products for income and

subsistence maintaining forest fragments that have key features that characterize the AMF, such as the presence of late-secondary species that define this forest.

Keywords: Araucaria Mixed Forest, AMF, *faxinal*, traditional community, Brazil, governance, local institutions, local management, diversity, resilience

INTRODUCTION

Ninety percent of the world's tropical forest exist outside of protected areas and is represented by secondary forests in human-modified landscapes. This includes agroforests and other managed forests governed by indigenous and traditional rural stewards (Chazdon et al. 2009a, WWF 2002). Recent studies in second growth forests showed their important role in preserving biodiversity and to provide for human needs (Chazdon et al. 2009a, 2009b, Gardner et al. 2009, Chazdon 2014, Fa et al. 2020) making it crucial to include second growth forests in conservation efforts. With forest loss occurring rapidly around the world, understanding whether and how these local governance systems conserve forests is critically important to guide actions, including policy to secure local and indigenous forest tenure and governance systems as means to protect both forests and traditional cultural practices.

Like Brazil's indigenous groups, traditional rural communities are recognized by federal and local governments as having sustainable livelihoods rooted in their territories. These groups have their rights to land ownership and to resource management and use protected by the legislation (Brasil 2007). The reasons why these groups' sustainable land management practices still exist and how their livelihoods contribute to protect natural habitats are various and can be unique to each situation. Some communities, for instance, have been physically and legally blocking extractive industries from entering their territories. The fact that these communities' material and non-material cultural needs are derived from the ecosystems they inhabit is also another explanatory factor for their precapitalistic and more sustainable logic of resource use and management (Fa et al. 2020). Both situations mentioned above are true for the *faxinal*, a traditional land management system from Southern Brazil.

The *faxinal* (Chang 1988, Sahr 2008, Souza 2009, Hauresko 2012, Correia and Gomes 2015, Nerone 2015) is characterized by a forested area that has traditionally been managed communally by local families for free range livestock farming, mainly pigs, and for the harvesting of non-timber forest products (NTFP). Under pressures for modernization and intensified production in areas of *faxinal*, the adoption of private uses of the land inside these communities is now a reality. As a result, several of these communities maintain a hybrid system where different land management strategies driven by both communal and enclosed private uses (e.g., monoculture agriculture) of the land are co-occurring. This reduces the forested areas available for the communal use, which can push for more pressure on the open-access forest fragments. As a *faxinal* transition to a hybrid governance system of the land, the forested landscape goes through changes that have not yet been investigated through a forest ecology perspective.

The forest within which the *faxinal* system is located is the Araucaria Mixed Forest (AMF). The AMF is a subtropical conifer forest that is part of the Atlantic Forest dominion in Brazil and Argentina (Souza 2020). The Brazilian Atlantic Forest originally covered approximately 120 million ha, but after over a century of deforestation there is now 12.4% of its original cover left (SOS Mata Atlântica 2019). The AMF has been highly degraded since early 1900's, mainly due to the arrival of logging companies and large-scale agriculture (Maack 1968, Lacerda 2016). In this sense, biodiversity loss in the AMF follows the pattern found for most of the forests around the world (Ellis et al. 2021) as it is mainly driven by the intensification of land-use. On the other hand, the history of the AMF also involves a type of human interference that shaped the structure and composition of this forest. The Amerindian people of the linguistic family Jê have been directly associated with the increase in abundance of the pine tree *Araucaria angustifolia* (Bertol.) Kuntze and the expansion of the AMF in the last 2,000 years (Reis et al. 2014, Souza 2020). Araucaria Mixed Forest fragments that are considered well conserved have the *A. angustifolia* as the most abundant species and occupying approximately 50% of canopy cover (Souza 2020). Most of the remaining forest fragments though, are characterized by second growth forest and by a lack of *A. angustifolia.*

The management of NTFP, like *erva-mate* (the leaves from *Ilex paraguariensis* A. St.-Hil.) and *pinhão* (the pine nuts from *A. angustifolia*), is an important cultural tradition and source of income in rural areas in the Brazilian AMF. The state of Paraná, where communities of *faxinal* are located, was the main producer of both *erva-mate* and *pinhão* in 2020, accounting for 87.4% and

34.6% of the national production, respectively (IBGE 2021). When thinking of the conservation of the AMF we must look at this forest as the cultural landscape it is and find ways to investigate the role of local management strategies in preserving this forest, but also in shaping its forest structure and composition. An important question to ask is whether traditional management strategies are favoring the maintenance of the AMF, or if they are shaping its fragments into some other type of forest that lack the key species that characterize this forest, such as the *A. angustifolia* and other late-secondary species like *Ocotea porosa* (Nees) Barroso. The *faxinal* is a valuable system in which to examine how economic, social, and cultural changes interact with forest stewardship because individual *faxinais* (plural) have undergone very different rates and types of change across their geographic region. The importance of the *erva-mate* and *pinhão* for income generation and subsistence, for example, varies across communities and this variation is directly related to differences in local governance of forest resources and types of land-uses prioritized in a community.

Given the high rates of historical deforestation in the region and the knowledge gap regarding how social-economic and governance changes in the *faxinal* system are affecting the status of this system's forest fragments, I investigated whether the traditional governance of forested areas in the *faxinal*, that is based on the collective use of the forest, favors forest conservation. My research focuses on the state of Paraná, as this is the only state in Brazil where these systems have persisted. Also, for the past 30 years, Paraná has had the highest rates of deforestation for the AMF (SOS Mata Atlântica 2016) and the main region where this deforestation has happened overlaps with the area where *faxinais* exist. This makes these communities potentially both vulnerable and of heightened importance if they are protecting remaining forest areas.

I used a social-ecological systems (SES) resilience approach to pinpoint how the heterogeneity in communal governance and socioeconomic changes, such as integration into commercial economies and privatization, are related to changes in forest protection and condition across communities of *faxinal*. The literature on SES resilience (Holling et al. 2002, Berkes et al. 2003, Ostrom 2007, 2012, Ostrom et al. 2014, Thiel et al. 2015, Cummings et al. 2020) calls for consistency on methodologies for data collection and analysis that link governance variables to sustainable resource management outcomes. Thiel et al. (2015) conducted a meta-analysis on this field of research and showed that the focus on causal relations and patterned explanations have been neglected and that the work on SES have been mainly descriptive. Here I am proposing an approach of building a governance score based on characteristics of the *faxinal* SES that promote the traditional collective use and governance of this system's forest to test hypotheses on how local governance affects forest structure and composition.

In this study I am addressing the following questions: (1) Do traditional *faxinal* governance preserve forest better than the hybrid governance system that evolved in less traditional *faxinais*? (2) How does intensity of use in the *faxinal* affect forest composition? For the first question, the condition of forest fragments is assessed in terms of metrics presented by Oliveira and Vibrans (2020) that represent what the authors call the naturalness of the AMF, which will tell the potential of a forest fragment to carry on with forest succession and maintain a forest community and also how similar a forest stand is to what is considered by the literature to be an old-growth AMF stand. The second question addresses how different forest management strategies in the *faxinal* might be affecting forest composition of AMF fragments. This question is a way to accommodate the heterogeneity of the intensity of use of open-access forest fragments found within a *faxinal* and that derive from the different forest management activities historically carried in a community. I hypothesized that (1) traditional *faxinal* governance favors the maintenance of old-growth forest communities, (2) traditional *faxinal* governance favors forest resilience (total diversity and diversity of regenerants), and (3) differences in intensity of use will result in differences in forest composition.

METHODS

Methodological constrains

There are two main methodological constrains that I had to consider when deciding how to assess the conservation status of the forest fragments in the communities. First, the AMF fragments are now almost entirely composed of second-growth fragments making it difficult to find a baseline for comparison. Secondly, the forest composition of the angiosperm-dominated layer of the AMF will vary naturally across its geographical range because of the climatic, topographic, and edaphic variation across the region. A literature review of the publications on the forest composition of AMF fragments across its geographical occurrence in Brazil found a total of 583 tree species from which 54% will occur in just one or two localities (Jarenkow and Budke 2009), showing a high rate of endemism for the AMF. Given this, I measured the conservation status of forest fragments in terms of (1) the potential of the forest fragments to regenerate (total diversity and diversity of the regenerants) and (2) the presence of old-growth species, which I used as a surrogate for how mature a fragment is.

Selection of sites

I set out to compare forest condition in communities of *faxinal* that vary across a governance score (n = 1-8). This governance score was built according to the presence of institutional arrangements that favor the traditional collective governance of the forest in the *faxinal*. I conducted preliminary field visits (2014-2016) to communities to look for general patterns in terms of local governance, forest structure, and forest management strategies. I visited 34 communities, from a database of 227 *faxinais* in Paraná (Souza 2009) (Figure 3.1), located in 11 municipalities, and I conducted informal interviews with community leaders (n=18) and community households (n=47), participated in government and community meetings, and conducted guided walks (Albuquerque et al. 2014) in forest fragments. These preliminary field observations showed that each community went through very different rates and types of socio-ecological change. I narrowed down my sample design for this forest study based on variables that can provide contrasting comparisons in terms of how collective forest governance change over time, including: differences on geographic location, cultural background, population density, area sizes, land-use histories, and the main agricultural and/or forestry commodities produced in their region.

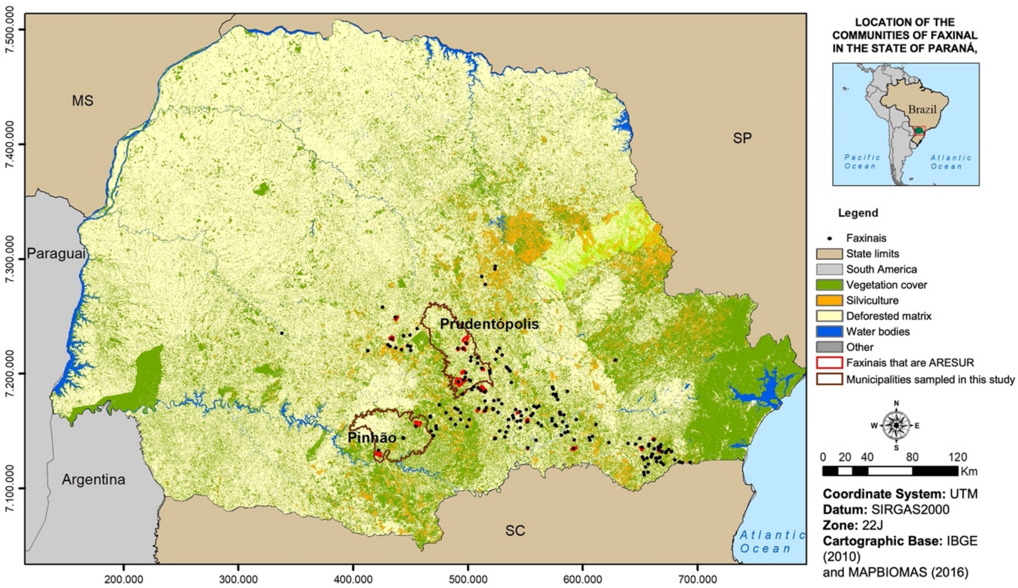

Figure 3.1. Map of the field site (1) the municipalities sampled in this study, Prudentópolis and Pinhão, (2) the *faxinais* inventoried by Souza (2009) for the state of Paraná (represented by the black dots), and (3) the *faxinais* that are considered ARESURs (for details on this refer to the section "the governance score") or that are in the process of becoming one (represented by the red polygons). Not all the 227 communities inventoried by Souza (2009) had their geographic location available to be displayed in the map, however the geographic range of the area occupied by the *faxinais* is accurate.

My final sample design includes six communities and 12 forest fragments located in two municipalities, Prudentópolis and Pinhão, with three communities and six fragments in each municipality, in the state of Paraná, Southern Brazil (Figures 3.1 and 3.2). The communities located in Pinhão and

Prudentópolis are represented hereby by the codes PIN1, PIN2, and PIN3 and PRU1, PRU2, PRU3, respectively. Table S3.1 is displaying important contextual characteristics and contrasting differences between Pinhão and Prudentópolis.

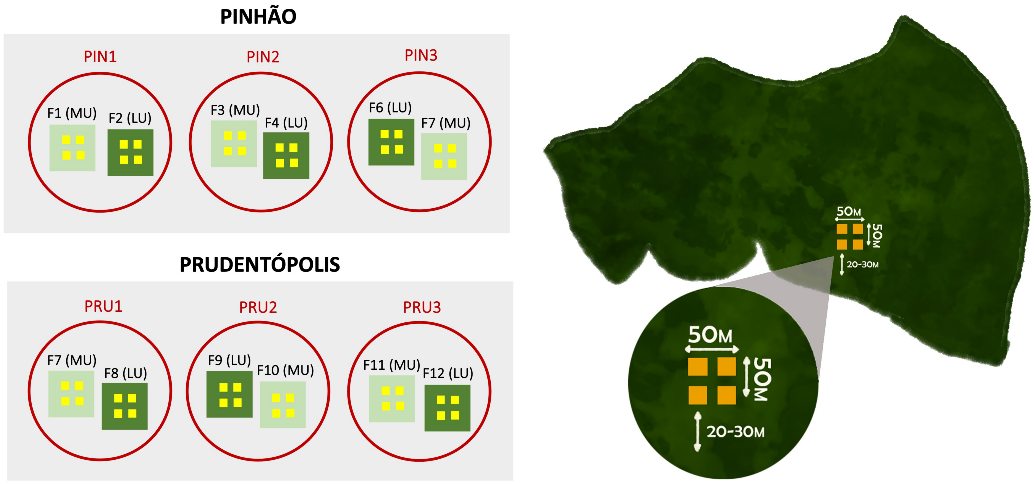

Figure 3.2. The diagrams on the left represent the study sample design with 48 plots (yellow squares), distributed in 12 fragments (F1-F12) and six communities (PIN1, PIN2, PIN3, PRU1, PRU2, PRU3) of two municipalities (Pinhão and Prudentópolis). In each community I sampled two types of fragments classified as MU (more used, light green square) and LU (less used, dark green square). The figure on the right shows how the four plots were placed on the corners of a larger 50 x 50 m plot and distant 20-30 m from the edge of the fragment.

Selection of forest fragments

In each community, I selected two fragments to conduct a vegetation survey. I decided to work with a non-random sampling design due to my small sample size and because I wanted to make sure that, in each community, I sampled the two types of fragments I found in the *faxinal* system. The different types of fragments represent the outcomes of different intensities of use I observed while doing visual assessments of the structure of forest fragments in the communities and described during group interviews[3] when I used maps of the communities printed out in large scale and asked questions about the history of use and the state of the forest fragments. The different intensities of use resulted in two main types of forest fragments classified here as "more used" (hereafter MU) and "less used" (hereafter LU) fragments. The MU fragments showed signs of more intense use, either current or historical, which included one or all of the following management signs: the presence of trails to move around the community, a higher frequency of livestock visitation, signs of selective harvesting of wood for fuel and other needs by community members, a higher density of pioneer herbaceous like grasses, and history of (and signs of) selective logging of large trees in the early 1900's, especially by logging companies.

Experimental design and data collection

Vegetation survey

From 3/2018 – 4/2019 I collected data on forest composition and structure of the regenerative and the adult strata in 48 plots (0.01ha each) distributed in 12 fragments (6 MU and 6 LU) located in six communities (PIN1,

[3] The group interviews were also used for introducing myself and my research to the community and for asking for their permission to collect data, in accordance with the UCSC IRB protocols.

PIN2, PIN3, PRU1, PRU2, PRU3) and two municipalities (Pinhão and Prudentópolis) (Figures 3.1 and 3.2). The four plots within a fragment were placed on the corners of a larger 50 x 50 m plot placed at a minimal distance of 20-30 m from the edge of a fragment (Figure 3.2). The total area sampled was 0.48 ha.

In each plot, I recorded all trees and shrubs taller than 1m and measured stems' height and DBH (diameter at breast height = 1.30 m). For individuals shorter than 1.30 m, I measured the diameter of the base of stems. All the individuals with DBH ≥ 5 cm were classified as adults and all individuals with DBH < 5cm were classified as regenerants. Plants were identified in the field when possible and with the help of taxonomists and by comparisons with herbaria specimens when needed. Vouchers of each specimen were deposited in the Herbarium of the Municipal Botanical Museum of Curitiba (MBM), the FLOR Herbarium of the Federal University of Santa Catarina (UFSC), and the herbarium of the Ethnobotany and Human Ecology Laboratory (ECOHE) of UFSC.

I also collected soil samples to control for soil parameters that could potentially influence forest composition and structure. The soil samples were collected at 0-20 cm depth using a soil probe and the physicochemical analysis were conducted by the soil analysis laboratory of the UNICENTRO university at Irati, Paraná. The parameters measured in these analyses were pH, K^+, Ca^{2+}, Mg^{2+}, $Ca^{2+}Mg^{2+}$, Al^{3+}, H^++Al^{3+}, OM, P, V%, coarse sand, fine sand, silt, and clay content. I run simple linear regressions using the function lm() on R to check which soil parameters varied across our 48 plots and found that OM, K^+,

Al^{3+}, pH, coarse sand and fine sand were the only parameters varying. I opted to keep OM (g/dm^3), pH, coarse and fine sand (g/100g) to use in my data analyses as OM content and soil acidity and texture can inform about past and current management practices and decisions. The OM was extracted using humid digestion, the pH was extract in $CaCl_2$ solution (1:2,5). All soil samples from all the 12 fragments were classified as having a clay soil texture, with clay content higher than or equal to 35%. Finally, I quantified livestock feces present in each plot to control for management parameters that could affect forest condition, such as the frequency of animals visiting a fragment and trampling and feeding on the natural regeneration. To estimate livestock feces, I subdivided each plot in four quadrats to facilitate the screening for feces and I used a score of 0-3 to quantify feces presence.

The governance score

The governance score was built using information from interviews that summarize conditions that facilitate collective action. The communities vary in a gradient that range between a more traditional institutional arrangement underlying forest governance and that is based on collective decisions and collective action to a more private-oriented institutional arrangement. The data for building this score was collected during group interviews in each of the six communities (n=6), semi-structure interviews with community leaders, also one per community (n=6), and informal interviews with key-informants from the communities, the state government, and from research centers in public universities. For the group interviews, I invited community members using a few strategies that included (1) going to their houses, introducing myself and the research and inviting them in person, (2) asking community members that I had already met to invite others, and (3) asking community leaders to invite people during their community meetings. The interviews followed the University of California Santa Cruz (UCSC) IRB requirements for this type of research, including proper informed consent. The interviews were built based on the forms developed by the International Forestry Resources and Institutions (IFRI 2016), which is a research network founded by Elinor Ostrom that investigate how governance arrangements shape forest outcomes.

Since my goal was to investigate the effect of the *faxinal* traditional governance on forest condition, I designed questions about management activities and decisions that have traditionally involved institutional arrangements supporting the collective action for managing common forest resources in the *faxinal*. Based on my interviews' data I came up with eight explanatory variables (Table 3.1) that I used to build the governance score: **(1) Open access forest** – this is a proxy for the absence of enclosure and tells if a community maintain open access to all forest fragments in a *faxinal* or if it has incorporated the enclosure of areas for private uses (e.g., bee keeping, monoculture agriculture, among others), **(2) Connection to the APF** (Association of the People of the Faxinal, for the acronym in Portuguese) – this variable tells if a community is connected to the social movement coordinated by the APF and that advocates for the maintenance of the collective action in the *faxinal*, **(3) Academia** – this measures whether a community participates in academic extension projects focused on reinforcing and protecting the collective action of the *faxinal* (e.g., projects that focus on informing communities about their legal rights regarding access to land and resources), **(4) ARESUR** (Special Area of Regulated Use, for the acronym in Portuguese) – whether a community is an ARESUR, which is a category of protected area created especially for the *faxinal* system and that focuses on preserving the traditional open-access use of the *faxinal* as this is regarded as a practice that promotes forest conservation, **(5) *Erva-mate* for income generation, (6) *Pinhão* for income generation**, **(7) *Erva-mate* for subsistence**, and **(8) *Pinhão* for subsistence**. The variables 5-8 tell whether communities still rely on the harvesting of *pinhão* and *erva-mate* for either or both subsistence and income generation and are activities that are related to the traditional use of the forest in a *faxinal* and based on collective action.

Table 3.1. The eight explanatory variables used to build the governance score (n=1-8) and that represent institutional arrangements that support the collective action for managing common forest in the *faxinal*. The governance score for each of the six communities (PIN1-3, PRU1-3) was calculated based on how many of these institutional arrangements were identified in a community.

Institutional arrangements that favor the traditional governance of forest fragments in the *faxinal*	**PIN1**	**PIN2**	**PIN3**	**PRU1**	**PRU2**	**PRU3**
Open access forest	1	0	1	0	0	0
Connection to APF	1	0	1	0	0	0
Academia	1	0	1	0	0	0
ARESUR	1	0	1	1	1	1
***Erva-mate* for income generation**	1	1	1	0	1	1
***Erva-mate* for subsistence**	1	0	1	0	1	1
***Pinhão* for income generation**	1	1	1	0	0	0
***Pinhão* for subsistence**	1	1	1	0	0	0
Total score	**8**	**3**	**8**	**1**	**3**	**3**

Data analyses

For conducting the data analysis, I partner with a researcher at the Human Ecology and Ethnobotany Lab (ECOHE) from the Federal University of Santa Catarina (UFSC). To test the hypothesis that traditional *faxinal* governance favors the maintenance of old-growth forest communities (H1), we measured old-growth forest in terms of total relative dominance (RDo) of late secondary species. Old-growth species presence in the AMF are described in the literature as indicators of forest naturalness (Oliveira and Vibrans 2020). To identify the late secondary species in my sample I consulted with specialists and conducted a literature review on the classification of the AMF species according to ecological groups (Dislich et al. 2001, Oliveira Filho et al. 2004, Lindenmaier and Budke

2006, Budke et al. 2008, Moro and Pereira 2010, Sühs and Budke 2011, Loregian et al. 2012, Meyer et al. 2013, Sawczuk et al. 2014, Maçaneiro et al. 2016, Hentz et al. 2017, Mazon et al. 2019, Vefago et al. 2019). To test the hypothesis that traditional *faxinal* governance favors forest resilience (H2), we measured resilience in terms of (a) total species richness (S), to look at the total portfolio of species available for forest maintenance, and (b) richness of the regenerants, to look at the total portfolio of species available for forest regeneration and maintenance.

We built mixed effects models with a Gaussian distribution using the RDo of late secondary species as a response variable to test the first hypothesis on old-growth forest (H1), and with a Poisson distribution using either total richness or the richness of the regenerants, as response variables to test the second hypothesis on forest resilience (H2). We treated governance score (gov), the soil parameters pH, OM, and coarse (c_sand) and fine sand (f_sand), as well as the variable feces as fixed effects. To account for my nested sampling design, we treated the two municipalities, six communities and 12 fragments as random effects terms (mun/com/fr_type) in all mixed effects models. Model selection was applied in the full model and based on the Akaike Information Criterion (AIC) (Zuur et al. 2009). Models were validated by a graphical analysis of randomized quantile residuals (Dunn and Smyth 1996, Gelman and Hill 2006). All explanatory variables were standardized using the z-score standardization method (Legendre and Legendre 2012).

Because there was an OM outlier value, we run models that include and that do not include this outlier for all response variables (i.e., total richness,

richness of the regenerants, and late secondary RDo). For models that did not include the outlier, the OM outlier value was replaced by an average value of all other three plots in the outlier fragment. We then proceeded with model competition using the R package MuMIn (Barton 2020) to select models with the AICc delta values ≤ 2 following the guidelines of the Grueber et al. (2011) and performed model averaging based on the AICc across all possible. We opted for this type of analyses to not discard a data value that could be a real number even if it is an outlier. In the results we are reporting (1) model average results with the outlier left in, and (2) model average results with all models with and without the outlier. For the RDo response variable there is no model averaging because there was only one model selected in the model competition. We assessed model performance through marginal and conditional R^2 for GLMM (Nakagawa and Schielzeth 2013). An example of the mixed model built is the following:

total_richness ~ gov + pH + feces + (1 | mun/com/fr_type)

We run a Permutational Multivariate Analysis of Variance (PERMANOVA) using community composition as a response variable to test my hypothesis that differences in intensity of use will result in differences in forest composition (H3). Analysis and partitioning sums of squares of the Bray-Curtis dissimilarities followed the algorithm proposed by Anderson (2001). Due to our nested design, 10000 permutations were restricted within each municipality. Prior to the analysis, the assumption of independence and homogeneity of multivariate dispersions within groups was tested and confirmed (F = 1.2168; Pr(>F) = 0.1786) using betadisper procedure (Oksanen et al. 2020). A Principal Coordinate Analysis (PCoA) was run to show a graphical visualization of the betadisper procedure. The Indicator Species Analysis (ISA) (Dufrene and Legendre 1997) was used to select most important species in each fragment and display in a PCoA ordination. After the PERMANOVA, a pairwise comparison test was applied to verify differences between pairs of fragments (Hervé 2021). To further explore the patterns found for the forest composition with the PERMANOVA analysis we calculated the Importance Value Index (IVI) for the adult and regenerant strata for both municipalities, Pinhão and Prudentópolis. The IVI is the average of relative tree species density, frequency, and dominance.

The IVI was calculated using Microsoft Excel. All other analyses were run in the R environment (R Core Team 2021) using the "vegan" and "labdsv" (Oksanen et al. 2020, Roberts 2019) packages for producing the ordinations, PERMANOVA and indicator species analysis, and "lme4", "lmerTest", and "MuMIn" (Barton 2020, Bates et al. 2015, Kuznetsova et al. 2017) for mixed effects models, and "DHARMa" for model validation (Hartig 2021).

RESULTS

Data overview

I recorded 3,131 individuals comprising 2,896 trees, 152 shrubs, 26 individuals that could not be distinguished between trees and shrubs, and 57 herbaceous. I identified a total of 142 species, 76 genera, and 41 families (one gymnosperm and 40 angiosperms) (Table S3.2). From the total individuals, 2,837 trees, 145 shrubs, and 56 herbaceous were identified to the species level accounting for 121, 14 and 7 species respectively. Thirty-eight individuals were identified to the genus level, with 30 trees accounting for 8 genera, 7 shrubs accounting for 6 genera, and one herbaceous accounting for one genus. There were also 18 individuals of trees and shrubs identified to the family level accounting for four families and 37 individuals of trees and shrubs that could not be identified. The most representative families and genera are summarized on table S3.3.

H1: Traditional *faxinal* governance favors the maintenance of old-growth forest communities (late secondary RDo)

For the model competition where the OM outlier was kept in the analysis, hereby OM1, the model best fitting differences in late secondary RDo in response to governance had coarse sand, fine sand, feces, governance, OM1, and soil pH (AICc = 432.6, weight = 0.675) as explanatory variables. For the model competition where the OM outlier was replaced by the averaged value for OM (i.e., average of the other three replicates/plots in the same fragment), hereby OM2, the model best fitting differences in late secondary RDo in response to governance had coarse sand, fine sand, feces, governance, OM2, and soil pH (AICc = 436.2, weight = 0.696) as explanatory variables. For the model competition including the two models described above, the model best fitting differences in late secondary RDo in response to governance had coarse sand, fine sand, feces, governance, OM1, and soil pH (AICc = 432.6, weight = 0.854) as explanatory variables. Because there was only one model selected, no model average was run in this case. The model selected showed an effect (negative relation) of OM1 ($p = 0.034$) on late secondary RDo, with a weaker effect of fine sand ($p = 0.142$), soil pH ($p = 0.356$), feces ($p = 0.466$), coarse sand ($p = 0.558$), and governance ($p = 0.986$). Even though all these other variables did not show significance, they were kept in the model because the model could only be validated when containing these variables. Fixed effects accounted for 16% of the differences in species richness (marginal $R^2 = 0.1641$), reaching 37% when considering both fixed and random effects (conditional $R^2 = 0.3718$). The model average importance value (Estimate) and the p-value for each explanatory variable included in the model are displayed on table 3.2.

H2: Traditional *faxinal* governance favors forest resilience (total richness and richness of the regenerants)

H2(A): Total species richness

For the model competition where the OM outlier was kept in analysis, the two models best fitting differences in total species richness in response to governance had (1) feces, governance, and soil pH (AICc = 297.2, weight = 0.498), and (2) governance and soil pH (AICc = 298.4, delta = 0.269) as explanatory variables. These two models were included in the final model average for the data with OM outlier kept in the analysis and that showed an effect of governance ($p = 0.009$) and soil pH ($p = 0.0006$) on total species richness, with a weaker effect of feces ($p = 0.0535$). The model average importance value (Estimate) and the p-value for each explanatory variable included in the model are displayed on table 3.2.

For the model competition where the OM outlier was replaced by the averaged value for OM (i.e., average of the other three replicates/plots in the same fragment), the three models best fitting differences in total species richness in response to governance had (1) feces, OM2, and soil pH (AICc = 296.3, weight = 0.437), (2) OM2, and soil pH (AICc = 297.1, weight = 0.281), and (3) feces, governance, OM2, and soil pH (AICc = 297.8, weight = 0.199) as explanatory variables.

For the model competition run with all the five models described above (i.e., the two models run with the OM1 and the three models run with the OM2), the four models best fitting differences in total species richness in response to governance had (1) feces, soil pH, and OM2 (AICc = 296.3, weight = 0.326), (2) soil pH and OM2 (AICc = 297.1, weight = 0.210), (3) feces, governance, and soil pH (AICc = 297.2, weight = 0.205), (4) feces, governance, soil pH, and OM2 (AICc = 297.8, weight = 0.148) as explanatory variables. All four models were included in the final model average that showed an effect of soil pH ($p = 0.0015$) and OM2 ($p = 0.0335$) on total species richness, with a weaker effect of feces ($p = 0.0616$) and governance ($p = 0.0865$). The model average importance value (Estimate) and the p-value for each explanatory variable included in the model are displayed on table 3.2.

The model best fitting differences in total species richness in response to governance with the OM outlier left in contained governance, feces, and soil pH as predictors with total richness showing positive relation (significant regression) with governance ($p = 0.0072$), and negative with soil pH ($p = 0.0005$) and feces ($p = 0.0466$). Fixed effects accounted for 42% of the differences in species richness (marginal $R^2 = 0.4274$), reaching 64% when considering both fixed and random effects (conditional $R^2 = 0.6497$). The model best fitting differences in total species richness in response to governance without the OM outlier contained soil pH, OM2, and feces as predictors with total richness showing positive relation (significant regression) with OM2 ($p = 0.0098$), and negative relation with soil pH ($p = 0.0019$) and feces ($p = 0.0574$). Fixed effects accounted for 40% of the differences in species richness (marginal $R^2 = 0.4094$), reaching 69% when considering both fixed and random effects (conditional $R^2 = 0.6946$). Figure 3.3 displayed the regressions for the best models with and without the OM outlier.

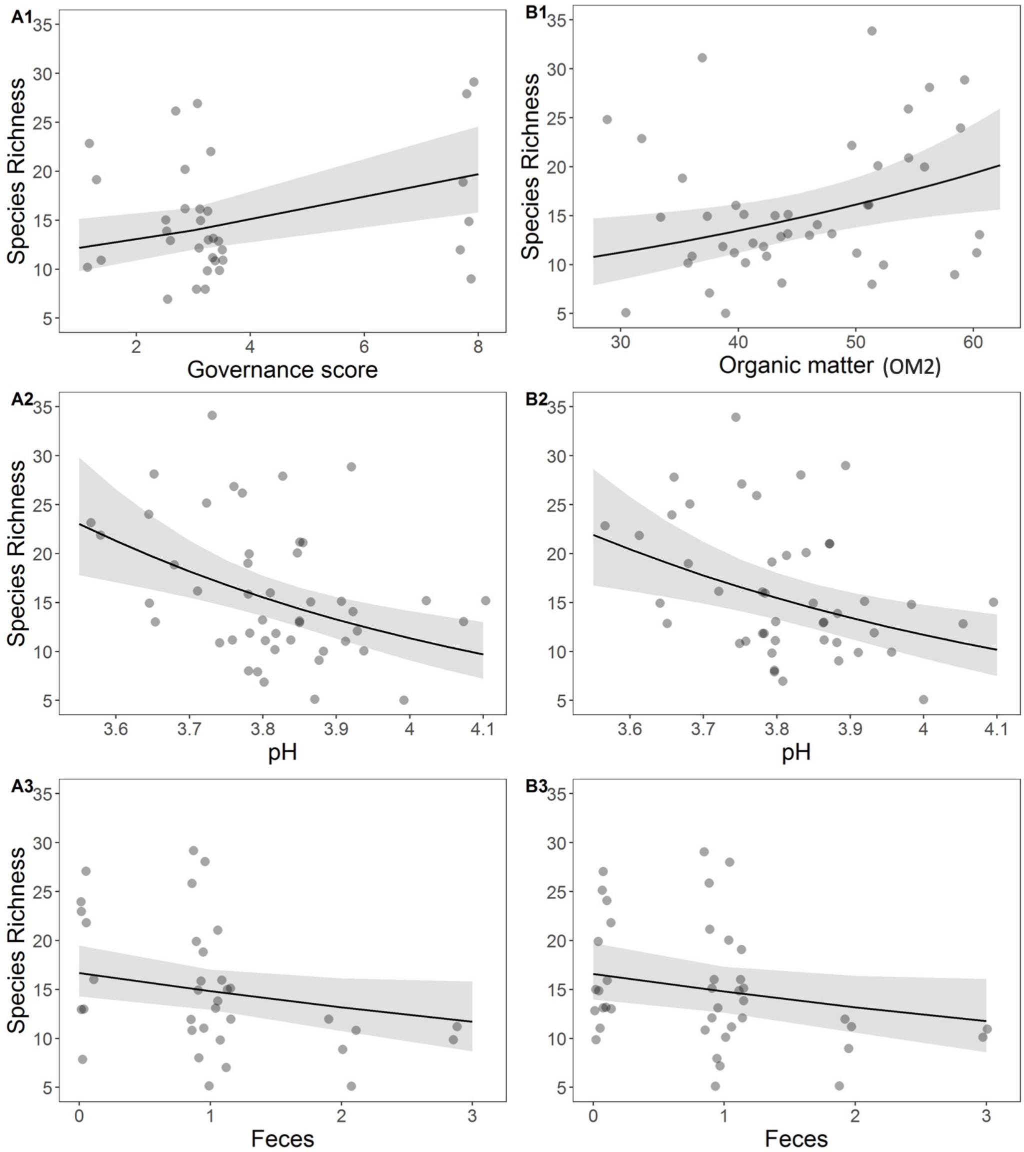

Figure 3.3. Graphs on the left are showing relationships between total species richness as a function of (A1) governance (p = 0.0072), (A2) soil pH (p = 0.0005), and (A3) feces (p = 0.0466), for the model best fitting differences in total species richness in response to governance with the OM outlier (marginal R^2 = 0.4274, conditional R^2 = 0.6497). Graphs on the right are showing relationships between total species richness as a function of (B1) organic matter without the outlier (OM2) (p = 0.0098), (B2) soil pH (p = 0.0019), and (B3) feces (p = 0.0574), for the model best fitting differences in total species richness in response to governance without the OM outlier (marginal R^2= 0.4094, conditional R^2 = 0.6946). All graphs show simple linear relationships between variables.

H2(B): Richness of the regenerants

For the model competition where the OM outlier was kept in, the three models best fitting differences in richness of the regenerants in response to governance had (1) governance and soil pH (AICc = 310.2, weight = 0.428), (2) feces, governance, and soil pH (AICc = 311.1, weight = 0.285), and (3) feces, governance, OM1, and soil pH (AICc = 311.5, weight = 0.224) as explanatory variables. These three models were included in the final model average that showed an effect of governance (p = 0.0374) and soil pH (p = 0.0007) on richness of the regenerants, with a weaker effect of feces (p = 0.1645) and OM1 (p = 0.1542). The model average importance value (Estimate) and the p-value for each explanatory variable included in the model are displayed on table 3.2.

For the model competition where the OM outlier was replaced by the averaged value for OM (i.e., average of the other three replicates/plots in the same fragment) the two models best fitting differences in richness of the regenerants in response to governance had (1) governance and soil pH (AICc = 310.2, weight = 0.488), and (2) feces, governance, and soil pH (AICc = 311.1, weight = 0.325) as explanatory variables.

For the model competition run with all the five models described above (i.e., the three models run with OM1 and the two models run with OM2), all models were selected as best fitting differences in richness of the regenerants in response to governance and had (1 and 2) governance and soil pH (AICc = 310.2, weight = 0.259), (3 and 4) governance, soil pH, and feces (AICc = 311.1, weight = 0.173), and (5) governance, soil pH, feces, and OM1 (AICc = 311.5, weight = 0.136) as explanatory variables. All these five models were included in the final model average that showed an effect of governance ($p = 0.0395$) and soil pH ($p = 0.0005$) on the richness of the regenerants, with a weaker effect of feces ($p = 0.169$) and OM1 ($p = 0.1542$). The model average importance value (Estimate) and the p-value for each explanatory variable included in the model are displayed on table 3.2.

The model best fitting differences in species richness of the regenerants in response to governance with the OM outlier left in contained governance and soil pH as predictors with richness of the regenerative showing positive relation (significant regression) with governance ($p = 0.0353$), and negative with soil pH ($p = 0.0001$). Fixed effects accounted for 29% of the differences in species richness (marginal $R^2 = 0.2939$), reaching 74% when considering both fixed and random effects (conditional $R^2 = 0.7402$). The model best fitting differences in species richness of the regenerants in response to governance without the OM outlier contained governance and soil pH as predictors with richness of the regenerative showing positive relation (significant regression) with governance ($p = 0.0353$), and negative relation with soil pH ($p = 0.0001$). Fixed effects accounted for 29% of the differences in species richness (marginal $R^2 = 0.2939$), reaching 74% when considering both fixed and random effects (conditional $R^2 = 0.7402$). Figure 3.4 displayed the regressions for the best models with and without the OM outlier.

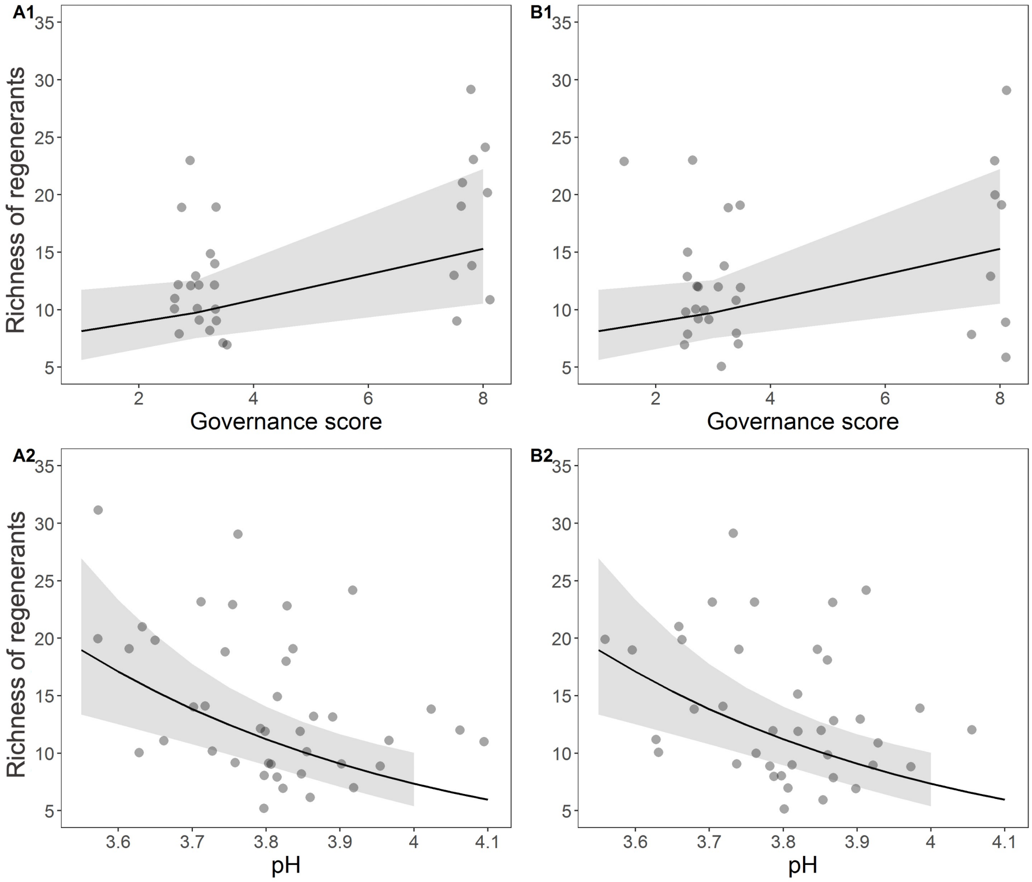

Figure 3.4. Graphs on the left are showing relationships between richness of regenerants as a function of (A1) governance (p = 0.0353) and (A2) soil pH (p = 0.0001), for the model best fitting differences in richness of regenerants in response to governance with the OM outlier (marginal R^2= 0.2939, conditional R^2 = 0.7402). Graphs on the right are showing relationships between richness of regenerants as a function of (B1) governance (p = 0.0353) and (B2) soil pH (p = 0.0001), for the model best fitting differences in richness of regenerants in response to governance without the OM outlier (marginal R^2= 0.2939, conditional R^2 = 0.7402). All graphs show simple linear relationships between variables.

Table 3.2. Summary of the results for the averaged models selected for each explanatory variable (i.e., total richness, richness of regenerants, late secondary RDo) and per averaged models (conditional average) with OM outlier and selected in the model competition and averaged models (conditional average) with and without the OM outlier and selected in the model competition.

Total richness				
Explanatory variables[1]	**Averaged models (conditional average) with OM outlier (and selected in the model competition**		**Averaged models (conditional average) with and without the OM outlier and selected in the model competition**	
	Estimate[2]	**Pr(>|z|)**	**Estimate**	**Pr(>|z|)**
pH	-0.19373	0.000547 ***	-0.17683	0.00145 **
OM			0.16491	0.03353 *
feces	-0.09376	0.053495 .	-0.09164	0.06160 .
governance	0.19130	0.008873 **	0.15433	0.08652 .

Richness of the regenerants				
Explanatory variables	**Averaged models (conditional average) with OM outlier (and selected in the model competition**		**Averaged models (conditional average) with and without the OM outlier and selected in the model competition**	
	Estimate	**Pr(>|z|)**	**Estimate**	**Pr(>|z|)**
pH	-0.23380	0.000685 ***	-0.23704	0.000517 ***
governance	0.24778	0.037381 *	0.24497	0.039473 *
OM	-0.10126	0.154220	-0.10126	0.154220
feces	-0.08060	0.164522	-0.07969	0.169030

Late secondary RDo		
	Model with OM outlier (best model across all models with and without the outlier)	
Explanatory variables	**Estimate**	**Pr(>|z|)**
OM	-11.0853	0.0341 *
fine sand	-9.0290	0.1420
pH	4.2965	0.3557
feces	2.8412	0.4656
coarse sand	3.1267	0.5585
governance	0.1199	0.9863

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

[1] All the explanatory variables included in the model runs.

[2] Model average importance value – this value is an indication across all averaged models of how much variation in the response variable is explained by each factor.

H3: Differences in intensity of use will result in differences in forest composition

PERMANOVA

The PERMANOVA analyses on the forest composition similarities between types of forest fragments (MU x LU) rejected the null hypothesis ($F = 4.209$, $p = 0.0048$) indicating that there is difference between the forest composition of the MU and LU fragments in each municipality. Pairwise comparisons showed differences among all four types of fragments, with the lowest p values for the comparisons between municipalities (Table 3.3). These differences between types of fragments and municipalities are displayed by the PCoA ordination (Figure 3.5). The ISA highlighted six indicator species for the municipality of Pinhão (*A. angustifolia*, *Eugenia handroana*, *I. paraguariensis*, *Myrceugenia myrcioides*, *Myrceugenia regnelliana*, and *Sapium glandulosum*) and five indicator species for the municipality of Prudentópolis (*Banara tomentosa*, *Campomanesia xanthocarpa*, *Casearia decandra*, *Casearia sylvestris*, and *Pouteria beaurepairei*). Table S3.4 displays the results of the ISA showing the most important species (IndVal (%) and p-values) in each fragment according to the combination of relative abundance and relative frequency. Table S3.5 gives the codes used for each species included in the analysis (e.g., ARA_ANG for *A. angustifolia*, ILE_PAR for *I. paraguariensis*, etc.)

Table 3.3. Results of the pairwise comparisons applied after running the PERMANOVA analysis to determine significant differences between the fragments.

	PIN_LU	PIN_MU	PRU_LU
PIN_MU	0.02556	-	-
PRU_LU	0.00015	0.00015	-
PRU_MU	0.00015	0.00015	0.03040

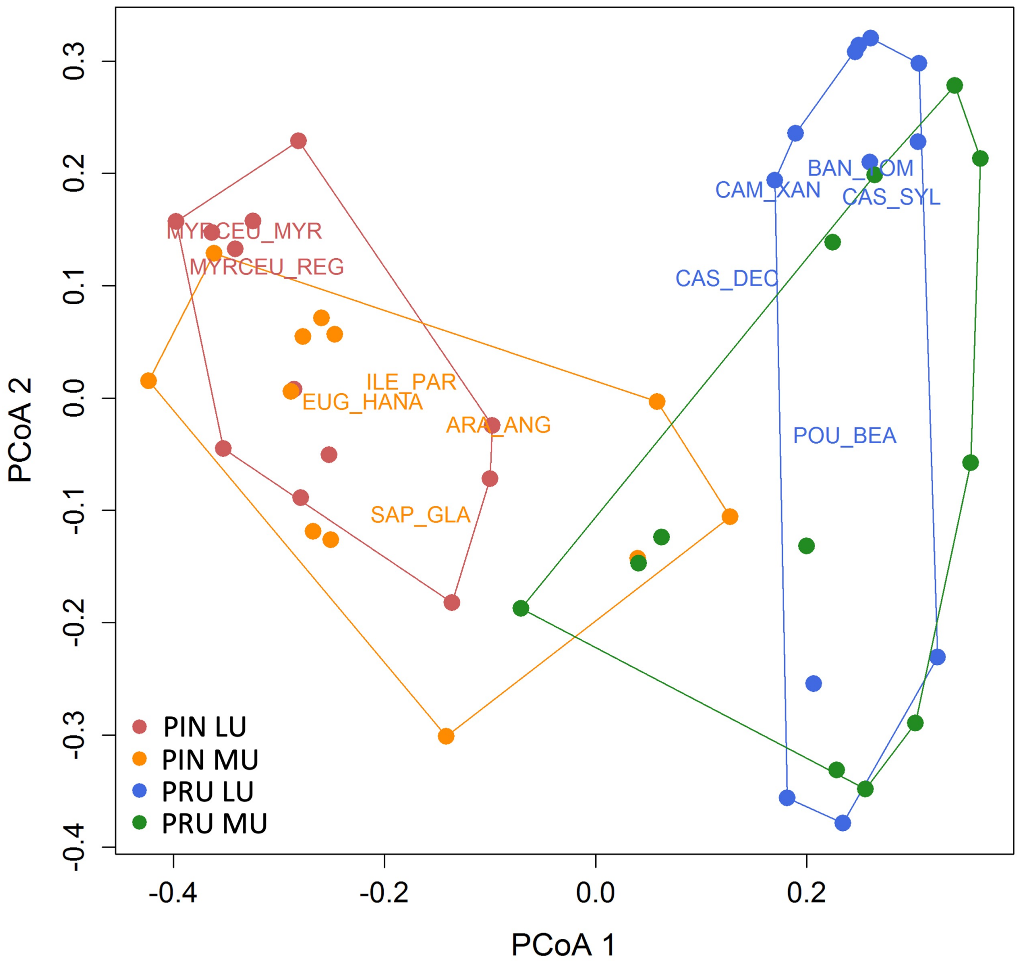

Figure 3.5. Principal Coordinate Analysis (PCoA) showing a graphical output of the betadisper procedure used to test the assumption of independence and homogeneity of multivariate dispersions. Only species with IndVal > 40% (metric of the ISA) were displayed in the graph.

Importance Index Value (IVI)

Most of the species with the highest IVIs for both the adult and regenerant strata for all communities sampled in Pinhão were late-secondary species. For Prudentópolis, most species with the highest IVIs for both the adult and regenerant strata for all communities were pioneer species. Like in the PERMANOVA, *A. angustifolia* and *I. paraguariensis* also ranked high in Pinhão in the IVI analysis, and not for Prudentópolis. *I. paraguariensis* ranked with sixth highest IVI in the adult (IVI = 12.27) and with third highest IVI in the regenerant strata (IVI = 12.28). *O. porosa* and *A. angustifolia* ranked first and third for the adult strata (IVI = 54.23, and IVI = 15.09, respectively) in Pinhão, but did not appear among the 15 species with the highest IVI neither in the Pinhão juvenile strata nor in either stratum for Prudentópolis. The IVI results for the fifteen species with the highest IVI for the adult and juvenile strata in Prudentópolis and Pinhão are displayed in Table S3.6-9.

DISCUSSION

Governance and soil pH were the two variables with an effect on both total richness and on richness of the regenerants across communities of *faxinal*, but not on late secondary species. The effect of governance was stronger on the regenerant strata and either keeping or removing the OM outlier from the model for this response variable did not change the effect of governance. On the other hand, removing the OM outlier from the total richness model strongly affected governance p-value and reduced largely the effect of this variable. Removing the OM outlier influenced the effect of the OM variable itself, with it not even being selected in the model when the outlier was kept in the analyses and showing an effect on total richness when the outlier was removed. The presence of feces, used as a proxy for the effect of the frequency of animal visitation in a fragment, showed to be important for total richness, but with marginal p-values. The only variable with an effect on the late secondary species RDo was OM.

The PERMANOVA showed a clear distinction between the forest composition in Prudentópolis and Pinhão, which was already expected as the AMF composition varies a lot across its geographical range with around 50% of its species showing a high rate of endemism (Jarenkow and Budke 2009). There was also an effect of differences in the LU and MU fragments on forest composition, meaning that the different management activities carried in these two types of fragments could be affecting forest composition at a more local scale. Both the ISA and IVI analyses showed the late secondary species *A. Angustifolia* and *O. porosa* as important species for *faxinais* in Pinhão. The IVI analyses further explored this data and showed that these species are more important in the adult strata of the forest fragments in Pinhão. The species *I. paraguariensis* also appeared as important in the ISA analyses for the fragments in Pinhão.

The results on governance and pH effect on total richness and the richness of the regenerants suggest that these variables are influencing the diversity and resilience of the future forest by affecting the species portfolio available to compose future forest. Soil pH had the strongest effect on diversity parameters suggesting that the variation found for the effect of governance is explained by environmental factors. In addition, these results coupled with the fact that OM was the only variable with an influence on late secondary species suggest that governance will have a stronger influence on the portfolio of species available in the regenerant strata, but once species are established, environmental factors will be the main drivers influencing which species will be more dominant as a forest fragment achieves old-growth status. Finally, it makes sense that governance will have a stronger effect on the regenerants as this is the age class that will respond more rapidly and directly to management decisions.

Some of the species that showed to be driving forest composition differences between municipalities are important either in terms of their ecological role and conservation status or in terms of their use as sources of food for the livestock or for income and subsistence related to the harvesting of NTFP. For example, *O. porosa* is an important old-growth species that is always associated with *A. angustifolia* in the AMF. These species together are described as defining species for the AMF (Oliveira and Vibrans 2020, Souza 2020), and their absence in forest fragments indicate that the AMF structure and composition in that region is compromised and rearranging into a different type of forest formation that no longer represents the AMF. Both species are highly threatened (Paraná 1995, MMA 2014) and the fact that they presented high values for IVI and ISA in Pinhão indicate that the communities of *faxinal* in this municipality have successfully promoted the conservation of the AMF in the region.

The entire AMF region went through a period of intense logging activity in the past century (Maack 1968, Lacerda 2016) and *A. angustifolia* and *O. porosa* were main targets of this activity. My data suggests that these historical deforestation patterns had different outcomes in the two municipalities included in this study. For instance, the communities of *faxinais* sampled in Pinhão have been involved in land disputes with a logging company for decades but have been able to secure their territories through all this time (Souza 2009, Ayoub 2013, Salles 2013, Correia and Gomes 2015, Ramos and Silva 2016). In this context, historically, the *faxinal* system in Pinhão has not only supported the livelihoods of local communities, but it has also physically blocked large-scale logging activity. In Prudentópolis, historical large-scale logging might have affected the AMF more intensely as *A. angustifolia* and *O. porosa* did not rank as important species for forest composition in this municipality. Also, the commodity agriculture-oriented land-use has advanced in communities of *faxinal* more intensely in Prudentópolis when compared to Pinhão, and that might have affected forest composition as well. For instance, tobacco is a major commodity grown in Prudentópolis and it requires the use of wood for the tobacco ovens. This activity had an impact in the AMF locally, as described by *faxinal* residents during informal interviews, because farmers would use native tree species for this activity. Nowadays, farmers are required to set an area aside to grow exotic trees (e.g., *Eucalyptus* sp.) that they can use for the tobacco ovens.

The *erva-mate* tree (*I. paraguariensis*) also ranked high in the ISA and IVI analyses in Pinhão. The IVI analysis ranked this is species higher in the regenerants strata (forest understory), which is the forest strata where the *erva-mate* is managed in the AMF both for income and subsistence. Different management systems for the *erva-mate*, with different outcomes in terms of how it affects forest structure, have been described in the literature on this species. The different cultural relations that farmers in Southern Brazil have built with this species translate into a diversity of management strategies that will shape different types of AMF landscapes (Marques 2014, Reis et al. 2018). The high IVI of this species in the understory could be indicating that forest fragments in the *faxinais* of Pinhão fall in the category of domesticated landscapes at a local scale (for more on domesticated landscapes see Wiersum 1996, Clement 1999), meaning that the management of a resource (*erva-mate*) influenced by cultural background has imprinted this forest fragments with human signature by affecting forest structure and composition (Reis et al. 2018). The AMF has been described in the literature as a domesticated landscape at the scale of its entire geographical range as researchers have demonstrated that Amerindian people actively influenced the increase in the abundance of the *A. angustifolia* and the expansion of the AMF in the last 2,000 years (Reis et al. 2014, Souza 2020). In this sense, the domestication of the AMF has been going on for thousands of years, with its forest structure and composition being affected by both ecological and social changes.

My data suggests that the current different needs and social dynamics in communities of Prudentópolis and Pinhão continue to shape the AMF locally. Even though the management practices that target the *erva*-mate in Pinhão might be contributing for the continued domestication of the AMF at the community scale, the AMF still maintains core characteristics in these communities as demonstrated by the ISA and IVI values for late secondary species that define the AMF. Thus, my data indicates that the *faxinal* traditional governance is favoring the conservation-by-use (Reis et al. 2018) of the AMF at a local scale. The fact that *O. porosa* is an important source of food for the pigs, as described in interviews, and that this species had the highest IVI for the adult stratum in Pinhão, is another piece of evidence from my data corroborating the conservation-by-use perspective for fragments in Pinhão. In this case, since this species' fruit is one of the main food resources consumed by the pigs (interview data), it is possible, for example, that the pigs are serving as seed dispersers for *O. porosa* at a local scale.

Finally, the intricated relationship between local communities of *faxinal* and the AMF structure, composition, and historical ecological dynamics, and the different management choices and paths followed by communities in different regions of the state of Paraná, should be taken into consideration by decision makers influencing policy for the conservation of the AMF in Paraná. Communities of *faxinal* have been securing forest cover in the region for over a century and that has been strongly influenced by how their cultural backgrounds are intertwined with their use of the forest. Overlooking this fact could have negative implications for both local livelihoods and the AMF itself.

CONCLUSION

Traditional governance has an imprint on forest diversity and resilience in the *faxinal* system and promotes the conservation of the AMF at a local scale. Also, the intricated relationship between these local communities and the AMF ecological dynamics are potentially promoting the continued domestication of the AMF landscapes that has been going on for thousands of years, as demonstrated by previous research. This evidence corroborates the idea that the AMF is a social-ecological system in which the human component not only relies on this forest for the maintenance of its livelihood, but also is one of the main components of this system responsible for the maintenance of the AMF in the region. These results have important implications for policy makers and government practitioners making decisions that affect the conservation of the AMF and the *faxinal* livelihood strategies. Thus, I recommend that this discussion is brought to the table to inform these decisions.

GENERAL CONCLUSION

The scale of analysis will influence the elements of a story on land-use and land-cover changes that we as scientists will reinforce and pay attention to. If my research had focused only on the spatial analysis presented on chapter 2, the details on coping strategies described on my first chapter and the imprint of local governance on the AMF fragments in communities of *faxinal* would have been dismissed from the whole story. If I had looked just at this spatial scale of land-use and land-cover changes in the region, perhaps my story would have highlighted the historical deforestation patterns both inside communities and in their surrounding areas. Perhaps I would have focused solely on this problem. Instead, I also brought to this dissertation plot the alternative paths, coping mechanisms, and the core institutional arrangements that work for forest conservation and that communities have been able to sustain over time, and how all this is translating into current forest condition and the condition of future forest. My work echoes what other scientists around the world working with human-environment interactions have been calling attention to for decades – the scale of analysis matter and contextual factors matter.

On a final note, one of the main criticisms to research projects that try to apply Ostrom's ideas on how to look for and analyze variables of interest in a social-ecological system is that, in general, researchers tend to focus mainly on inductive type of research, which is what I did on my first chapter. Even though this is a crucial component of this type of research, and it is important that people keep doing it, what is still lacking in the literature on social-ecological resilience is the deductive type of research, which is what I did in my second and third chapters. I went to the field and measured the outcomes for the ecological component of the social-ecological system that I studied and tested the influence of institutional arrangements and governance structures on these ecological outcomes. The approach I proposed and demonstrated in my dissertation research can now be taken by other colleagues to be improved and help keep advancing this area.

SUPPLEMENTAL MATERIAL

Figure S1.1. Picture taken with a drone and showing the overview of a community of *faxinal*. The main forested area is the collective area. Family's farm plots located outside of the collective area are visible on the slopes in the back of the picture. Photo credit: Mike Fox.

Figure S1.2. Pictures showing the landscape of different communities of *faxinal* in the state of Paraná, Brazil. Picture (a) shows a communal area used by a local family to feed pig herds, picture (b) portrays an overview of the communal area of the *faxinal* with both pasture and forested areas, picture (c) is showing the same area portrayed in picture (a), but through a different angle and where a pig herd from one family is feeding, picture (d) shows a common practice of the local herds, which by the end of the day gather in front of their owner's house waiting for them to open the gate. Photo credit: Flavia Oliveira (photos a, b, d), Iracema Correa dos Santos (photo c).

Table S1.1. Socio-economic descriptors that differentiate the two municipalities included in this study and the three communities sampled in each municipality (n=6) PIN1-3 and PRU1-3.

Table S3.1. Contextual characteristics and contrasting differences between the municipalities of Pinhão and Prudentópolis.

Table S3.2. Species and individuals count per family recorded in the 0.48 ha sampled in the six communities included in this study. Data is organized in order of the most to the least abundant family.

Table S3.3. The ten most representative families and genera identified among the 3,131 individuals sampled in the forest inventory.

Table S3.4. Results of the Indicator Species Analysis (ISA) showing the most important species (IndVal (%) and p-values) in each fragment according to the combination of relative abundance and relative frequency.

Table S3.5. Codes used to refer to each species in the PERMANOVA and ISA analyses.

Table S3.6. IVI results for the fifteen species with the highest IVI for the regenerant stratum (DAP < 5cm) in Prudentópolis.

Table S3.7. IVI results for the fifteen species with the highest IVI for the adult stratum (DAP ≥ 5cm) in Prudentópolis.

Table S3.8. IVI results for the fifteen species with the highest IVI for the regenerant stratum (DAP < 5cm) in Pinhão

Table S3.9. IVI results for the fifteen species with the highest IVI for the adult stratum (DAP ≥ 5cm) in Pinhão

Figure S1.1. Picture taken with a drone and showing the overview of a community of *faxinal*. The main forested area is the collective area. Family's farm plots located outside of the collective area are visible on the slopes in the back of the picture. Photo credit: Mike Fox.

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Table S1.1. Socio-economic descriptors that differentiate the two municipalities included in this study and the three communities sampled in each municipality (n=6) PIN1-3 and PRU1-3.

Socio-economic descriptors		
Municipalities	**Prudentópolis**	**Pinhão**
Area (km^2)	2,237	2,002
Population size (2021)	~52,776	~32,722
Population density (people/km^2)	21.14	15.09
HDI* (2010)	0.676	0.654
Communities' size (ha)	PRU1: 290 PRU2: 416 PRU3: 277	PIN1: 1,500 PIN2: 3,146 PIN3: 1,200
Communities' population density (families/km^2)	PRU1: 19 PRU2: 43.3 PRU3: 19.9	PIN1: 2 PIN2: 12.7 PIN3: 2.2
Communities' distance to closest urban area (km)	PRU1: 22 PRU2: 13 PRU3: 19	PIN1: 22 PIN2: 25 PIN3: 40

*HDI = Human Development Index

Table S3.1. Contextual characteristics and contrasting differences between the municipalities of Pinhão and Prudentópolis.

Socio-economic descriptors		
Municipalities	**Prudentópolis**	**Pinhão**
Area (km²)	2,237	2,002
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Communities' population density (families/km^2)	PRU1: 19 PRU2: 43.3 PRU3: 19.9	PIN1: 2 PIN2: 12.7 PIN3: 2.2
Communities' distance to closest urban area (km)	PRU1: 22 PRU2: 13 PRU3: 19	PIN1: 22 PIN2: 25 PIN3: 40

Biophysical descriptors		
Municipalities	**Prudentópolis**	**Pinhão**
Main soil types	Oxisols, Ultisols, Alfisols, Entisols	Inceptisols, Oxisols, Ultisols, Alfisols, Entisols
Mean annual temperature (°C)	18.4	17.2
Mean annual precipitation (mm)	1446	1999
Elevation (m)	840	1,048
Communities' Richness (S)	PRU1: 61 PRU2: 35 PRU3: 44	PIN1: 41 PIN2: 55 PIN3: 75
Communities' Shannon diversity index (H')	PRU1: 3.28 PRU2: 2.57 PRU3: 2.58	PIN1: 2.97 PIN2: 2.85 PIN3: 3.50

S3.2. Species and individuals count per family recorded in the 0.48 ha sampled in the six communities included in this study. Data is organized in order of the most to the least abundant family.

Life form*	Species	Family	Count (spp)	Count (ind.)
T	*Campomanesia* sp.	Myrtaceae	40	1064
T	*Calyptranthes concinna* DC.			
T	*Calyptranthes grandifolia* O.Berg			
T	*Campomanesia guaviroba* (DC.) Kiaersk.			
T	*Campomanesia guazumifolia* (Cambess.) O.Berg			
T	*Campomanesia xanthocarpa* (Mart.) O.Berg			
T	*Eugenia ternatifolia* Cambess.			
T	*Eugenia burkartiana* (D.Legrand) D.Legrand			
T	*Eugenia dodonaeifolia* Cambess.			
T	*Eugenia handroana* D.Legrand			
T	*Eugenia handroi* (Mattos) Mattos			
T	*Eugenia hiemalis* Cambess.			
T	*Eugenia involucrata* DC.			
T	*Eugenia blastantha* (O.Berg) D.Legrand			
T	*Eugenia neotristis* Sobral			
T	*Eugenia pluriflora* DC.			
T	*Eugenia pyriformis* Cambess.			
T	*Eugenia ramboi* D.Legrand			
T	*Eugenia subterminalis* DC.			
T	*Myrceugenia acutiflora* (Kiaersk.) D.Legrand & Kausel			

S3.2. Continued

Life form*	Species	Family	Count (spp)	Count (ind.)
T	*Myrceugenia alpigena* (DC.) Landrum			
T	*Myrceugenia campestris* (DC.) D.Legrand & Kausel			
T	*Myrceugenia euosma* (O.Berg) D.Legrand	Myrtaceae	40	1064
T	*Myrceugenia glaucescens* (Cambess.) D.Legrand & Kausel			
T	*Myrceugenia miersiana* (Gardner) D.Legrand & Kausel			
T	*Myrceugenia myrcioides* (Cambess.) O.Berg			
T	*Myrceugenia oxysepala* (Burret) D.Legrand & Kausel			
T	*Myrceugenia pilotantha* (Kiaersk.) Landrum			
T	*Myrcia guianensis* (Aubl.) DC.			
T	*Myrcia hartwegiana* (O.Berg) Kiaersk.			
T	*Myrcia hebepetala* DC.			
T	*Myrcia multiflora* (Lam.) DC.			
T	*Myrcia selloi* (Spreng.) N.Silveira			
T	*Myrcia splendens* (Sw.) DC.			
T	Myrtaceae 1			
T	Myrtaceae 2			
T	Myrtaceae 3			
T	Myrtaceae 4			
T	*Plinia rivularis* (Cambess.) Rotman			
S	*Myrceugenia ovata* var. *regnelliana* (O.Berg) Landrum			
T	*Aiouea amoena* (Nees & Mart.) R. Rohde	Lauraceae	11	124

S3.2. Continued

Life form*	Species	Family	Count (spp)	Count (ind.)
T	Lauraceae 1			
T	*Nectandra lanceolata* Nees & Mart.			
T	*Ocotea diospyrifolia* (Meisn.) Mez			
T	*Ocotea indecora* (Schott) Mez			
T	*Ocotea lancifolia* (Schott) Mez	Lauraceae	11	124
T	*Ocotea nutans* (Nees) Mez			
T	*Ocotea odorifera* (Vell.) Rohwer			
T	*Ocotea porosa* (Nees & Mart.) Barroso			
T	*Ocotea puberula* (Rich.) Nees			
T	*Ocotea silvestris* Vattimo			
N.I. (T or S)	Asteraceae 1	Asteraceae	11	18
T	*Vernonanthura discolor* (Spreng.) H.Rob.			
S	*Vernonanthura* sp.1			
S	*Vernonanthura* sp.2			
S	*Vernonanthura* sp.3			
S	*Baccharis oblongifolia* (Ruiz & Pav.) Pers.			
S	*Baccharis punctulata* DC.			
S	*Chromolaena pedunculosa* (Hook. & Arn.) R.M.King & H.Rob.			
S	*Chromolaena* sp.			
S	*Vernonanthura puberula* (Less.) H.Rob.			
S	*Vernonanthura westiniana* (Less.) H.Rob.			

S3.2. Continued

Life form*	Species	Family	Count (spp)	Count (ind.)
T	*Cestrum intermedium* Sendtn.	Solanaceae	11	22
T	*Solanum compressum* L.B. Sm. & Downs			
T	*Solanum mauritianum* Scop.			
T	*Solanum pabstii* L.B. Sm. & Downs			
T	*Solanum paranense* Dusén			
T	*Solanum sanctae-katharinae* Dunal			
S	*Capsicum baccatum* L.	Solanaceae	11	22
S	*Cestrum bracteatum* Link & Otto			
S	*Solanum ramulosum* Sendtn.			
N.I. (T or S)	Solanaceae 1			
T	*Brunfelsia pilosa* Plowman			
T	*Casearia* sp.	Salicaceae	9	728
T	*Banara parviflora* (A.Gray) Benth.			
T	*Banara tomentosa* Clos			
T	*Casearia decandra* Jacq.			
T	*Casearia lasiophylla* Eichler			
T	*Casearia obliqua* Spreng.			
T	*Casearia sylvestris* Sw.			
T	*Xylosma ciliatifolia* (Clos) Eichler			
T	*Xylosma pseudosalzmanii* Sleumer			
T	*Miconia cinerascens* Miq.	Melastomataceae	8	151

S3.2. Continued

Life form*	Species	Family	Count (spp)	Count (ind.)
T	*Miconia sellowiana* Naudin			
H	*Miconia alterninervia* (Cogn.) R. Goldenb.			
H	*Miconia australis* (Cham.) R. Goldenb.			
H	*Miconia ciliolata* (Cogn.) R. Goldenb.			
H	*Miconia hyemalis* A. St.-Hil. & Naudin			
H	*Acinodendron regnellii* (Cogn.) Kuntze	Melastomataceae	8	151
H	*Miconia sublanata* (Cogn.) R. Goldenb			
T	*Cordiera concolor* (Cham.) Kuntze	Rubiaceae	8	69
T	*Coussarea contracta* (Walp.) Benth. & Hook.f. ex Müll.Arg.			
T	*Psychotria carthagenensis* Jacq.	Rubiaceae	8	69
T	*Randia armata* (Sw.) DC.			
S	*Chiococca alba* (L.) Hitchc.			
S	*Psychotria leiocarpa* Cham. & Schltdl.			
S	*Psychotria suterella* Müll.Arg.			
S	*Rudgea parquioides* (Cham.) Müll.Arg.			
T	*Lonchocarpus* sp.	Fabaceae	8	20
T	*Calliandra foliolosa* Benth.			
T	*Dahlstedtia floribunda* (Vogel) M.J. Silva & A.M.G. Azevedo			
T	*Inga semialata* (Vell.) C.Mart.			
T	*Machaerium stipitatum* (DC.) Vogel			
T	*Myrocarpus frondosus* Allemao			
T	*Parapiptadenia rigida* (Benth.) Brenan			

S3.2. Continued

Life form*	Species	Family	Count (spp)	Count (ind.)
S	*Senegalia* sp.			
T	*Allophylus edulis* (A.St.-Hil., A.Juss. & Cambess.) Radlk.	Sapindaceae	5	136
T	*Allophylus guaraniticus* (A.St.-Hil.) Radlk.			
T	*Cupania vernalis* Cambess.			
T	*Diatenopteryx sorbifolia* Radlk.			
T	*Matayba elaeagnoides* Radlk.			
T	*Myrsine coriacea* (Sw.) R.Br. ex Roem. & Schult.	Primulaceae	5	54
T	*Myrsine gardneriana* A. DC.			
T	*Myrsine parvula* (Mez) Otegui			
T	*Myrsine* sp.			
T	*Myrsine umbellata* Mart.	Primulaceae	5	54
T	*Sebastiania commersoniana* (Baill.) L.B.Sm. & Downs	Euphorbiaceae	5	43
T	*Gymnanthes* sp.			
T	*Sapium glandulosum* (L.) Morong			
S	*Bernardia pulchella* (Baill.) Müll.Arg.			
S	*Bernardia* sp.			
T	*Ilex brevicusp*is Reissek	Aquifoliaceae	4	117
T	*Ilex integerrima* Reissek			
T	*Ilex paraguariensis* A.St.-Hil.			
T	*Ilex theezans* Mart.			
T	*Sloanea* sp.	Elaeocarpaceae	3	30
T	*Sloanea hirsuta* (Schott) Planch. ex Benth.			

S3.2. Continued

Life form*	Species	Family	Count (spp)	Count (ind.)
T	*Sloanea lasiocoma* K. Schum.			
T	*Mollinedia clavigera* Tul.	Monimiaceae	2	135
T	*Mollinedia elegans* Tul.			
T	*Chrysophyllum marginatum* (Hook. & Arn.) Radlk.	Sapotaceae	2	39
T	*Pouteria beaurepairei* (Glaz. & Raunk.) Baehni			
T (exotic)	*Citrus* sp.	Rutaceae	2	32
T	*Zanthoxylum rhoifolium* Lam.			
T	*Aegiphila integrifolia* (Jacq.) B.D.Jacks.	Lamiaceae	2	28
T	*Vitex megapotamica* (Spreng.) Moldenke			
T	*Lamanonia ternata* Vell.	Cunoniaceae	2	5
T	*Weinmannia paulliniifolia* Pohl			
T	*Rhamnus* sp.	Rhamnaceae	2	4
T	*Frangula sphaerosperma* (Sw.) Kartesz & Gandhi			
T	*Annona emarginata* (Schltdl.) H.Rainer	Annonaceae	1	74
T	*Drimys brasiliensis* Miers	Winteraceae	1	34
T	*Clethra scabra* Pers.	Clethraceae	1	24
T	*Araucaria angustifolia* (Bertol.) Kuntze	Araucariaceae	1	22
T	*Cinnamodendron dinisii* Schwacke	Canellaceae	1	22
T	*Luehea divaricata* Mart.	Malvaceae	1	21
H	*Lantana camara* L.	Verbenaceae	1	19
T	*Prunus myrtifolia* (L.) Urb.	Rosaceae	1	16
T	*Monteverdia evonymoides* (Reissek) Biral	Celastraceae	1	13

S3.2. Continued

Life form*	Species	Family	Count (spp)	Count (ind.)
T	*Strychnos brasiliensis* (Spreng.) Mart.	Loganiaceae	1	8
T	*Jacaranda puberula* Cham.	Bignoniaceae	1	7
T	*Picramnia excelsa* Kuhlm. ex Pirani	Picramniaceae	1	3
T	*Celtis iguanaea* (Jacq.) Sarg.	Cannabaceae	1	2
T	*Styrax leprosus* Hook. & Arn.	Styracaceae	1	2
T	*Syagrus romanzoffiana* (Cham.) Glassman	Arecaceae	1	1
T	*Cabralea canjerana* (Vell.) Mart.	Meliaceae	1	1
T	*Roupala montana* Aubl.	Proteaceae	1	1
T	*Meliosma sellowii* Urb.	Sabiaceae	1	1
T	*Symplocos tenuifoli*a Brand	Symplocaceae	1	1
T	*Gordonia fruticosa* (Schrad.) H.Keng	Theaceae	1	1
T	*Daphnopsis racemosa* Griseb.	Thymelaeaceae	1	1
H	*Boehmeria* sp.	Urticaceae	1	1

***Life form**: T = tree, S = shrub, H = herbaceous, N.I. = not identified.

S3.3. The ten most representative families and genera identified among the 3,131 individuals sampled in the forest inventory.

Ten most representative families	Number of species	Number of individuals
Myrtaceae	40	1064
Lauraceae	13	124
Asteraceae	11	18
Solanaceae	11	22
Salicaceae	9	728
Melastomataceae	8	151
Rubiaceae	8	69
Fabaceae	8	20
Sapindaceae	5	136
Primulaceae	5	54
Ten most representative genera	**Number of species**	**Number of individuals**
Eugenia sp.	13	212
Myrceugenia sp.	10	582
Miconia sp.	8	151
Ocotoea sp.	8	116
Myrcia sp.	6	88
Vernonanthura sp.	6	12
Solanum sp.	6	9
Casearia sp.	5	697
Myrsine sp.	5	54
Ilex sp.	4	117

Table S3.4. Results of the Indicator Species Analysis (ISA) showing the most important species (IndVal (%) and p-values) in each fragment according to the combination of relative abundance and relative frequency.

Species name	Fragment	IndVal (%)	p-value
M. myrcioides	PIN_LU	67.3	0.0001
M. regnelliana	PIN_LU	53.9	0.0003
M. coriacea	PIN_LU	29.2	0.0380
P. myrtifolia	PIN_LU	28.1	0.0417
R. parquioides	PIN_LU	31.3	0.0202
A. angustifolia	PIN_MU	44.3	0.0004
D. brasiliensis	PIN_MU	33.3	0.0297
E. handroana	PIN_MU	45.2	0.0015
I. paraguariensis	PIN_MU	39.7	0.0155
M. evonymoides	PIN_MU	28.2	0.0276
Myrtaceae 1	PIN_MU	25.0	0.0484
O. porosa	PIN_MU	32.7	0.0410
S. glandulosum	PIN_MU	40.0	0.0072
S. lasiocoma	PIN_MU	30.0	0.0267
A. integrifolia	PRU_LU	33.3	0.0097
A. edulis	PRU_LU	31.9	0.0375
B. tomentosa	PRU_LU	53.5	0.0003
C. xanthocarpa	PRU_LU	52.8	0.0026
C. decandra	PRU_LU	46.3	0.0078
C. sylvestris	PRU_LU	67.9	0.0001
O. nutans	PRU_LU	27.8	0.0360
P. beaurepairei	PRU_LU	46.1	0.0006
M. multiflora	PRU_MU	30.5	0.0131

Table S3.5. Codes used to refer to each species in the PERMANOVA and ISA analyses.

species code	species name
AEG_INT	*Aegiphila integrifolia*
AIO_AMO	*Aiouea amoena*
ALL_EDU	*Allophylus edulis*
ALL_GUA	*Allophylus guaraniticus*
ANN_EMA	*Annona emarginata*
ARA_ANG	*Araucaria angustifolia*
AST_1	Asteraceae 1
BAC_OBL	*Baccharis oblongifolia*
BAC_PUN	*Baccharis punctulata*
BAN_PAR	*Banara parviflora*
BAN_TOM	*Banara tomentosa*
BER_PUL	*Bernardia pulchella*
BER_sp	*Bernardia* sp.
BRU_PIL	*Brunfelsia pilosa*
CAB_CAN	*Cabralea canjerana*
CAL_FOL	*Calliandra foliolosa*
CALY_CON	*Calyptranthes concinna*
CALY_GRA	*Calyptranthes grandifolia*
CAM_GUAV	*Campomanesia guaviroba*
CAM_GUAZ	*Campomanesia guazumifolia*
CAM_sp	*Campomanesia* sp.
CAM_XAN	*Campomanesia xanthocarpa*
CAP_BAC	*Capsicum baccatum*
CAS_DEC	*Casearia decandra*
CAS_LAS	*Casearia lasiophylla*
CAS_OBL	*Casearia obliqua*
CAS_sp	*Casearia* sp.
CAS_SYL	*Casearia sylvestris*
CEL_IGU	*Celtis iguanaea*
CES_BRA	*Cestrum bracteatum*
CES_INT	*Cestrum intermedium*
CHI_ALB	*Chiococca alba*
CHRO_PED	*Chromolaena pedunculosa*
CHRO_sp	*Chromolaena* sp.
CHRY_MAR	*Chrysophyllum marginatum*
CIN_DIN	*Cinnamodendron dinisii*

S3.5. Continued

species code	species name
CLE_SCA	*Clethra scabra*
COR_CON	*Cordiera concolor*
COU_CON	*Coussarea contracta*
CUP_VER	*Cupania vernalis*
DAH_FLO	*Dahlstedtia floribunda*
DAP_RAC	*Daphnopsis racemosa*
DIA_SOR	*Diatenopteryx sorbifolia*
DRI_BRA	*Drimys brasiliensis*
EUG_BLA	*Eugenia blastantha*
EUG_BUR	*Eugenia burkartiana*
EUG_DOD	*Eugenia dodonaeifolia*
EUG_HANA	*Eugenia handroana*
EUG_HAOI	*Eugenia handroi*
EUG_HIE	*Eugenia hiemalis*
EUG_INV	*Eugenia involucrata*
EUG_NEO	*Eugenia neotristis*
EUG_PLU	*Eugenia pluriflora*
EUG_PYR	*Eugenia pyriformis*
EUG_RAM	*Eugenia ramboi*
EUG_SUB	*Eugenia subterminalis*
EUG_TER	*Eugenia ternatifolia*
FRA_SPH	*Frangula sphaerosperma*
GOR_FRU	*Gordonia fruticosa*
GYM_sp	*Gymnanthes* sp.
ILE_BRE	*Ilex brevicuspis*
ILE_INT	*Ilex integerrima*
ILE_PAR	*Ilex paraguariensis*
ILE_THE	*Ilex theezans*
ING_SEM	*Inga semialata*
JAC_PUB	*Jacaranda puberula*
LAM_TER	*Lamanonia ternata*
LAU_1	Lauraceae 1
LON_sp	*Lonchocarpus* sp.
LUE_DIV	*Luehea divaricata*
MAC_STI	*Machaerium stipitatum*
MAT_ELA	*Matayba elaeagnoides*
MEL_SEL	*Meliosma sellowii*
MIC_CIN	*Miconia cinerascens*
MIC_SEL	*Miconia sellowiana*

S3.5. Continued

species code	**species name**
MOL_CLA	*Mollinedia clavigera*
MOL_ELE	*Mollinedia elegans*
MON_EVO	*Monteverdia evonymoides*
MYRCEU_ACU	*Myrceugenia acutiflora*
MYRCEU_ALP	*Myrceugenia alpigena*
MYRCEU_CAM	*Myrceugenia campestris*
MYRCEU_EUO	*Myrceugenia euosma*
MYRCEU_GLA	*Myrceugenia glaucescens*
MYRCEU_MIE	*Myrceugenia miersiana*
MYRCEU_MYR	*Myrceugenia myrcioides*
MYRCEU_OXY	*Myrceugenia oxysepala*
MYRCEU_PIL	*Myrceugenia pilotantha*
MYRCEU_REG	*Myrceugenia ovata var. regnelliana*
MYR_GUI	*Myrcia guianensis*
MYR_HAR	*Myrcia hartwegiana*
MYR_HEB	*Myrcia hebepetala*
MYR_MUL	*Myrcia multiflora*
MYR_SEL	*Myrcia selloi*
MYR_SPL	*Myrcia splendens*
MYRO_FRON	*Myrocarpus frondosus*
MYRS_COR	*Myrsine coriacea*
MYRS_GAR	*Myrsine gardneriana*
MYRS_PAR	*Myrsine parvula*
MYRS_sp	*Myrsine* sp.
MYRS_UMB	*Myrsine umbellata*
MYRT_1	Myrtaceae 1
MYRT_2	Myrtaceae 2
MYRT_3	Myrtaceae 3
MYRT_4	Myrtaceae 4
NEC_LANCE	*Nectandra lanceolata*
OCO_DIO	*Ocotea diospyrifolia*
OCO_IND	*Ocotea indecora*
OCO_LAN	*Ocotea lancifolia*
OCO_NUT	*Ocotea nutans*
OCO_ODO	*Ocotea odorifera*
OCO_POR	*Ocotea porosa*
OCO_PUB	*Ocotea puberula*
OCO_SIL	*Ocotea silvestris*
PAR_RIG	*Parapiptadenia rigida*

S3.5. Continued

species code	**species name**
PIC_EXC	*Picramnia excelsa*
PLI_RIV	*Plinia rivularis*
POU_BEA	*Pouteria beaurepairei*
PRU_MYR	*Prunus myrtifolia*
PSY_CAR	*Psychotria carthagenensis*
PSY_LEI	*Psychotria leiocarpa*
PSY_SUT	*Psychotria suterella*
RAN_ARM	*Randia armata*
RHA_sp	*Rhamnus* sp.
ROU_MON	*Roupala montana*
RUD_PAR	*Rudgea parquioides*
SAP_GLA	*Sapium glandulosum*
SEB_COM	*Sebastiania commersoniana*
SEN_sp	*Senegalia* sp.
SLO_HIR	*Sloanea hirsuta*
SLO_LAS	*Sloanea lasiocoma*
SLO_sp	*Sloanea* sp.
SOL_1	Solanaceae 1
SOL_COM	*Solanum compressum*
SOL_MAU	*Solanum mauritianum*
SOL_PAB	*Solanum pabstii*
SOL_PAR	*Solanum paranense*
SOL_RAM	*Solanum ramulosum*
SOL_SAN	*Solanum sanctae-katharinae*
STR_BRA	*Strychnos brasiliensis*
STY_LEP	*Styrax leprosus*
SYA_ROM	*Syagrus romanzoffiana*
SYM_TEN	*Symplocos tenuifolia*
VER_DIS	*Vernonanthura discolor*
VER_PUB	*Vernonanthura puberula*
VER_sp1	*Vernonanthura* sp.1
VER_sp2	*Vernonanthura* sp.2
VER_sp3	*Vernonanthura* sp.3
VER_WES	*Vernonanthura westiniana*
VIT_MEG	*Vitex megapotamica*
WEI_PAU	*Weinmannia paulliniifolia*
XYL_CIL	*Xylosma ciliatifolia*
XYL_PSE	*Xylosma pseudosalzmanii*
ZAN_RHO	*Zanthoxylum rhoifolium*

Table S3.6. IVI results for the fifteen species with the highest IVI for the regenerant stratum (DAP < 5cm) in Prudentópolis

municipality	**species name**	**RD (%)**	**RF (%)**	**RDo (%)**	**IVI**
PRUDE	*C. sylvestris*	17.3160	7.5314	20.0395	44.8869
PRUDE	*C. decandra*	11.4719	7.1130	12.1674	30.7522
PRUDE	*C. obliqua*	9.1991	6.6946	7.9486	23.8423
PRUDE	*C. xanthocarpa*	5.4113	5.4393	7.6257	18.4763
PRUDE	*E. hiemalis*	3.8961	3.3473	7.6913	14.9347
PRUDE	*M. elaeagnoides*	4.8701	3.3473	4.8768	13.0942
PRUDE	*C. lasiophylla*	4.6537	3.7657	3.8930	12.3124
PRUDE	*M. cinerascens*	6.4935	2.0921	3.3722	11.9578
PRUDE	*A. emarginata*	3.8961	2.0921	4.2739	10.2620
PRUDE	*A. edulis*	2.1645	2.9289	2.4612	7.5545
PRUDE	*M. multiflora*	2.2727	1.6736	3.1982	7.1445
PRUDE	N.I.	1.6234	3.7657	1.2704	6.6595
PRUDE	*L. divaricata*	1.8398	2.9289	1.2694	6.0381
PRUDE	*V. megapotamica*	1.9481	1.6736	2.0018	5.6235
PRUDE	*P. beaurepairei*	1.1905	2.0921	2.2465	5.5290

Table S3.7. IVI results for the fifteen species with the highest IVI for the adult stratum (DAP ≥ 5cm) in Prudentópolis

municipality	**species name**	**RD (%)**	**RF (%)**	**RDo (%)**	**IVI**
PRUDE	*C. sylvestris*	17.7305	7.6923	6.4285	31.8513
PRUDE	*C. obliqua*	11.1111	8.8757	8.3983	28.3852
PRUDE	*M. elaeagnoides*	9.4563	5.3254	10.4638	25.2455
PRUDE	*C. xanthocarpa*	7.8014	5.9172	10.6668	24.3854
PRUDE	*C. decandra*	8.9835	11.2426	3.4079	23.6339
PRUDE	*P. beaurepairei*	6.3830	4.7337	7.3315	18.4482
PRUDE	*E. longipedunculata*	0.2364	0.5917	10.6220	11.4502
PRUDE	*E. hiemalis*	4.4917	4.1420	1.8248	10.4586
PRUDE	*C. dinisii*	3.5461	4.1420	2.5218	10.2099
PRUDE	*M. multiflora*	5.2009	2.3669	2.1417	9.7095
PRUDE	*O. nutans*	0.7092	1.7751	5.2319	7.7163
PRUDE	*A. angustifolia*	0.4728	1.1834	4.5620	6.2182
PRUDE	*A. edulis*	1.8913	3.5503	0.5577	5.9993
PRUDE	*V. megapotamica*	1.4184	1.7751	2.6479	5.8415
PRUDE	*M. miersiana*	1.4184	2.9586	1.0262	5.4032

Table S3.8. IVI results for the fifteen species with the highest IVI for the regenerant stratum (DAP < 5cm) in Pinhão

municipality	species name	RD (%)	RF (%)	RDo (%)	IVI
PIN	*M. myrcioides*	25.8982	4.7887	23.5402	54.2272
PIN	*M. regnelliana*	6.8114	2.5352	8.9555	18.3021
PIN	*I. paraguariensis*	4.5659	5.9155	7.8012	18.2825
PIN	*M. clavigera*	7.9341	2.8169	7.2366	17.9877
PIN	*C. decandra*	2.8443	4.7887	2.8390	10.4721
PIN	*M. cinerascens*	3.8922	4.2254	2.1358	10.2534
PIN	*A. emarginata*	2.2455	2.5352	4.9193	9.7001
PIN	*C. obliqua*	2.9940	3.3803	3.3083	9.6826
PIN	*C. concinna*	2.3952	2.8169	2.9642	8.1764
PIN	*M. miersiana*	2.2455	1.9718	3.7862	8.0036
PIN	*C. contracta*	2.8443	1.9718	1.9586	6.7747
PIN	*E. beaurepairiana*	1.8713	1.6901	2.4733	6.0347
PIN	*E. handroana*	1.7964	2.5352	1.3012	5.6328
PIN	*D. brasiliensis*	1.4222	2.2535	1.4277	5.1034
PIN	*Z. rhoifolium*	1.1228	3.0986	0.3604	4.5817

Table S3.9. IVI results for the fifteen species with the highest IVI for the adult stratum (DAP ≥ 5cm) in Pinhão

municipality	species name	RD (%)	RF (%)	RDo (%)	IVI
PIN	*O. porosa*	10.7417	7.1770	36.3100	54.2287
PIN	*C. decandra*	8.1841	5.2632	2.1688	15.6161
PIN	*A. angustifolia*	3.8363	5.2632	5.9937	15.0932
PIN	*C. obliqua*	6.1381	4.7847	3.2100	14.1328
PIN	*M. myrcioides*	7.1611	4.7847	1.5515	13.4973
PIN	*I. paraguariensis*	5.3708	5.7416	1.1621	12.2745
PIN	*M. pilotantha*	3.8363	1.4354	5.7057	10.9775
PIN	*M. clavigera*	5.3708	3.3493	0.8720	9.5921
PIN	*C. scabra*	3.8363	2.8708	2.1905	8.8977
PIN	*D. brasiliensis*	2.5575	3.8278	1.9470	8.3323
PIN	*M. regnelliana*	3.5806	1.9139	1.5740	7.0684
PIN	*C. xanthocarpa*	2.0460	2.8708	1.3918	6.3087
PIN	*S. glandulosum*	1.5345	2.8708	1.6406	6.0460
PIN	*M. miersiana*	2.3018	2.3923	0.7213	5.4154
PIN	*G. klotzschiana*	2.3018	0.9569	1.7559	5.0146

APPENDICES

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