land

MDPI

Article

Leveraging Traditional Agroforestry Practices to Support Sustainable and Agrobiodiverse Landscapes in Southern Brazil

André Eduardo Biscaia Lacerda [1], Ana Lúcia Hanisch [2] and Evelyn Roberta Nimmo [3,*]

[1] EMBRAPA Forestry, Colombo 83411-000, Brazil; andre.biscaia@embrapa.br
[2] EPAGRI Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina, Canoinhas 89466-500, Brazil; analucia@epagri.sc.gov.br
[3] Department of History, Universidade Estadual de Ponta Grossa, Ponta Grossa 84030-900, Brazil
* Correspondence: evelynnimmo@uepg.br; Tel.: +55-41-99211-0645

Received: 11 March 2020; Accepted: 28 May 2020; Published: 1 June 2020

check for updates

Abstract: Integrated landscape approaches have been identified as key to addressing competing social, ecological, economic, and political contexts and needs in landscapes as a means to improve and preserve agrobiodiversity. Despite the consistent calls to integrate traditional and local knowledge and a range of stakeholders in the process of developing integrated landscape approaches, there continues to be a disconnect between international agreements, national policies, and local grassroots initiatives. This case study explores an approach to address such challenges through true transdisciplinary and multi-stakeholder research and outreach to develop solutions for integrated landscapes that value and include the experience and knowledge of local communities and farmers. Working collaboratively with small-scale agroforestry farmers in Southern Brazil who continue to use traditional agroecological practices to produce erva-mate (*Ilex paraguariensis*), our transdisciplinary team is working to collect oral histories, document local ecological knowledge, and support farmer-led initiatives to address a range of issues, including profitability, productivity, and legal restrictions on forest use. By leveraging the knowledge across our network, we are developing and testing models to optimize and scale-out agroforestry and silvopastoral systems based on our partners' traditional practices, while also supporting the implementation of approaches that expand forest cover, increase biodiversity, protect and improve ecosystem services, and diversify the agricultural landscape. In so doing, we are developing a strong evidence base that can begin to challenge current environmental policies and commonly held misconceptions that threaten the continuation of traditional agroforestry practices, while also offering locally adapted and realistic models that can be used to diversify the agricultural landscape in Southern Brazil.

Keywords: yerba mate; agroforestry; integrated landscape; agrobiodiversity; silvopastoral systems

1. Introduction

Several high-level reports from a range of international agencies highlight the need to rethink conventional agricultural systems through innovative and sustainable approaches, including agroecology, forest landscape restoration, and agroforestry, among many others [1–6]. These reports emphasize that business as usual in terms of conventional agriculture is continuing to have lasting negative impacts on agricultural biodiversity, soil health, water and landscape management, greenhouse gas (GHG) emissions, and human health and food security. The United Nation Food and Agricultural Organization's (FAO) recent report on the state of the world's biodiversity for food and agriculture (BFA) argues that "many of the drivers that have negative impacts on BFA, including overexploitation, overharvesting, pollution, overuse of external inputs, and changes in land and water management, are at least partially caused by inappropriate agricultural practices" [2] (p. xxxviii). Meanwhile, Padoch and Sunderland [7] argue that using conventional practices and technologies for sustainable intensification may not necessarily have the desired effects on forest and biodiversity conservation, but rather lead to greater loss of forests and associated ecosystem services, with little or no benefits for some agricultural regions in which small-scale farming is predominant. They highlight that "producing food in diverse, multifunctional landscapes challenges dominant agricultural development paradigms, but it also presents issues and difficulties. For example, many types of integrated landscape approach have not been studied by scientists, and the existing research and policy framework may be insufficiently integrated to improve either agricultural production or environmental protection in such diverse landscapes" [7] (p. 6).

From a landscape ecology perspective, taking a holistic approach to land management planning and modeling is a key aspect of the discipline [8,9]. Understanding the mechanisms and impacts of land use and land cover change (LULCC) over time in farming regions, including forest fragmentation, habitat loss, and human–environment interactions, is crucial to determining the likely impacts of the continuation of conventional agriculture not only at the local scale, but also how this will affect rural and urban human and non-human populations in the long term. In order to support sustainable management and changes to land use and land cover (LULC) that focus on biodiversity conservation, increased ecosystem services and connectivity, as well as human food security and livelihoods, debates have focused on land sharing vs. land sparing as methods to address the competing needs in landscapes [7]. This debate either calls for land to be set aside for conservation with intensive agriculture conducted separately, or land to be shared across a range of goals from food production to biodiversity conservation through less intensive practices such as agroecology [10]. Although many involved in the debate acknowledge that both land set aside for conservation and alternative approaches to agriculture can occur simultaneously, there are few examples of how this might work on a practical level or how to scale up what works on individual farms to address issues of managing sustainable, biodiverse productive landscapes.

One of the methods used in landscape management planning that bridges the divide across the various competing social, ecological, economic, and political contexts and needs in landscapes are integrated landscape approaches. As defined by the Consultative Group on International Agricultural Research (CGIAR) [11], such approaches consider not only multiple land uses (including agriculture and forests) but also the livelihoods dependent on such land uses, moving beyond conventional perceptions of management and governance. It seeks "to provide tools and concepts to identify, understand and address a complex set of environmental, social and political challenges, and to enable evidence-based and inclusive prioritization, decision-making and implementation" [6] (p. 1). Importantly, such an approach highlights stakeholder engagement as key to managing conflicting perceptions of the value and function of land use types in a landscape across a range of scales, from the local to the national [6]. What is important here is that analyzing and developing solutions for integrated landscapes requires a truly transdisciplinary lens, in which a range of researchers and other stakeholders, including local communities and farmers, are actively engaged in the research design, data collection and analysis, implementation, and assessment.

Agroforestry systems have been identified as one of the key approaches that can be implemented in integrated landscape management as they offer a range of ecological and social benefits. As noted in the recent High Level Panel of Experts (HLPE) report, forests contribute extensively to food and nutritional security (FSN) through the "direct provision of food; provision of energy, especially for cooking; income generation and employment; and provision of ecosystem services that are essential for FSN, human health and well-being" [6]. Specifically, the implementation of agroforestry systems offers multifunctional landscapes that support the development of regenerative agricultural systems that offer not only a diverse, multi-layer food production system, but also land use that can restore or conserve ecological resources [12]. The International Union for Conservation of Nature (IUCN) together with the World Resources Institute (WRI) have highlighted agroforestry methods as an important strategy in forest landscape restoration (FLR) to address climate change mitigation and food security issues worldwide [4]. Research on the benefits of agroforestry systems and their ecological, social, economic, and cultural importance have been conducted in a range of contexts around the world (see for example [13,14]).

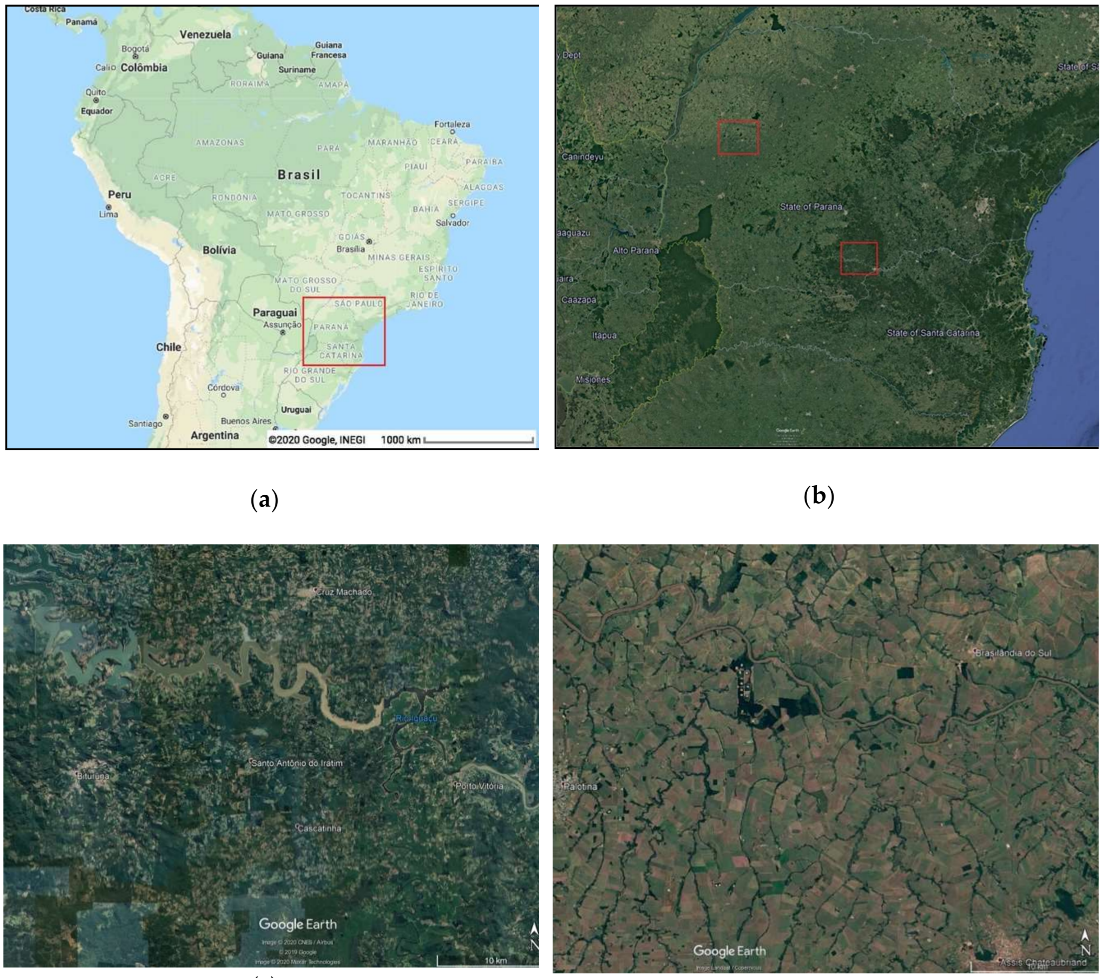
In Southern Brazil, previous research has shown that forest fragments, including those managed in agroforestry systems, are important havens of biodiversity on the landscape scale, particularly in terms of tree species [15–18], but also act as crucial connectivity corridors that enable genetic flows and buffer the impacts of anthropogenic activities along waterways [19]. Traditional agroforestry systems have continued in the central-south of Paraná state and Northern Santa Catarina state mainly due to the extraction of erva-mate (*Ilex paraguariensis*, also known as yerba mate), a tree species that grows well in the shaded understory of the region's iconic Araucaria Forest. These systems have been important in maintaining ecosystem services and biodiversity corridors, but they are also important to the maintenance of cultural and traditional agroecological practices on small-scale family farms that include a heterogenic mosaic of crops, livestock, vegetable gardens, and productive forest areas, all of which are essential to family and local food security [20].

We understand these traditional systems as outcomes of generations of adaptive practices based on local ecological knowledge (LEK), resource management techniques, and cultural and historic subjectivities [21]. We leverage the premise outlined by Berkes et al. [22] and Fonseca-Cepeda et al. [21] of traditional ecological knowledge (TEK), which Berkes [23] (p. 3) defined as "a cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment. Further, TEK is an attribute of societies with historical continuity in resource use practices." Although such a concept is often associated with indigenous knowledge paradigms, we consider how such an approach can apply to settler communities that have continual, historical resource use practices, as this knowledge is "cumulative and dynamic, builds on the experience of generations", but also adapts to new technological and socioeconomic realities [24] (p. 281). Nevertheless, these systems have received little research attention, particularly from federal and state agricultural research and outreach institutions, as they tend to be viewed as remnants of outdated, subsistence agricultural practices that require modernization, rather than being valued as systems developed and adapted to the forest environment in which they have continued for generations.

In this paper, we discuss some preliminary results of our ongoing participatory research and outreach project with small-scale traditional agroforestry producers in Southern Brazil and present models being developed to optimize and scale-out agroforestry systems based on our partners' traditional practices. Through the implementation of these models and systems, we are beginning to address some of the main concerns of small-scale farmers, mainly profitability, productivity, and legal restrictions on forest use, while also developing strategies that can be used in landscape management to expand forest cover, increase biodiversity, protect and improve ecosystem services, and diversify the agricultural landscape. Our collaborative approach ensures that the research addresses the needs of communities and is applicable to local realities. In so doing, we are developing a strong evidence base that can begin to challenge current environmental policies and commonly held misconceptions that threaten the continuation of traditional agroforestry practices.

2. Traditional Land Use and Conventional Agriculture

The land use legacy of Paraná state helps to clarify the current LULC in the region and how the continuation of forest resources in some regions has been more pronounced than others, as shown in Figure 1. At the beginning of the nineteenth century, most of Southern Brazil was covered by forests, from the coastal Atlantic Forest through to the sub-tropical Araucaria Forest biome on the central plateaus, and the tropical semi-deciduous forests of the Paraná River basin in the west. Although the forests had been managed by indigenous groups for thousands of years [25] and while there was continued indigenous and settler occupation of these forest landscapes from the sixteenth century [26], forest cover was relatively uniform, interspersed with the naturally occurring grasslands on the higher elevation plains. By the end of the eighteenth century, a process of westward colonization began in Paraná, and to some extent Santa Catarina state, originating from the coastal/eastern region and moving through the region's highlands. This colonization process was characterized by an economy based on cattle husbandry, erva-mate harvesting (a resource that had only recently begun to be exploited in the regional economy, despite its economic importance since early Spanish colonization in the seventeenth century [27]) and the logging of araucaria or Paraná pine (*Araucaria angustifolia*) [28]. More intense colonization did not happen until later, with a migratory influx of Germans, Italians, Poles, and Ukrainians, among others, in the nineteenth and early twentieth centuries, as part of a government policy to occupy the 'unoccupied' hinterlands of the country [29]. This second wave of migration, along with the expansion of the railroad and extensive exploitation of araucaria, led to much more intensive land occupation. Yet, in our study region, many settler communities maintained forest cover on their lands for animal husbandry and erva-mate harvesting, developing farming systems that integrated European and indigenous practices with local crops (corn, manioc, beans, etc.) and forests. Today, forests still occupy significant portions of the landscape, as shown in Figure 1c, in which small-scale farmers continue to use traditional practices that have been passed on for generations.



(**a**) (**b**)

(**c**) (**d**)

Figure 1. Forest and land use and land cover (LULC) in Paraná state as a result of differing land use legacies: (**a**) location of the region in Brazil; (**b**) Paraná state with northern and southern regions highlighted; (**c**) land use in southern region with a significant incidence of forest cover; (**d**) land use in northern region mostly covered by soy plantations.

In other areas of Paraná, where forest cover has been almost completely decimated, the process of colonization was much later and with quite a different focus. Beginning in the early to mid-twentieth century, the Southwest was occupied by colonization companies expanding from the southernmost state of Rio Grande do Sul; their economies were linked to a subsistence agriculture based on grains and pork husbandry. Finally, a colonization wave coming from the north (São Paulo state) in search of land for coffee production occupied the north of Paraná [29]. The vast majority of the area originally occupied by the colonization from São Paulo and Rio Grande do Sul is currently covered by large-scale soy farms, as shown in Figure 1d.

3. Methods to Leverage Traditional Agroforestry Practices

Our approach to implementing participatory methods to develop land management planning systems that integrate multiple uses of natural resources in a socially and politically complex context was conceptualized as Locally Adapted Participatory Sustainable Forest Management Systems—lapSFM, outlined by Lacerda et. Al [30]. This approach provides a roadmap for managing rural properties, focusing on forested lands, while the decision-making process includes local ecological knowledge (LEK) as a key input necessary for establishing the goals and objectives and is based on the demands and interests of landowners. As such, in 2011, we began by leveraging long-term agroecological initiatives in place for more than 30 years that involved key partners (Federation of Family Farmers' Unions—FETRAF; Agronomic Institute of Paraná—IAPAR; and the Brazilian Agricultural Research Company—EMBRAPA), and started to conceptualize these productive systems by consolidating communication, information, and activities among farmers, outreach technicians, researchers, and environmental agencies through workshops, field-days, social media, farmers' union meetings, and scientific conferences.

Beginning in 2017, we began a new phase of the project which focused on conducting oral history interviews with traditional erva-mate producers as a means of gaining a better understanding of the historical, social, and cultural aspects of traditional practices, how landscape and environmental changes are perceived by farmers, as well as the socio-political implications of their lived experiences [31]. As Williams and Riley [32] argue, oral history interviews provide an understanding of the ways in which people produce meaning of the places they inhabit, and how they perceive and value the natural world around them. As such, they offer unique perspectives on issues of the environment, forests, and conservation as narratives are situated within the environment in question, grounded in the everyday challenges of rural life. To date, we have conducted interviews with 39 erva-mate producers and members of their families across seven different municipalities in Paraná and Santa Catarina [33].

Across the range of participatory methods employed, participants were encouraged to discuss the challenges faced in conducting agroecological and traditional agroforestry practices on small-scale farms (economic, technical, social, and political) and possible solutions that included creation of co-ops, cooperative/participatory research to deal with gaps in scientific knowledge, youth-focused farming, and increased participation of women, among others. As a result, we have established action plans and models that integrate a range of perspectives and issues in terms of the technical, social, cultural, and economic.

Herein, we discuss two particular outcomes of project to date: optimized LEK-based agroforestry systems; and models of Productive Agroforestry Restoration. These optimized productive systems have been implemented at EMBRAPA Research Station in Caçador (ERSC) and in over 50 properties across more than 20 municipalities in Paraná, Santa Catarina, and Rio Grande do Sul states, for a total of 3000 hectares under management. Both lines of research seek to add value to these systems and the knowledge behind them, while also testing alternatives that do not require high rates of investment or debt, and may offer small-scale farmers the opportunity to transition some of their land from high-input commodities (i.e., corn, tobacco, soy) to other more sustainable products. The dissemination of results and co-creation of knowledge include technical and scientific documents [19,20,34–40], conferences e.g., [41], monthly technical visits to ERSC, and bi-monthly visits to farms across the region.

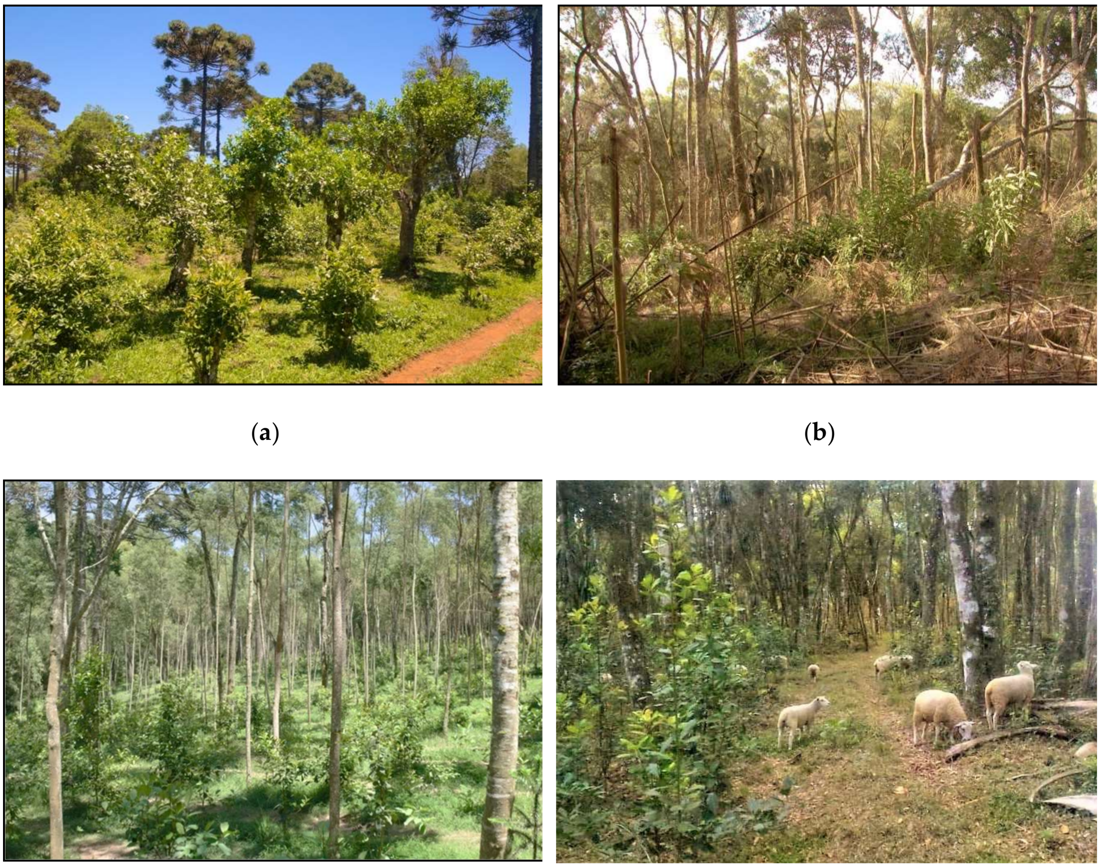
3.1. Traditional Agroforestry Optimization

The diversity of forest management systems based on the traditional use of erva-mate reflect the variations in the natural environmental that led to an extensive accumulation of LEK over generations. Forest structure, tree diversity, presence of dominant or invasive species, and land use history and legacy are all integral factors that play a role in the decision-making process related to how forests are managed for erva-mate production and have been described in depth by Mattos [42], Chaimsohn and Souza [18], Marques [43], and Hanisch [44]. In most cases, forest structure and diversity are gradually managed, aiming at a spatial distribution that favors an understory with a homogeneous light availability considered empirically as ideal for erva-mate development. The intensity and frequency of forest interventions depend on various factors that include forest development (successional stage), historic and contemporary use, presence of dominant or invasive species, and natural occurrence of erva-mate trees, among others. Despite the fact that traditional agroforestry systems in Southern Brazil in most cases have erva-mate as one of the key products, practices vary widely between properties and municipalities, with the presence of cattle husbandry as one of the most significant characteristics that differentiates the systems in the region [20].

3.1.1. Agrisilvicultural Systems

Erva-mate production occurs across a range of forest successional stages, from well-developed (late successional) forest stands relying mainly on native, naturally regenerating trees, to younger, secondary forests that rely more heavily on planting and silvicultural management. Well-developed forest stands typically have lower density (number of trees), higher diversity with long-living species (i.e., *Araucaria angustifolia* and *Ocotea porosa*), with a more complex structure (trees with various sizes distributed in forest layers), while younger forests commonly have a much simpler structure (homogeneous sizes), lower levels of diversity with short-lived species (i.e., *Mimosa scabrella*) but with much greater density. Research has shown that agroforestry systems with erva-mate in Southern Brazil present significant levels of tree diversity, with 107 tree species identified across 39 botanical families [18], which represent a significant proportion of the region's diversity [15]. They also show high levels of nutrient cycling through litter that far exceed the nutrient exportation that takes place during erva-mate harvesting [45].

In well-developed forests, erva-mate occurs naturally as large trees and is harvested through radical pruning in 2- to 4-year production cycles. Erva-mate can be also be planted and managed at shrub size for ease of harvesting, but production is often limited due to low levels of luminosity for plant development. Although well-developed forests are mostly found in an "open" state [43], in which historic management has reduced tree density, as shown in Figure 2a, some management is required to ensure optimal conditions for erva-mate growth. However, canopy management as a means to increase light in the understory is limited by very restrictive legislation governing the use of such forests (see the Brazilian Forest Code [46,47] and Atlantic Forest Law [48]). Consequently, production in well-developed forests tends to be restricted to animal husbandry with low stock density and naturally growing erva-mate plants. Contrastingly, younger forests tend to be more actively managed in Southern Brazil for erva-mate production. In most cases, the understory is maintained mostly clear in order to make space for erva-mate plants, while thinning is applied if insufficient light permeates the forest canopy. The intensity of thinning is established empirically and ranges widely from intense tree reduction where producers aim at production levels similar to monoculture stands, to agroecological practices that try to maintain sustainable multispecies environments.



(**a**) (**b**)

(**c**) (**d**)

Figure 2. Traditional agroforestry optimization: (**a**) traditional erva-mate production where the lack of adequate forest management caused canopy decline leading to monoculture-like erva-mate production; (**b**) understory management, with initial removal of invasive native bamboos, for production and species diversification; (**c**) induced forest regeneration for canopy restoration (white trunks), followed by erva-mate plantation (increased production) and diversified tree plantation (species and forest structure diversification); (**d**) sheep used for weed control in a newly implemented erva-mate intensification stand.

Our research on the management of young forests has led to the establishment of best practices that aim to achieve a more stable income while maintaining or increasing ecosystem diversity and complexity using innovative silvicultural treatments focused both on erva-mate plants and management of other forest elements [39]. In this method, erva-mate is harvested annually at much lower intensities (~50%) that maintain plant vigor as opposed to the 2- to 4-year cycles during which almost all plant foliage is removed, causing significant plant stress. Site-specific silviculture is used to define the plant's shape, height, and pruning, and regeneration tending. We introduced the use of spreaders (strings, bamboo) to widen erva-mate tree crowns into a goblet shape that allows for a greater production per plant compared to traditional growth based on a cluster of vertical branches growing from a main trunk (lower leaf-to-branch ratio). Furthermore, branches are trained away from the main vertical axis of the tree creating a sharp to near horizontal angle from which new sprouts can be harvested. Leaf harvesting from secondary branches instead of a radical pruning from the main trunk dramatically reduces the damage caused by water seepage that rots the trunk interior and often occurs after consecutive pruning, ultimately reducing the plant's life-span.

Additionally, areas where light is more available at the understory level will have plants pruned and harvested at 1–3m in height, whereas a darker understory will require taller trees (3–8m) to improve production. Similarly, spacing between trees will determine pruning methods: sparser plantations (e.g., 3 × 2 m) allows for shaping a much wider crown which in turn produces abundant foliage that can be harvested annually at less stressful levels (~50%).

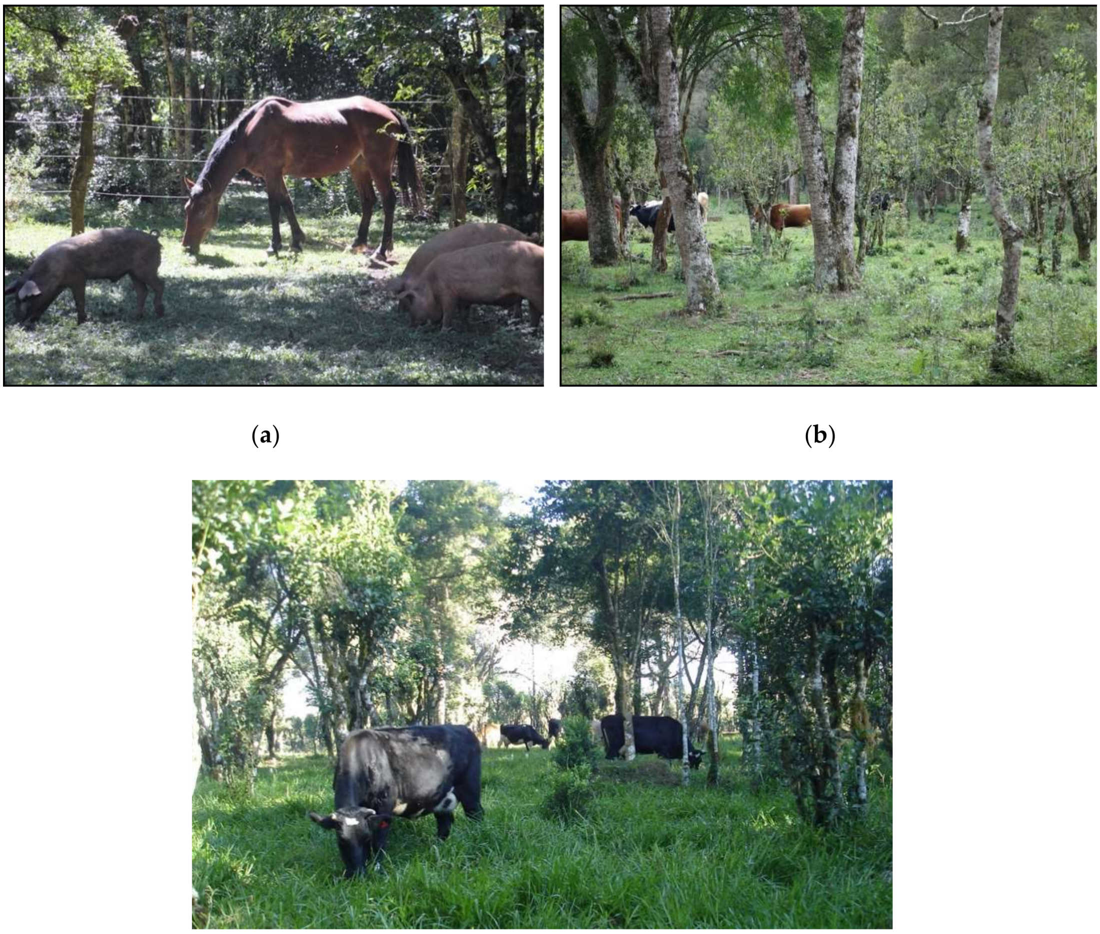
We also introduced practices to ensure forest regeneration for maintaining forest cover and diversity in the long term, avoiding the expensive and impractical need to reintroduce trees through seedling planting. Two simple methods were successfully tested [39] and currently applied in farms: (i) identification and marking of seedlings from natural regeneration using bamboo/wood sticks prior to weed trimming; (ii) defining areas in which weed trimming is not conducted—plots of 1 m^2 are marked using sticks where natural regeneration is protected and encouraged. Our results show that after one year, at least one native tree seedling was successfully recruited in 75% of these plots (reaching up to more than 20 recruits in a single plot). We recommend that such areas of regeneration are introduced together with the planting of erva-mate, replacing one erva-mate seedling every 5–9 m to support forest succession.

One of the opportunities identified through this research and by others [43] is the management of young forests in the region that are dominated by native invasive bamboo species, as shown in Figure 2b. Bamboos are a determinant factor in forest dynamics as they tend to impede the development of seedlings and young trees [37,49,50]. Our previous research has shown that these bamboo species, when dominant, create a simplified plant community in which succession is arrested [37,51] and an impractical environment for the development of productive systems. In terms of landscape management planning, the areas in which bamboo are dominant require practical management solutions that kick-start forest succession to improve biodiversity and maintain forest connectivity, but also offer benefits to property owners. In these areas, farmers can manage the understory, eliminating bamboo cover and establishing erva-mate plantations in densities varying from 1500 to 10,000 seedlings per hectare, as shown in Figure 2c. Again, farmer's objectives define specific practices: production maximization tends to lead to very dense plantations with the use of chemical fertilizers and pesticides (an illegal process as no pesticide is regulated for use with erva-mate) along with the removal of forest regeneration and continuous canopy thinning; whereas traditional and agroecological producers use organic (or no) fertilizers with forest management aiming at maintaining forest structure and diversity in the long term. Typically, the former produces more leaves per area, while the latter often obtains a premium for the quality of the product.

New techniques to improve traditional agroforestry practices are also incorporating farmer-led initiatives that have found innovative ways to optimize production and minimize environmental impacts. One very promising solution is the use of sheep husbandry for weed control in erva-mate plantations, as shown in Figure 2d. The introduction of the sheep breed "Texel" for controlling weeds reduces substantially the demand for labor, which is one of the most pressing limitations in farming today. One important characteristic of the Texel breed is the fact that they do not graze on erva-mate plants and have minimal impact on soil compaction. Finally, sheep farming can play an important role in food security for farmers and can be a smart solution to halt the current trend of using glyphosate herbicides for weed control. Such low-tech, practical approaches to optimizing production and reducing the use of chemical inputs can be scaled out from individual small-scale farms to create regional approaches and best practices that recognize and support the knowledge and participation of farmers, and in turn can have lasting impact on the forested landscape.

3.1.2. Silvopastoral Systems

The use of animal husbandry in traditional agroforestry in Southern Brazil has two main systems: *caívas* in North Santa Catarina state and *faxinais* in South Paraná state. *Faxinais* were once a common feature in the landscape in Paraná, where communities use a large forest area as a commons for animal husbandry, as shown in Figure 3a, and erva-mate harvesting, with a wide diversity of food crops (including corn, beans, manioc, and rice) in fenced fields protected from animal grazing [43]. These multifunctional land use systems were typical of the indigenous descendants that occupied the region and later assimilated by settler communities, especially Ukrainian and Polish immigrants. On the other hand, *caívas* are generally found in the Northern Plateau region of Santa Catarina on individual properties in which dairy cattle husbandry is carried out in forest patches usually combined with erva-mate production, as shown in Figure 3b [20].



(**a**) (**b**)

(**c**)

Figure 3. Traditional silvopastoral systems: (**a**) animal husbandry within forest stands in a *faxinal*; (**b**) *caíva* with low productivity pasture and senile erva-mate trees (small trees in the background, to the right); (**c**) view of a *caíva* with improved pasture.

The natural pasture in *caívas* typically has low levels of productivity, particularly in the winter when plant regrowth cannot keep up with grazing demands [44,52]. Thus, animal productivity is low, leading to food insecurity and low economic income and resilience. Undernourished animals have knock-on economic impacts on erva-mate production as they look for grazing alternatives and damage erva-mate trees or consume the leaves. Furthermore, environmental sustainability may also be affected because grazing on forest regeneration can compromise forest renovation and physical damage caused by bark consumption, which compromises tree health, ultimately reducing tree lifespan.

As farmers look for more profitable economic alternatives, *caívas* have been replaced by monoculture production based on forest plantations and commodity crops with direct loss of forest cover and biodiversity and traditional practices. As a response, a participatory research project carried out by EPAGRI, the Agricultural Research and Rural Outreach Company of Santa Catarina, and EMBRAPA has focused on developing strategies to increase household income by improving animal and erva-mate productivity while also maintaining or restoring forest structure and diversity [20,44,52]. The project framework includes testing innovative practices related to pasture improvement, renovation of forest stands and erva-mate trees, and defining ideal levels of canopy cover and regeneration management.

In 2010, EPAGRI initiated the implementation of improved practices for traditional *caívas* that include pasture overseeding during the winter that evolved into the development of the genetically improved *Axonopus catharinensis* SCS 315 (referred to locally as *missioneira-gigante* or giant missionary grass) [53], a pasture species that is better suited for *caíva* environments due to its tolerance to shade [44,54,55]. The process to implement this technique includes the removal of native grasses and the introduction of giant missionary grass (detailed information about the process can be found in [44]; Figure 3c). The improved *caíva* system has been implemented successfully in eight farms across four municipalities in Santa Catarina [44] and another ten properties will adopt the technology by the end of 2020; those farms will be used as reference properties for outreach agencies to disseminate the results.

Along with the goal of increasing animal productivity, the project also developed practices to improve erva-mate production. These include a set of activities aimed at creating a highly diverse, healthy forest with multi-aged and multi-strata elements. Due to years of neglect and prohibitive laws that severely restrict forest management, as noted above, most traditional *caívas* have inconsistent forest structure ranging from large, frequent gaps to very dense clusters of trees. Thus, we developed forest management guidelines to support forest restoration, canopy refinement, and erva-mate intensification. Forest restoration seeks to restore gaps in forest cover and reintroduce a multi-aged tree population which can be achieved by designating areas for restoration where animal grazing is temporarily restricted (usually by using electrical fencing) for 3–5 years, after which foraging is again allowed and a new area is fenced. Monitoring of these areas showed that regeneration was highly effective in restoring species diversity and structure as 59 different tree species were recorded in the fenced areas [56,57], which was greater than the diversity of the adult tree population. Additionally, we recommend thinning of abundant species and tree clusters in order to increase species diversity and establish a more even forest canopy, respectively. Simultaneously, in fenced areas, erva-mate can be planted at densities between 1000 and 3000 seedlings per hectare to increase productivity.

Through the implementation of the higher-productivity, shade-adapted perennial grass in *caívas*, farmers are producing five times more pasture per area, enabling a triplication in the stocking rate and consequent increases in milk production [43]. Furthermore, erva-mate production can increase tenfold depending of the level of degradation of the erva-mate trees. Finally, in order to monitor changes over time and help evaluate the impacts of new practices as they are implemented, we adapted the Sustainability Assessment of Food and Agriculture Systems (SAFA) developed by FAO [58] to assess the sustainability of farms considering 77 indicators across themes of environmental integrity, economic resilience, quality of life (social), and good governance [20]. The overall results showed that the implementation of the improved practices outlined above enabled farmers to obtain a ranking of good (based on a classification as unacceptable, limited, or good) for 87% of indicators, in comparison to 65% ranked as good for *caívas* that had not implemented improved practices.

As is the case in many other countries [7], current agricultural and environmental policies in Southern Brazil do not recognize traditional practices, as they are often excluded from scientific analyses or assessments and intensification through conventional agriculture is still seen as the way forward. As such, landscape policies and management strategies do not consider how traditional systems might be leveraged to mitigate the increasing homogeneity of the landscape through monoculture farming and the consequential impacts on human health and nutrition, biodiversity, gene flow, and ecosystem services. Without a recognition of, or support for, traditional systems, the tendency is for this local knowledge to be lost, along with the associated cultural identities and environmental subjectivities. Thus, analyses, participatory approaches, and farmer-led initiatives such as those we have outlined in this section that optimize traditional systems, provide the evidence base necessary for these practices to be integrated into policy and governance structures, which in turn can provide landscape managers with practical approaches that are culturally relevant and can be implemented across the landscape.

3.2. Productive Agroforestry Restoration

As noted above, Southern Brazil has been subjected to devastating rates of deforestation and forest fragmentation over the last century, as shown in Figure 1. While current policies have been essential in reducing rates of deforestation, they have been ineffective in reforesting already degraded ecosystems as legal restrictions severely limit the use of forested areas (Legal Reserves and Areas of Permanent Protection) on all rural properties [47]. These regulations have been difficult to implement as reforesting lands is viewed negatively by landowners as the assumption is that once the forest recovers, the land becomes worthless or untouchable. The question remains as to how to incentivize transformative changes to the landscape when the predominant perception is that monoculture crops, with inevitable forest loss and detriments to the agroecological landscape, produce higher yields?

Aiming at reintegrating degraded agroecosystems into ecologically and economically functional areas, we developed and implemented Productive Agroforestry Restoration models focusing on restoring degraded or underused agricultural land into a multispecies productive system maintained as a forested environment [40]. The goal is to allow for a variety of outputs that take advantage of the inherent spatial and temporal variations of the system and produce direct (e.g., crops) and indirect (e.g., ecosystem services) benefits. We designed Productive Agroforestry Restoration as a response to the need for innovative productive systems that can generate income and restore ecosystems for the benefit of rural communities and society in general, offering land management solutions that can be implemented across the region.

Thus, the process of developing Productive Agroforestry Restoration models began with the premise that any land to be restored or (re)integrated into a sustainable agroecosystem (namely agroforestry) should not only focus on the restoration of ecological attributes but also be integral to the socioeconomic reality of the farm; the system must be both ecologically and economically sustainable. In 2011, with financial support from the Brazilian National Council for Scientific and Technological Development (CNPq) and EMBRAPA, we began implementing a project to leverage LEK in order to optimize traditional management practices and create agroforestry models for restoration. In collaboration with farmers, we developed a comprehensive list of potential agroforestry systems and species that farmers would be interested in cultivating. From this, we collectively chose models that were deemed more feasible and implemented these models at the EMBRAPA Research Station in Caçador (ERSC) replicated across an area of 40 ha. The results [35,36,39,40] allowed us to expand the implementation of such models to more than 50 small-scale farms in the region. Importantly, we also integrated the needs and expectations of farmers as four key requirements of the models. Specifically, the models must be easy to understand and implement; fast, through the rapid (re-)establishment of a forest canopy by using fast-growing pioneer species; profitable, as investment should result in economic return; and flexible to regional characteristics, property, and goals. Implementation can take place at different places and scales in a property and be integrated into a landscape restoration program.

The species selection for Productive Agroforestry Restoration varies depending on the region in which it is implemented. Initially, a few key species should be identified in order to fulfill the need for rapid forest cover establishment and acting as a cash crop. In many tropical and subtropical regions, the use of native, fast-growing species from the legume family is highly recommended for their multiple benefits, which include use for firewood and lumber, rapid deposition of soil litter, and nitrogen fixation, among others [59,60]. As some fast-growing trees are short-lived, sometimes with cycles of less than 20 years, their replacement should be considered early in the management planning. On the other hand, cash crops should be based on long-lived species in order to create financial predictability. There is a myriad of species and combinations but the design of a system with initial complex arrangements should consider possible constraints, such as seed/seedling availability, potential market outlets, local labor capacity due to systems with higher management requirements, and lack of technical knowledge about the species and their interactions, among others. Thus, biological complexity and product variety is often better achieved after the establishment of an initial simple system.

Among the Productive Agroforestry Restoration systems implemented at the ERSC and currently being used in farms across Southern Brazil, the most successful was designed to be implemented in any region of the subtropical highlands of Southern Brazil and is based on two species: the fast-growing bracatinga (*Mimosa scabrella*) and erva-mate. While bracatinga is a legume pioneer tree that regenerates spontaneously in the region and is used for firewood and slab props, erva-mate is a shade tolerant low maintenance tree with a consolidated market.

This system was first used to restore a degraded agroecosystem that after several decades of high intensity commodity monoculture had extremely impoverished and compacted soil. Following the Productive Agroforestry Restoration model, we planted the fast-growing bracatinga in rows 6 m apart (1.5 m distance within rows; Figure 4a) that rapidly formed a forest canopy, as shown in Figure 4b. As a pioneer species, bracatinga is expected to very rapidly form a forest canopy as it reaches average heights of 2.8 m after one year, 6.8m by year two, and 9.5 by year three (at which point a forest environment is established), and 13.3 m by year four (diameter at breast height of 2.2, 7.6, 11, 13.3 cm, respectively) [36,61,62]. With ideal shaded conditions for erva-mate in place with the establishment of forest cover by year three, erva-mate seedlings are planted in double rows between bracatingas (~3000 plants per hectare), as shown in Figure 4c.

(**a**)

(**b**)

(**c**)

(**d**)

Figure 4. Productive Agroforestry Restoration carried out in a degraded agroecosystem: (**a**) initial planting of the fast-growing bracatinga for rapid canopy development (year 1); (**b**) developed canopy allowed for the plantation of erva-mate (year 3); (**c**) commercial maturity of erva-mate generates profitability for the system (year 8); (**d**) different methods of bracatinga harvesting: left—alternate full row removal for optimized financial return from lumber; right—in row-alternate tree girdling (trees with brown crowns) for subsequent harvesting to minimize environmental change.

Bracatinga demands yearly pruning until at least year three to obtain trees with higher market value (timber without knots) and high branching that does not disturb erva-mate cultivation [40], while erva-mate should be cultivated following the silvicultural practices developed described above. Combined with the planting of bracatinga, in the first two years we cultivated soy between rows which helped to ameliorate revenue/investment financial ratio during this period. Later, by year five, income was again generated through bracatinga thinning (at 50%) and finally at year eight, erva-mate harvesting reached commercial levels when the system become profitable, as shown in Figure 4c, with cost–benefit ratio varying between 2.0 and 2.6 with higher levels obtained when bracatinga is harvested for lumber [36,40].

The system presented offers an alternative for land restoration, but its elements are open to variation and diversification. As environmental conditions gradually improve over time, especially soil structure and fertility, with much lower levels of humidity and temperature fluctuations, other species can be integrated to the model, taking advantage of the horizontal and vertical space available, which includes vines, herbs, and shrubs for various uses (food, medicinal, handcraft, etc.). Importantly, landscape managers can support the use of these systems as a means to reforest Legal Reserves on rural properties, while remaining productive.

We are currently undergoing a comprehensive monitoring and modeling effort in order to quantify and qualify the socioeconomic benefits and improvement of environmental services provided by the practices discussed herein. Our initial results show extensive improvement in terms of forest species diversity, which increased from the initially two tree species planted to 40 species successfully recruited [39] in five years. Furthermore, the occurrence of vines, shrubs, herbs, and an abundant natural regeneration in a multi-strata forest seems to confirm the widely held assumption that species diversity is expected to increase with habitat complexity [63]. Moreover, those results contrast sharply with our control area (no intervention since 2010; unpublished data) in which no trees to date have managed to recruit. In terms of the land sparing approach, our results suggest that merely setting aside land for forest restoration and conservation may be insufficient. Our model does not have some of the common pitfalls of other restoration systems that focus solely on maximizing substrate stability or primary productivity, often resulting in arrested succession and demanding additional efforts to encourage successional change [64]. While detailed carbon monitoring is underway, we have already been able to estimate large-scale benefits of restoring riparian forests in the region [65], which can be used as a proxy to estimate the benefits of restoring degraded lands and forests.

4. Stakeholder Engagement and Current Challenges

The introduction of new technologies in traditional agroforestry systems help initiate a process of social, economic, and environmental transformation in family farming involved in the participatory research. Firstly, our focus on participatory research that values the knowledge of small-scale farming families has led to self-reflection and a growing self-awareness of the value of this knowledge and the associated environmental identities in wider socioenvironmental discourses, and also their rights as farmers and food producers. Our focus on documenting and sharing knowledge across institutional, class, and gendered divisions has enabled the creation of a knowledge network that has led to many new initiatives, ideas, and solidarities. We are in the process, for example, of supporting the development of a network of women farmers that will identify the needs and challenges women face in participating as active members of decision-making and knowledge sharing circles, not only on the farm, but in the wider context of agroecological production. Farm visits that bring together a variety of farmers, practitioners, and researchers have also shown to be fruitful in knowledge exchange across various spheres, leading to innovative management strategies for pruning and pest management, among many others. Our initiatives are also helping to consolidate our partner communities into a collective network with a stronger political voice. One major advancement has been the creation of a strategic council (*Observatório dos Sistemas Tradicionais e Agroecologicos da Erva-mate do Paraná*) for traditional and agroecological erva-mate production systems, spearheaded by the Public Prosecutor of Labor of

Paraná, which supports the continuation and expansion of these systems. This council brings together 27 organizations that are working together to bring greater awareness to the ecological and cultural value of traditional erva-mate production, while also incentivizing new products, markets, and other economic benefits.

In terms of economic impact, optimization strategies, such as those tested and implemented in the *caíva* systems, are showing promise in terms of improved incomes for farmers [20], while the models being tested at the ERSC have shown possibilities of economic returns in relatively short periods of time [40]. The restoration model is also being rolled out through partnerships with industry to better test these productive systems at a larger scale and gain more concrete insights into the economic capacities of these models. Part of our ongoing research is to determine the indirect environmental benefits of these agroforestry systems, particularly in terms of carbon capture, water quality, soil health, and biodiversity, as support for the development of payment for ecosystem services models. As noted above, traditional erva-mate agroforestry systems have been shown to have significant levels of tree biodiversity [18,40], and despite consistent cattle grazing for several generations, the tree regeneration potential of *caíva* systems has been shown to be quite strong, with significant levels of diversity in terms of regeneration in comparison to those found in the Santa Catarina Forest Inventory [44]. Clearly, these productive forest systems have substantial environmental resilience and offer compelling strategies that can be implemented across the region. Preliminary results on ecosystem services, as noted above, are also showing greater potential for total carbon and nitrogen capture in erva-mate agroforestry systems than in monoculture erva-mate production areas. Nevertheless, more detailed data is required to continue to inform policy and regulatory frameworks.

Despite the benefits, several challenges still face the continuation and expansion of traditional and agroecological systems in the region. Current legislation related to forest management, for example, severely restricts silvicultural practices on private properties, with relatively arbitrary quotas placed on the number of trees that can be removed from native forests, while regulations related to livestock grazing and production in silvopastoral systems remain unclear. Although current legislation has been important in stemming the devastating loss of forests that occurred throughout the twentieth century, small-scale farmers feel disproportionately affected by the regulations, which has led to mistrust on both sides of the issue [38]. The oral history interviews conducted as part of our research have clearly underscored how tensions between small-scale farmers and environmental agencies have led many farmers to question the continuation of these systems as the current impasse seems insurmountable [33]. Yet, through research and advocacy in collaboration with farmers, changes are taking place, with environmental agencies such as Paraná State Environmental Institute (IAP) and the federal Brazilian Institute of the Environment and Natural Resources (IBAMA) participating in recent events and outreach activities organized as part of this project, and in the *Observatório*. Promisingly, these agencies are looking to update regulations and change legal restrictions based on the current state of forests in Brazil, supported by the data and experiences projects such as ours are sharing.

Although changes are taking place within policy circles, one of the biggest challenges we face is the inherent bias not only against forests, as they continue to be viewed as useless, which is directly related to current legislation that prohibits use, but also the culture of agricultural research and outreach agencies that are very much focused on conventional agriculture and mechanization and/or modernization at the expense of traditional knowledge and practices. Agroecological or traditional farming practices are generally excluded from agronomy courses in universities and technical colleges, and as such, the majority of outreach workers have little experience engaging with these alternative approaches. Despite the myriad policies that have been enacted to support small-scale family farming and agroecology/organic production in Brazil (see [66,67]), these policies have not necessarily trickled down to have clear impacts on small-scale farming communities, while others have reinforced the dominant model of intensification based on monoculture commodity crops. Nevertheless, recent developments occurring through ongoing engagement with environmental agencies and other institutions are starting to show promising shifts in the top-down approaches to governance and agricultural outreach.

Despite national policy initiatives implemented in the last 10 years that have focused on drastically increasing the amount of data related to land use in Brazil (for example the Environmental Rural Registry (CAR) [47] and the National Forest Inventory [68]), federal and state land management planning is still in its infancy. One of the major challenges land management attempts face, however, stems from conflicting perceptions of productive land use. On one side, agriculture research and outreach agencies and large agrobusiness are pushing to modernize production through intensive, high-input monocultures, such as soy and corn. While these systems are seen as more productive, offering greater yields and thus higher income than traditional systems, there is a range of negative consequences including human health and food security, loss of farmer autonomy and increased debt, deforestation and loss of biodiversity and LEK, and impacts on water and nutrient cycles. On the other hand, environmental policies focus on protecting the remaining old growth forests and attempt to increase forest cover through restrictive laws that prohibit the use of forest resources, for example through Legal Reserves in which 20% of the property must be forested [47]. Furthermore, there remains an underlying assumption across both agriculture and environmental policy areas that native forests are not productive land, meaning either that the land must be deforested to become 'productive', or the burden of maintaining the land as forest (i.e., untouchable) falls on the landowner. This conflict is disproportionately felt by small-scale producers who use traditional agroforestry systems because it is exactly these farms that continue to maintain forest cover, which often extends well beyond the required 20%. Yet the law prohibits most types of forest management and agencies that monitor and inspect farms tend to administer fines with the onus on the landowner to prove they are within their legal limits, an unrealistic requirement for most small-scale farmers (for a full discussion, see [30]).

Our research is demonstrating that there is middle ground between these two competing land use perceptions that offer economic, cultural, and environmental benefits at both the local and regional scales. Implementing such models and practical approaches at the landscape scale can have dramatic impacts on the amount of land under forest cover, with the inherent returns of improved ecosystem services, biodiversity, and carbon sequestration. It can also bring about significant changes to the economic, cultural, and social value associated with forests and the products derived from them. By supporting and disseminating the knowledge, environmental subjectivities, and intangible heritage associated with traditional agroforestry systems, small-scale producers have an opportunity to create and capture niche markets that value ecologically and culturally significant products and processes. Thus, agroforestry systems using native species can be productive and economically, culturally, and environmentally viable, and through a transdisciplinary approach, land managers can work with traditional producers to develop best practices that can be implemented on farms across the region to have a real impact on sustainable land use on a larger scale.

5. Conclusions

The research presented herein demonstrates innovative approaches to documenting, valuing, and leveraging traditional agroforestry practices as a means to support diverse, resilient agroecological landscapes. While the focus of our research is on small-scale farms, the models we are testing show potential for scaling-out, offering promising alternatives that landscape managers can use to support sustainable land use and land cover change. The collaborative approach to research has been fundamental in this project as we are integrating and valuing different perceptions of agroecosystems and ensuring that communities are central to all aspects of the work, from defining research questions, to developing monitoring systems, and disseminating the results. Grassroots initiatives and locally adapted agroecological practices, such as those used in erva-mate agroforestry, are often ignored by research and government agencies, resulting in serious disconnect between overarching policy frameworks, such as the United Nations Sustainable Development Goals, and actual strategies that have the potential for transformational change at the landscape scale. Our work is attempting to bridge this divide by leveraging the knowledge and practices small-scale farmers have been developing for generations before they are lost to the dominant paradigm of conventional agriculture.

Author Contributions: The authors contributed to the development, implementation, analysis, and writing of this study as follows: conceptualization and methodology, A.E.B.L. and E.R.N.; formal analysis, A.L.H., A.E.B.L., and E.R.N; resources and funding, A.E.B.L. and E.R.N.; writing—original draft preparation, A.E.B.L. and E.R.N; writing—review and editing, E.R.N., A.L.H., and A.E.B.L.; project administration, A.E.B.L. and E.R.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by EMBRAPA, grant number (16.16.05.002.00.00), EPAGRI, Programa SC Rural of the Government of the State of Santa Catarina, Social Sciences and Humanities Research Council of Canada, FLEdGE Partnership Grant, and Wilfrid Laurier University's Centre for Sustainable Food Systems. ERN was supported PNPD/CAPES.

Acknowledgments: The authors are sincerely grateful to the farmers and their families who have shared their stories with us. Particularly we thank Maria Izabel Radomski, Ednilson Pereira Gomes, Demerval Pessin de Farias, Bernardo Vergopolen, Carlos Urio, Arnaldo Soares, João F.M.M. Nogueira, Ricardo Gomes Luiz, Alessandra I. de Carvalho, and Robson Laverdi.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Food and Agriculture Organization; Information Intergovernmental Technical Panel on Soils. *Status of the World's Soil Resources—Main Report*; Food and Agriculture Organization of the United Nations; Intergovernmental Technical Panel on Soils: Rome, Italy, 2015.
2. Food and Agriculture Organization. *The State of the World's Biodiversity for Food and Agriculture: A Call to Action?* Bélanger, J., Pilling, D., Eds.; FAO Commission on Genetic Resources for Food and Agriculture Assessments: Rome, Italy, 2019.
3. Food and Agriculture Organization. *Catalysing Dialogue and Cooperation to Scale up Agroecology: Outcomes of the FAO Regional Seminars on Agroecology*; FAO: Rome, Italy, 2018.
4. The International Union for Conservation of Nature; World Resources Institute. *A Guide to the Restoration Opportunities Assessment Methodology (ROAM): Assessing Forest Landscape Restoration Opportunities at the National or Sub-National Level*; IUCN: Gland, Switzerland, 2014.
5. Intergovernmental Panel on Climate Change; Summary for Policymakers. *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*; Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H.-O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., van Diemen, R., et al., Eds.; IPCC: Geneva, Switzerland, 2019.
6. High Level Panel of Experts. *Sustainabile Forestry for Food Security and Nutrition*; A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security; HLPE: Rome, Italy, 2017.
7. Padoch, C.; Sunderland, T. Managing landscapes for greater food security and improved livelihoods. *Unasylva* **2013**, *64*, 3–13.
8. Hobbs, R.; Wu, J. Perspectives and prospects of landscape ecology. In *Key Topics in Landscape Ecology*; Wu, J., Hobbs, R., Eds.; Cambridge University Press: Cambridge, UK, 2006.
9. Naveh, Z.; Lieberman, A.S. *Landscape Ecology: Theory and Application*, 2nd ed.; Springer Science Business Media: New York, NY, USA, 1994.
10. Fischer, J.; Abson, D.J.; Butsic, V.; Chappell, M.J.; Ekroos, J.; Hanspach, J.; Kuemmerle, T.; Smith, H.G.; von Wehrden, H. Land sparing versus land sharing: Moving forward. *Conserv. Lett.* **2014**, *7*, 149–157. [CrossRef]
11. Free Trade Agreement; Consultative Group for International Agricultural. *Research Program on Forests, Trees and Agroforestry: Landscape Approaches to Tackle Climate Change, and Achieve Sustainable Development and Food Security*; CGIAR: Bogor, Indonesia, 2017.
12. Elevitch, C.R.; Mazaroli, N.D.; Ragone, D. Agroforestry standards for regenerative agriculture. *Sustainability* **2018**, *10*, 3337. [CrossRef]
13. Food and Agriculture Organization; Convention on Biological Diversity. *Mainstreaming Ecosystem Services and Biodiversity into Agricultural Production and Management in East Africa*; Food and Agriculture Organization of the United Nations (FAO); Secretariat of the Convention of Biological Diversity: Rome, Italy, 2016.

14. Kumar, C.; Begeladze, S.; Calmon, M.; Saint-Laurant, C. *Enhancing Food Security Through Forest Landscape Restoration: Lessons from Burkina Faso, Brazil, Guatemala, Viet Nam, Ghana, Ethiopia and Philippines*; Kumar, C., Begeladze, S., Calmon, M., Saint-Laurant, C., Eds.; IUCN: Gland, Switzerland, 2015.
15. Vibrans, A.C.; Sevegnani, L.; de Gasper, A.L.; Lingner, D.V. *Diversidade e Conservação dos Remanescentes Florestais*; Edifurb: Blumenau, Brazil, 2012.
16. Vibrans, A.C.; Sevegnani, L.; de Gasper, A.L.; Lingner, D.V. *Floresta Ombrófila Mista*; Edifurb: Blumenau, Brazil, 2013.
17. Hanisch, A.L.; Vogt, G.A.; Marques, A.D.C.; Bona, L.C.; Bosse, D.D. Estrutura e composição florística de cinco áreas de caíva no planalto norte de Santa Catarina. *Pesqui. Florest. Bras.* **2010**, *30*, 303–310. [CrossRef]
18. Chaimsohn, F.P.; de Souza, A.M. *Sistemas de Produção Tradicionais e Agroflorestais de Erva-Mate no Centro-Sul do Paraná e Norte Catarinense*; Chaimsohn, F.P., de Souza, A.M., Eds.; IAPAR: Ponta Grossa, Brazil, 2013.
19. Lacerda, A.E.B. Conservation strategies for Araucaria Forests in Southern Brazil: Assessing current and alternative approaches. *Biotropica* **2016**, *48*, 537–544. [CrossRef]
20. Hanisch, A.L.; Negrelle, R.R.B.; Bonatto, R.A.; Nimmo, E.R.; Lacerda, A.E.B. Evaluating Sustainability in Traditional Silvopastoral Systems (caívas): Looking Beyond the Impact of Animals on Biodiversity. *Sustainability* **2019**, *11*, 3098. [CrossRef]
21. Fonseca-Cepeda, V.; Julián Idrobo, C.; Restrepo, S. The changing chagras: Traditional ecological knowledge transformations in the Colombian amazon. *Ecol. Soc.* **2019**, *24*, 8. [CrossRef]
22. Berkes, F.; Colding, J.; Folke, C. Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecol. Appl.* **2000**, *10*, 1251–1262. [CrossRef]
23. Berkes, F. Traditional Ecological Knowledge in Perspective. In *Traditional Ecological Knowledge: Concepts and Cases*; Inglis, J.T., Ed.; International Program on Traditional Ecological Knowledge; International Development Research Centre: Ottawa, ON, Canada, 1993; pp. 1–10.
24. Stevenson, M.G. Indigenous knowledge in environmental assessment. *Arctic* **1996**, *49*, 278–291. [CrossRef]
25. Bonomo, M.; Costa Angrizani, R.; Apolinaire, E.; Noelli, F.S. A model for the guaraní expansion in the La Plata Basin and littoral zone of southern Brazil. *Quat. Int.* **2015**, *356*, 54–73. [CrossRef]
26. Noelli, F.S. A Ocupação Humana na Região Sul do Brasil: Debates e perspectivas 1872–2000. *Rev. USP* **2000**, *44*, 218–269. [CrossRef]
27. Nimmo, E.R.; Nogueira, J.F.M.M. Creating hybrid scientific knowledge and practice: The Jesuit and Guaraní cultivation of yerba mate. *Can. J. Lat. Am. Caribb. Stud.* **2019**, *44*, 347–367. [CrossRef]
28. Westphalen, C.M.; Machado, B.P.; Balhana, A.P. *Nota Prévia ao Estudo da Ocupação da Terra no Paraná Moderno*; Boletim (Universidad Federal do Paraná. Departamento de História); Universidade Federal do Paraná, Conselho de Pesquisas de Pesquisas: Curitiba, Brazil, 1968.
29. Mota, L.T. *As Guerras dos Índios Kaingang: A História Épica dos Índio Kaingang no Paraná (1769–1924)*, 2nd ed.; Universidade Estadual de Maringá: Maringá, Brazil, 2009.
30. Lacerda, A.E.B.; Rosot, M.A.D.; Filho, A.F.; Garrastazú, M.C.; Nimmo, E.R.; Kellermann, B.; Radomski, M.I.; Beimgraben, T.; Mattos, P.P.; Oliveira, Y.M.M. Sustainable Forest Management in Rural Southern Brazil: Exploring Participatory Forest Management Planning. In *Sustainable Forest Management—Case Studies*; Martin-Garcia, J., Diez, J.J., Eds.; IntechOpen: Rijeka, Croatia, 2012; pp. 97–118. [CrossRef]
31. Persson, J.; Johansson, E.L.; Olsson, L. Harnessing local knowledge for scientific knowledge production: Challenges and pitfalls within evidence-Based sustainability studies. *Ecol. Soc.* **2018**, *23*, 38. [CrossRef]
32. Williams, B.; Riley, M. The Challenge of Oral History to Environmental History. *Environ. Hist. Camb.* **2020**, *26*, 207–231. [CrossRef]
33. Nimmo, E.R.; de Carvalho, A.I.; Laverdi, R.; Lacerda, A.E.B. Oral history and traditional ecological knowledge in social innovation and smallholder sovereignty: A case study of erva-Mate in Southern Brazil. *Ecol. Soc.* **2020**. Accepted.
34. Maran, J.C.; Rosot, M.A.D.; Rosot, N.C.; Radomski, I.; Cardoso, J.D.; Lacerda, A.E.B.; Kellermann, B. Análise de sobrevivência em plantios de enriquecimento com Araucaria angustifolia usando mudas de grande e pequeno porte. In *Congresso Florestal Paranaense*; Associação Paranaense de Empresas de Base Florestal: Curitiba, Brazil, 2015; p. 11.

35. Radomski, M.I.; Lacerda, A.E.B.; Kellermann, B. *Sistemas agroflorestais: Restauração ambiental e produção no âmbito da Floresta Ombrófila Mista*; Documentos 276; Empresa Brasileira de Pesquisa Agropecuária; Embrapa Florestas; Ministério da Agricultura, Pecuária e Abastecimento: Colombo, Brazil, 2014. Available online: http://ainfo.cnptia.embrapa.br/digital/bitstream/item/121202/1/Doc.-276-Izabel.pdf (accessed on 1 June 2020).
36. Radomski, M.I.; Lacerda, A.E.B. *Plantios de bracatinga na Estação Experimental da Embrapa em Caçador, SC*; Doc. Embrapa Florestas 328; Embrapa Florestas: Colombo, Brazil, 2019. Available online: https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1111377/plantios-de-bracatinga-na-estacao-experimental-da-embrapa-em-cacador-sc (accessed on 20 February 2020).
37. Kellermann, B.; Lacerda, A.E.B. Arrested development? Investigating the role of bamboo in Araucaria Forest succession in Southern Brazil. *J. Plant Ecol.* **2019**, *12*, 1034–1046. [CrossRef]
38. Blay-Palmer, A.; Spring, A.; Nimmo, E.R.; Lacerda, A.E.B. Traditional food, the Right to Food and Sustainable Food Systems. In *The Routledge Handbook of Sustainable and Regenerative Food Systems*; Duncan, J., Carolan, M., Wiskerke, H., Eds.; Routledge: Abingdon, UK, 2020.
39. Lacerda, A.E.B. Série erva-Mate sombreada (1): Sistema de produção de erva-mate baseado no manejo tradicional: Bracatingais dominados por bambus (taquarais). *Comun. Técnico Embrapa Florestas* **2019**, *439*. Available online: http://ainfo.cnptia.embrapa.br/digital/bitstream/item/205467/1/CT-439-1682-final-1.pdf (accessed on 18 January 2020).
40. Lacerda, A.E.B. Série erva-mate sombreada (2): Sistema de restauração produtivo agroflorestal. *Comun. Técnico Embrapa Florestas* **2019**, *400*. Available online: http://ainfo.cnptia.embrapa.br/digital/bitstream/item/205685/1/CT-440-1677-final.pdf (accessed on 18 January 2020).
41. Chaimsohn, F.P.; Radomski, M.I. Anais do III Seminário sobre caracterização de sistemas de produção tradicionais e agroecológicos de erva-mate de agricultores familiares nas regiões Centro Sul e Norte Catarinense. *Doc. Embrapa* **2016**, *292*. Available online: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/155047/1/Doc-292-Anais-do-III-Seminario-sobre-caracterizacao.pdf (accessed on 6 January 2020).
42. Mattos, A.G. Caracterização das Práticas de Manejo e das Populações de Erva-Mate (Ilex paraguariensis A. Sant. Hil) Nativa em Exploraçao no Planalto Norte Catarinense. Master's Thesis, Universidade Federal de Santa Catarina, Florianópolis, Brazil, 2011.
43. Da Marques, A.C. As Paisagens do Mate e a Conservação Socioambiental: Um Estudo Junto aos Agricultores Familiares do Planalto Norte Catarinense. Ph.D. Thesis, Universidade Federal do Paraná, Curitiba, Brazil, 2014.
44. Hanisch, A.L. Intensificação do uso da Pastagem em Sistema Silvipastoril Tradicional (Caívas) Como Estratégia de Uso Sustentável de Remanescentes de Floresta Ombrófila Mista. Ph.D. Thesis, Universidade Federal do Paraná, Curitiba, Brazil, 2018.
45. Machado, N.C. Produção de Serapilheira, Aportes de Nutrientes e Atributos de Fertilidade do Solo em Sistemas Agroflorestais de Erva-Mate. Master's Thesis, Universidade Estadual de Ponta Grossa, Ponta Grossa, Brazil, 2014.
46. Brasil Lei N° 12.651, de 25 de Maio de 2012; Dispõe Sobre a Proteção da Vegetação Nativa. 2012. Available online: https://www2.camara.leg.br/legin/fed/lei/2012/lei-12651-25-maio-2012-613076-normaatualizada-pl.pdf (accessed on 6 January 2020).
47. Machado, F. *Brazil's New Forest Code: A Guide for Decision-Makers in Supply Chains and Governments 2015 GUIA*; WWF Brazil: Brasilia, Brazil, 2016.
48. Brasil Lei N° 11428/2006—"Dispõe Sobre a Utilização e Proteção da Vegetação Nativa do Bioma Mata Atlântica, e dá Outras Providências". 2006. Available online: http://www.planalto.gov.br/ccivil_03/_Ato2004-2006/2006/Lei/L11428.htm (accessed on 2 February 2020).
49. Kellermann, B.; Lacerda, A.E.B. Bambus nativos como espécies invasoras no sul do Brasil. In *Bambus no Brasil: Da Biologia à Tecnologia*; Drumond, P.M., Wiedman, G., Eds.; Embrapa: Brasilia, Brazil, 2017; pp. 179–196.
50. Budke, J.C.; Alberti, M.S.; Zanardi, C.; Baratto, C.; Zanin, E.M. Bamboo dieback and tree regeneration responses in a subtropical forest of South America. *For. Ecol. Manag.* **2010**, *260*, 1345–1349. [CrossRef]
51. Lacerda, A.E.B.; Kellermann, B. What is the Long-Term Effect of Bamboo Dominance on Adult Trees in the Araucaria Forest? A Comparative Analysis between Two Successional Stages in Southern Brazil. *Diversity* **2019**, *11*, 165. [CrossRef]

52. Hanisch, A.L.; Radomski, M.I.; Bona, L.C.; Marques, A.D.C. Melhoria da produção animal em áreas de caíva e sua contribuição para a viabilização de corredores ecológicos. *Desenvolv. Reg. Debate* **2016**, *6*, 170–188. [CrossRef]
53. EPAGRI SCS315 Catarina Gigante Pastagem Perene de Verão. Available online: www.epagri.sc.gov.br/index.php/solucoes/tecnologias/tecnologias-em-destaque-catarina-gigante/ (accessed on 10 January 2020).
54. Hanisch, A.L.; Negrelle, R.R.B.; Balbinot Junior, A.A.; de Almeida, E.X. Produção, composição botânica e composição química de missioneira-gigante consorciada com leguminosas perenes. *Rev. Bras. Ciências Agrárias* **2016**, *11*, 60–66. [CrossRef]
55. Hanisch, A.L.; Dalgallo, D.; Almeida, E.X.; Negrelle, R.R.B. Desempenho e composição química de missioneira-gigante cultivada em sistema silvipastoril tradicional em duas alturas de pastejo. *Rev. Ciências Agrárias* **2016**, *59*, 345–351. [CrossRef]
56. Pinotti, L.C.A.; Hanisch, A.L.; Negrelle, R.R.B. The impact of traditional silvopastoral system on the Mixed Ombrophilous Forest remnants. *Floresta Ambient.* **2018**, *25*, e20170192. [CrossRef]
57. Pinotti, L.C.A. Subsídios à Conservação e Manejo Sustentável de Remanescentes de Floresta Ombrófila Mista. Master's Thesis, Universidade Federal do Paraná, Curitiba, Brazil, 2017.
58. Food and Agriculture Organization; Sustainability Assessment of Food and Agriculture Systems. Smallholders App; Version: 2.0.0. Available online: https://apkdownloadforandroid.com/org.fao.mobile.safa (accessed on 15 February 2017).
59. Chaer, G.M.; Resende, A.S.; Campello, E.F.C.; De Faria, S.M.; Boddey, R.M.; Schmidt, S. Nitrogen-Fixing legume tree species for the reclamation of severely degraded lands in Brazil. *Tree Physiol.* **2011**, *31*, 139–149. [CrossRef]
60. Sprent, J.I. *Legume Nodulation: A Global Perspective*; Wiley-Blackwell: Chichester, UK, 2009.
61. Carpanezzi, A.A.; Laurent, J.-M.E.; Carvalho, P.E.R.; Pegoraro, A.; Baggio, A.J.; Zanon, A.; Oliveira, E.B.; Tadeu Iede, E.; Rotta, E.; Sturion, J.A.; et al. Manual técnico da bracatinga (*Mimosa scabrella* Benth). *Documentos* **1988**, *20*, 1–70.
62. Carvalho, P.E.R. Composição e crescimento da bracatinga em povoamento natural. In *Proceedings of the Seminário Sobre Atualidades E Perspectivas Florestais*; Embrapa—URPFCS: Curitiba, Brazil, 1991; pp. 67–75.
63. Falk, D.A.; Palmer, M.A.; Zedler, J. *Foundations of Restoration Ecology*; Island Press: Washington, DC, USA, 1997.
64. Mansourian, S.; Vallauri, D.; Vallauri, N. *Forest Restoration in Landscapes*; Springer: New York, NY, USA, 2005.
65. Garrastazú, M.C.; Mendonça, S.D.; Horokoski, T.T.; Cardoso, D.J.; Rosot, M.A.D.; Nimmo, E.R.; Lacerda, A.E.B. Carbon sequestration and riparian zones: Assessing the impacts of changing regulatory practices in Southern Brazil. *Land Use Policy* **2015**, *42*, 329–339. [CrossRef]
66. Sambuichi, R.H.R.; de Moura, I.F.; de Mattos, L.M.; de Ávilda, M.L.; Spínola, P.A.C.; da Silva, A.P.M. (Eds.) *A Política Nacional de Agroecologia e Produção Orgânica No Brasil: Uma Trajetória de Luta Pelo Desenvolvimento Rural Sustentável*; Ipea: Brasilia, Brazil, 2017.
67. Food and Agriculture Organization. *Experiencias Exitosas de Políticas Agroambientales en Brasil*; De Andrade, R.B., Cabral, P.G., Eds.; FAO: Santiago, Chile, 2018.
68. Serviço Florestal Brasileiro Inventário Florestal Nacional. Available online: www.florestal.gov.br/inventario-florestal-nacional (accessed on 15 April 2020).