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Estimating costs of ecological restoration across degradation scenarios in South Brazilian grasslands

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Abstract

Introduction: Grassland ecosystems are among the most threatened worldwide, and the *Campos Sulinos*—a region of subtropical grasslands in southern Brazil—experiences degradation driven by multiple factors. This study provides initial cost estimates for different restoration approaches, offering guidance for technical and budgetary planning.

Objectives: To estimate the costs of distinct grassland restoration strategies under three common degradation scenarios: (1) overgrazing, (2) invasion by *Eragrostis plana*, and (3) land conversion to annual crops.

Methods: Costs for three restoration approaches—(1) stocking rate adjustment, (2) chemical control combined with oversowing of cultivated forage species, and (3) introduction of native seeds associated with rotational grazing—were estimated using technical literature and data from restoration projects implemented on rural properties in the *Campos Sulinos*.

Results: Costs varied according to degradation intensity and the method employed. Restoration of overgrazed areas had the lowest cost (U.S. dollars [USD] 1169.50/ha). Control of *E. plana* cost USD 5196.56/ha, whereas restoration of converted croplands was estimated at USD 4697.77/ha.

Conclusions: Low-cost strategies are suitable for moderately degraded areas, while severely altered sites require higher investments. The estimated values are comparable to those reported for other ecosystems, and the use of native seeds, although still incipient in the region, appears economically feasible. Strengthening seed supply chains can support local economies and inform policy development. The results provide a stronger basis for restoration planning and highlight the need for permanent financing mechanisms for the *Campos Sulinos*.

Implications for Practice: Estimated costs (U.S. dollars 1169.50–5196.56/ha) reflect degradation gradients and support realistic technical and financial planning for restoration. Stocking rate adjustment—a low-cost strategy—can promote natural regeneration where native vegetation remains resilient. In more degraded areas, chemical control combined with forage introduction or direct seeding of native species demands greater investment but is essential to restore ecological functioning. These techniques vary in operational complexity, required labor, and recovery time, reinforcing the need to align method choice with site conditions, producer capacity, and long-term goals. Scaling up restoration will depend on financing mechanisms capable of supporting these interventions and ensuring consistent monitoring.

Key words: ecosystem services, *Eragrostis plana*, grassland restoration, land use change, native seeds, overgrazing

Introduction

The United Nations Decade on Ecosystem Restoration (2021–2030) aims to reverse the degradation of terrestrial, freshwater, and marine ecosystems, promote biodiversity recovery, and strengthen ecosystem services (FAO 2021). Achieving these goals requires setting clear targets and ensuring adequate funding for the implementation of best practices (FAO 2021). Rigorous accounting of restoration costs has become increasingly relevant, promoting transparency and supporting the selection of effective methods (Andres et al. 2024). Costs vary widely, from hundreds to thousands of dollars per hectare (e.g. Knight & Overbeck 2021). Inaccurate cost data during the planning phase and in project documentation can create uncertainties about the feasibility of large-scale initiatives (Bodin et al. 2021; Andres et al. 2024). However, many analyses still lack detailed cost components, limiting policy development (Brancalion et al. 2019).

Natural grasslands, among the most diverse ecosystems on the planet, play a key role in the global carbon cycle (Bai & Cotrufo 2022) and hold high biodiversity (Wilson et al. 2012). However, alien species invasion, land use conversion, and inadequate management threaten their biodiversity and ecosystem services (Lyons et al. 2023). The *Campos Sulinos*, found in the

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South Brazilian Pampa region and in the southern part of the Brazilian Atlantic Forest, include highly biodiverse grassland ecosystems in South America, with over 3200 recorded plant species and significant floristic variation associated with environmental variation and historical factors (Boldrini 2009; Menezes et al. 2022; Andrade et al. 2023). These grasslands have historically been shaped by both natural and anthropogenic disturbances, such as fire and grazing, which play a key role in maintaining structural heterogeneity and floristic diversity (Overbeck et al. 2007; Baggio et al. 2021). However, these grasslands remain without adequate consideration in conservation (e.g. Overbeck et al. 2022). Land use intensification, including conversion to croplands, and invasion by exotic species such as *Eragrostis plana* Ness, have caused significant losses in diversity and ecological function (Andrade et al. 2018; Krob et al. 2021). According to MapBiomas (2024), the Pampa region lost approximately 26.4% of its grassland vegetation between 1985 and 2022, corresponding to 3.9 million hectares.

In this context, ecological restoration is important for its role in biodiversity conservation and for its potential to contribute to climate change mitigation, as well-managed soils store high levels of organic carbon (Krob et al. 2021; Overbeck et al. 2022). In grassland ecosystems, different ecological restoration strategies can be adopted depending on the degree of degradation and ecosystem resilience. When the ecosystem still retains functional native vegetation and degradation results principally from changes in management, such as overgrazing or fire suppression, reintroducing traditional disturbance regimes, e.g. by prescribed burning and rotational grazing, can allow spontaneous recovery of grassland structure and diversity (Andrade et al. 2015; Baggio et al. 2021). Other restoration techniques, in contrast, become necessary when ecological processes have been severely disrupted, such as in areas invaded by aggressive exotic species or converted to intensive agriculture. In these contexts, intensive and complex interventions are required, including invasive species control, soil amendment, and the reintroduction of native species through seeding or planting (Andrade et al. 2015; Rolim et al. 2022).

Despite their importance (Overbeck et al. 2022), *Campos Sulinos* grasslands remain underrepresented in national restoration agendas (Guerra et al. 2020; Michel & Overbeck 2024), and their restoration faces major challenges, particularly regarding the consolidation of methods, the scarcity of appropriate plant material (Michel & Overbeck 2024; Overbeck et al. 2024; Thomas et al. 2024), and incipient legal frameworks (Dutra-Silva et al. 2024). Knowledge of economic aspects of restoration is also scanty. In Brazil, restoration cost analyses have mainly focused on forest ecosystems (e.g. Brancalion et al. 2019), whereas data for the southern grasslands are still based on rough estimates (Benini et al. 2021), which complicates project planning.

This study aims to develop detailed cost estimates for different restoration approaches in the *Campos Sulinos*, considering practices commonly described in the literature and applied in restoration projects by the *Associação Riograndense de Empreendimentos de Assistência Técnica e Extensão Rural* (Emater/RS), the rural extension service of Rio Grande do Sul (RS), Brazil. Techniques considered here include stocking rate adjustment, fencing, rotational grazing, invasive species control, and the introduction of native species (Thomas et al. 2024). To estimate restoration costs in realistic contexts, this study considered three representative degradation scenarios in the *Campos Sulinos*, based on different intensities and types of impact: (1) native grassland areas degraded by overgrazing, (2) native grassland areas severely invaded by *E. plana*, and (3) former grassland areas converted to intensive agricultural use. These scenarios reflect situations widely documented in the literature (e.g. Medeiros & Ferreira 2011; Andrade et al. 2015; Guido & Pillar 2017) and observed in extension practice. No published cost catalog exists for restoration or conservation actions in the region (as occurs, e.g. for landscape conservation in southern Germany, Bayerisches Landesamt für Umwelt 2022). To develop realistic cost estimates, we used values derived from ongoing rural extension projects, with the overall aim to advance restoration science in subtropical grassland regions and contribute to the planning and implementation of restorative actions at the landscape scale.

Methods

Study Area

The Río de la Plata grasslands are temperate grassland ecosystems located in southern Brazil, all of Uruguay, and northeastern Argentina. The Brazilian portion corresponds to the Pampa region and, together with grassland areas within the Atlantic Forest, is regionally referred to as the "*Campos Sulinos*"—Figure 1 (Overbeck et al. 2024). These ecosystems are characterized by herbaceous vegetation composed of grasses, herbs, and small shrubs, forming mosaics with Araucaria forests and riparian forests in part of their extent (Vélez et al. 2009). Climate is humid subtropical, with annual rainfall ranging from 1200 to 2000 mm and average temperatures between 16 and 20°C, with

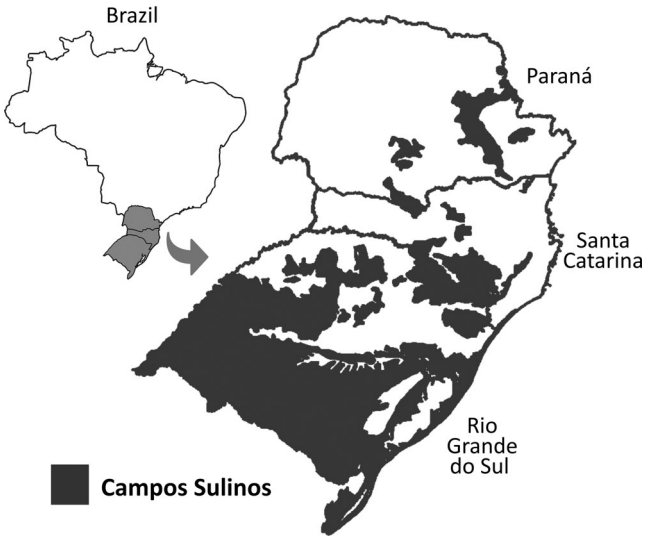


Figure 1. Original distribution of the *Campos Sulinos* in Southern Brazil.

cold winters and the possibility of frosts (RS 2021). Soils are naturally low in fertility, and some are shallow including Litholic and Regolithic Neosols, Latosols, Argisols, and Gleysols (Pillar & Lange 2015). The *Campos Sulinos* face growing threats from agricultural expansion, overgrazing and biological invasion, leading to the degradation of native grasslands (Overbeck et al. 2022).

Degradation Scenarios and Cost Estimation

To develop restoration cost estimates, three common degradation scenarios in the *Campos Sulinos* were developed based on scientific studies (Michel & Overbeck 2024; Thomas et al. 2024) and practical experience of Emater/RS. Cost estimates were developed assuming the application of restoration methods in a standard 10 ha area, with values presented per hectare over a 3-year period.

Cost data were obtained from a technical–operational database internally structured by Emater/RS, comprising accumulated records from reference units implemented between 2019 and 2024 across different *Campos Sulinos* sites. These records include detailed cost spreadsheets, field maps, georeferenced imagery, technical reports, monitoring photographs, and operational descriptions of field activities. Records are standardized across publicly funded projects, following a methodology that can be replicated in different sites.

The construction of cost estimates for each scenario and restoration approach involved organizing the data into expense categories (inputs, labor, equipment, transportation, and monitoring) and excluding records with errors or inconsistencies. Data were analyzed and presented comparatively across scenarios. Inherent uncertainties from regional variations—such as soil type, climate, and input prices—were addressed by adopting mean values updated to April 2025, ensuring representativeness for the current context. All costs were converted from Brazilian reais (R$) to U.S. dollars (USD) using the average exchange rate of April 2025 (R$ 5.728 per USD 1.00). No statistical variance analyses between sites or probabilistic approaches were applied, as the aim was to provide realistic technical parameters for planning ecological restoration projects in similar contexts.

The estimates were validated by multidisciplinary teams from Emater/RS and academic partners involved in the original projects, ensuring technical consistency of operations and coherence between scenarios and proposed values. The costs of each operational stage are also presented separately (Table S1), allowing adjustments to different conditions. These figures reflect actual expenditures from applying techniques that contribute to the ecological restoration of grassland formations in rural properties of the *Campos Sulinos*, particularly those associated with family livestock farming.

Scenario 1: Native Grassland Degraded by Overgrazing

Overgrazing occurs when the stocking rate—that is, the number of animals per area over a given period—exceeds the vegetation's carrying capacity, leading to excessive removal of aboveground biomass, loss of plant vigor, and structural and compositional changes in the grassland (Briske et al. 2008; Nabinger et al. 2009; Herrero-Jáuregui & Oesterheld 2018). In practical terms, this results in reduced pasture height, lower soil cover, an increasing presence of grazing-tolerant species, and a decline in the diversity of plants with good ecological and productive value (Barbosa et al. 2008). In this study, as widely described in the literature for the sustainable management of the *Campos Sulinos* and other grassland ecosystems, stocking rate adjustment was adopted as the central strategy to promote vegetation recovery (Teague & Dowhower 2003; Nabinger et al. 2009; McDonald et al. 2025). The stocking rate was adjusted to maintain forage availability equivalent to four to five times the animals' daily dry matter intake, which corresponds to a maximum of 3% of live weight (Nabinger et al. 2009). This approach aims to maintain a residual leafy stratum with an average height of 7–9 cm (Mezzalira et al. 2011) favoring light interception, promoting greater vegetation cover and soil protection, reducing degradation risks, and optimizing ingestive behavior (Teague & Dowhower 2003; Carvalho et al. 2007; Briske et al. 2008). The adopted principle is based on adaptive management, with periodic adjustments of the stocking rate according to forage availability and restoration goals (Briske et al. 2008; Nabinger & Carvalho 2009; Herrero-Jáuregui & Oesterheld 2018). For cost calculation, the intervention was estimated for a 10 ha area under continuous grazing, with the installation of permanent perimeter fencing to control access, in which a pasture measuring stick was used as the basic equipment for monitoring sward height and adjusting the stocking rate. The costs reflect the labor involved and specialized technical monitoring over 3 years.

Scenario 2: Native Grassland Severely Invaded by Tough Lovegrass (*Eragrostis plana* Ness)

The invasion of *Eragrostis plana*, considered the most problematic exotic species in the *Campos Sulinos*, reduces biodiversity and forage value (Medeiros & Ferreira 2011; Guido & Pillar 2017). When cover exceeds 50%—strong dominance (Perez 2015), the Integrated Pasture Recovery Method (Método Integrado de Recuperação de Pastagens (MIRAPASTO)) (Perez 2015, 2010) is recommended, combining selective chemical control, overseeding, and conservation-oriented management (Medeiros & Ferreira 2011; Thomas et al. 2019). The protocol involves systemic herbicide applications and, after the first application in autumn, overseeding with Ryegrass (*Lolium multiflorum* Lam.) and White clover (*Trifolium repens* L.), followed by another application at the end of spring or early summer, after Ryegrass seed set. Before overseeding, soil amendment and fertilization are carried out according to physical–chemical analyses (Nabinger et al. 2009; Perez 2015). The combination of chemical control, overseeding, soil correction, and stocking rate adjustment gradually replaces *E. plana* with desirable species, improving productivity and functionality (Perez 2015, 2022). Winter forages play a strategic role in ensuring soil cover, reducing erosion, improving soil structure, and limiting reinvasion. Because overseeding is used,

higher seeding rates are required compared to conventional direct seeding to offset competition with resident vegetation (Nabinger et al. 2009). Standardized values for liming and fertilization were adopted, reflecting the acidic soils and low phosphorus and potassium levels typical of southern Brazilian grasslands (Perez 2015). Although Emater/RS projects use property-specific soil analyses, standardization was necessary to allow comparability among scenarios. For cost estimation, a 10 ha area was considered, including stocking rate adjustment, fencing, selective chemical control, forage introduction, soil correction and fertilization, plus maintenance and monitoring over 3 years. Costs included materials, soil analyses, equipment, inputs, labor, transportation, and machinery.

Scenario 3: Complete Land Use Conversion in an Area Originally Covered by Grassland

The conversion of natural areas to agriculture is one of the main causes of biodiversity loss (Baeza et al. 2022), especially through replacement by annual crops such as soybean and rice, recurrent in the *Campos Sulinos* (Pillar & Vélez 2010; Krob et al. 2021; MapBiomas 2023). After intensive use and abandonment, these areas tend to be dominated by ruderal and exotic species (Rai 2022), requiring the reintroduction of native species (Kiehl et al. 2010; Andrade et al. 2015). A native seed market is practically nonexistent, although recent research indicates potential for mechanized harvesting (Dutra-Silva et al. 2024). In this context, the scenario proposed in the first year is the overseeding with Pensacola bahiagrass (*Paspalum notatum* var. *saurae*), an adapted native cultivar, commercially available and with rapid stoloniferous/rhizomatous growth, which ensures initial soil cover and the return of livestock production (Silva 2014). Over 3 years, the introduction of a mix of native seeds collected mechanically from nearby remnants is foreseen (Pereira Machín 2017; Panella 2022), a technology already used in restoration reference units monitored by Emater/RS. As with Pensacola bahiagrass (Fachinetto 2010), native species adapted to acidic and nutrient-poor soils are expected to establish without liming or fertilization, as shown by trials in Uruguay (Panella 2022). Although regional studies on germination are still lacking (Thomas et al. 2025), there are parallels with the North American Tallgrass Prairie, where direct seeding is widely used (Packard & Mutel 2005; Overbeck et al. 2018). Rotational grazing was incorporated as a restoration strategy, reconciling livestock production and conservation by promoting native regeneration and controlling invasive species through alternating use and rest periods and stocking rate adjustment (Boavista et al. 2019; Herrero-Jáuregui & Oesterheld 2018; Abagandura et al. 2024). This management increases spatial and temporal heterogeneity, favoring attributes such as height, cover, and functional diversity (Soares et al. 2011; Herrick et al. 2023), being an accessible practice already consolidated in different contexts (Nabinger & Carvalho 2009; Dong et al. 2024). The budget includes the purchase and seeding of Pensacola bahiagrass, collection and introduction of native species, fencing of the propagule source area, installation and maintenance of electric fences and drinking troughs, as well as cattle management in 10 ha subdivided into ten 1 ha paddocks, with stocking adjustments over 3 years. It also covers materials, equipment, labor, transportation, machinery use, and specialized technical monitoring.

Results

The analysis of ecological restoration costs in the *Campos Sulinos* allowed the identification of distinct cost levels across the evaluated degradation and restoration scenarios, reflecting the complexity and specific demands of each situation. Table 1 presents a cost and action comparison for each of the three scenarios, indicating the cost per hectare and the planned interventions in each case. Per-hectare costs varied among the analyzed scenarios: the overgrazing scenario showed the lowest cost (USD 1169.50/ha), followed by the complete land use conversion scenario (USD 4697.77/ha), while the *E. plana* invasion scenario had the highest cost (USD 5196.56/ha). This analysis supports a more efficient allocation of resources for the initial implementation of ecological restoration projects (see complete data in Table S1) and facilitates restoration planning. Table 2 complements this information by providing a detailed description of the methods employed and the cost components of each restoration and management action, covering inputs, labor, equipment, frequency, and duration of activities over 3 years. This approach allows for a better understanding of the relationship between actions and costs, as well as the practical application of interventions in different degradation contexts.

Discussion

This study presents initial cost estimates derived from restoration projects either underway or already implemented by Emater/RS. We do not assess the ecological effectiveness of the proposed methods, but provide a technical and budgetary overview useful for planning restoration actions in the *Campos Sulinos*. Unlike previous estimates (Benini et al. 2021), which only distinguished between generally favorable and unfavorable conditions based on landscape context, our analysis incorporates different degradation levels and restoration requirements. Understanding these specific costs is essential to support managers and decision-makers in addressing the economic aspects of restoration in the face of the ongoing environmental and biodiversity crises. Notably, cost data are closely linked to current rangeland and agricultural management practices.

Our results indicate that the restoration of areas degraded by overgrazing (scenario 1), in the absence of additional degradation, presents low costs (USD 1169.50/ha). In such cases, grassland restoration is assumed to occur through adjustments in grazing management (Andrade et al. 2015; Fedrigo et al. 2018). Our estimate nonetheless is higher than that of Benini et al. (2021), who reported USD 364.87/ha for natural regeneration under favorable conditions. In this case, the authors considered only punctual initial management costs, such as mowing and, in some cases, prescribed burning. This represents a minimum value, applicable to areas with high potential for natural regeneration, which is quite different from the overgrazed

Table 1. Comparative costs and restoration actions for *Campos Sulinos* under three degradation scenarios. Costs refer to the total for a 3-year implementation period. All costs were converted from Brazilian reais (R$) to U.S. dollars (USD) using the average exchange rate of April 2025 (R$ 5728.00 per USD 1.00)

Scenario 1			*Scenario 2*			*Scenario 3*		
Native grassland degraded by overgrazing	Fencing	$925.61	Native grassland severely invaded by *Eragrostis plana* Ness	Fencing	$925.61	Total land use conversion in an originally grassland area	Rotational grazing	$1630.76
	Stocking rate adjustment	$76.29		Stocking rate adjustment	$76.29		Stocking rate adjustment	$76.29
				Chemical control of invasive exotic species	$1960.02		Source area fencing	$203.00
				Introduction of winter species with soil correction/ fertilization.	$2067.04		Introduction of *Paspalum notatum* var. *saurae*	$537.71
	Restoration monitoring	$167.60					Introduction of native species	$1914.80
				Restoration monitoring	$167.60		Restoration and source area monitoring	$335.20
Total cost/ha $1169.50			Total cost/ha $5196.56			Total cost/ha $4697.77		

situations evaluated in our study. It is important to highlight that in the *Campos Sulinos*, the maintenance of management regimes such as grazing is fundamental to conserve plant diversity (Pillar & Vélez 2010; Ferreira et al. 2020); the concept of "natural regeneration," that is, the cessation of all human intervention, including grazing, as commonly applied in forest restoration, is not applicable here: management is essential to maintain the characteristics of a native grassland (Baggio et al. 2021).

According to Kimball et al. (2015), the cost of restoring 1 ha of overgrazed native grassland in California ranges from USD 8719.00 to USD 18223.00, depending on the techniques used and local site conditions. In Germany, estimates indicate costs between USD 2700.00 and USD 6500.00/ha (Bayerisches Landesamt für Umwelt 2022), including interventions such as direct seeding, soil amendment, and invasive species control. These differences may be related to the composition and quality of plant communities. Here, we assume that reducing grazing pressure enables community recovery (Silva et al. 2007; Nabinger et al. 2009; McDonald et al. 2025); otherwise, additional investments in seeding would be required (see scenarios 2 and 3).

Adjusting grazing provides immediate financial benefits by increasing productivity, as overgrazing entails considerable losses. For example, in cattle farms in Zimbabwe, the costs of overgrazing ranged from USD 0.15 to 2.00 per kg of excess herbivores (Kreuter & Workman 1994). In addition to stocking rate adjustment, management can be complemented by grazing deferment, a low-cost practice that supports native vegetation regeneration, enhances ecosystem resilience, and contributes to more efficient livestock systems (Nabinger et al. 2009; Fedrigo et al. 2018; Boavista et al. 2019). Its simplicity makes it accessible to producers and improves forage quality and availability (Rickert 1996).

Scenario 2 focuses on the restoration of grasslands degraded by the widespread presence of *Eragrostis plana* Ness, an invasive alien species that is difficult to control. Native to Africa, *E. plana* is considered invasive in 10 regions worldwide, with particular concern in South America (Baggio et al. 2018; Pyšek et al. 2020; Zabala-Pardo & Lamego 2024). Its high seed viability and long-term persistence in the soil further complicate management efforts (Bittencourt et al. 2017). Between 1985 and 2019, it caused economic losses of approximately USD 105.53 billion in Brazil, although only 1.1% of the resources invested in invasive plant control were allocated to its management (Adelino et al. 2021). Its expansion is one of the main threats to biodiversity and livestock-based economies in the *Campos Sulinos* (Dresseno et al. 2018).

Proper pasture management is essential to prevent or contain *E. plana* invasion in its early stages, by avoiding soil disturbances that facilitate its spread. Baggio et al. (2018) showed that in areas with grazing control, the invasive species' cover remained below 10%. Reducing or avoiding overgrazing helps mitigate this risk; however, in areas with more than 50% *E. plana* cover, other actions are necessary.

Herbicides such as glyphosate are effective in controlling *E. plana*, but they can impact biodiversity by altering the composition of native plant communities (Guido & Pillar 2017; Zabala-Pardo & Lamego 2024), which requires further evaluation of their application as an ecological restoration method.

Table 2. Methods and detailed descriptions of restoration and management actions in *Campos Sulinos*.

Method	*Detailed description*
Chemical control of invasive exotic species	Management with selective herbicide application in areas with invasive exotic species, using chemical mowers and hoes twice a year. Includes herbicides, markers, personal protective equipment, labor, transportation, and machinery. Repeated twice per year for 3 years.
Fencing	Installation of fixed fencing to delimit the stocking rate adjustment area, including materials, equipment, labor, transportation, machinery, and maintenance over 3 years.
Introduction of *Paspalum notatum* var. *saurae*	Overseeding of Pensacola bahiagrass in the first year. Includes seeds, labor, and freight.
Introduction of native species	Collection, preparation, selection, and seeding of native grassland seeds. Includes labor, machinery, equipment, and freight, applied twice a year over 3 years.
Introduction of winter species	Soil analysis for correction and fertilization, followed by overseeding with winter forage species. Includes analysis, inputs, labor, transportation, and machinery. Repeated annually with adjustments over 3 years.
Restoration and source area monitoring	Specialized monitoring of restoration indicators and source area evaluation, with specialized labor. One evaluation per year in the restoration area and two per year in the source area over 3 years.
Restoration monitoring	Specialized monitoring of native grassland restoration indicators, with annual evaluations and labor costs over 3 years.
Rotational grazing	Implementation of rotational grazing with 1 ha paddocks, using electric fencing and a hydraulic system. Includes materials, labor, transportation, machinery, and maintenance over 3 years.
Source area fencing	Installation of fixed fencing to isolate a 2 ha source area, including materials, equipment, labor, transportation, and maintenance over 3 years.
Stocking rate adjustment	Monthly measurement of forage availability at different points, including ruler and labor costs over 3 years.

Research on controlling the invasion of *Urochloa decumbens*, another aggressive African grass, conducted by Thomas et al. (2019) in the *Campos Sulinos* and by Assis et al. (2020) in the Cerrado biome, showed that both chemical control and physical removal are effective for managing this invasive species. However, in the Cerrado, chemical control proved more affordable compared to the cost of manual weeding, which requires a significant amount of labor. The difference between the cost of selective chemical control of *E. plana* (USD 1960.02/ha, in this study) and the values reported by Assis et al. (2020) for *U. decumbens* in the Cerrado (USD 435.29/ha) is due to several factors. *Eragrostis plana* requires multiple applications due to its high reinfestation capacity (Perez 2015), in addition to costs associated with the use of specialized equipment such as chemical mowers. Differences in labor costs and calculation methods also contribute to this variation.

The Integrated Pasture Recovery Method (MIRAPASTO; Perez 2015), which we use in our scenario has shown positive results in reducing invasive species and increasing pasture productivity, especially when combined with overseeding of grasses and legumes such as *Lolium multiflorum* and *Trifolium repens*, due to their rapid soil coverage, ease of management, and wide commercial availability (Kiehl et al. 2010; Medeiros & Ferreira 2011; Nunes et al. 2012). These species are important for livestock feeding during winter, when native grasslands have low forage production (Nabinger et al. 2009).

The introduction of cultivated winter forage species involves costs with soil analysis, correction, fertilization, and overseeding, including labor, transportation, and machinery. Although widely used in the *Campos Sulinos*, its high cost can be limiting for small farmers. An alternative is to adopt management practices that promote natural reseeding, ensuring species persistence and reducing *E. plana* reinfestation (Perez 2010, 2015). Deferring areas during seed production is an effective, low-cost strategy that favors vegetation regeneration, particularly of *L. multiflorum* (Nabinger et al. 2009; Fedrigo et al. 2018; Boavista et al. 2019).

When aiming to restore grasslands after complete conversion to other land uses, intensive practices are required to restore biodiversity and ecological functions, as the resulting degradation level compromises the ecosystem's self-recovery capacity (Andrade et al. 2015). When livestock reintroduction is planned, the introduction of forage species is essential to reestablish biodiversity, particularly in areas of prolonged use and with soil alterations that reduce the resilience of native vegetation (Andrade et al. 2015). The chemical and physical conditions of the soil may be altered after other land uses, which can affect the establishment of native species; however, few studies have been conducted on this topic in the region. Research on spontaneous vegetation development in areas after agricultural use (i.e. without ecological restoration) does not indicate general restrictions to the growth of native species, although vegetation composition is different (Koch et al. 2016), which can be interpreted as a result of seed limitation: dominant native species are not highly abundant in the seed bank, and even less so after land use change (Minervini-Silva & Overbeck 2020; Vieira & Overbeck 2020).

In this context, the initial introduction of Pensacola bahiagrass (*Paspalum notatum* var. *saurae*), a cultivar adapted to regional conditions and widely available, is recommended to ensure rapid soil cover and forage supply in the first year of restoration (Silva 2014). An application rate of 80 kg/ha of seeds is suggested, necessary to offset adverse conditions and favor pasture establishment. *Paspalum notatum* is a key species of the lower stratum of Pampa grasslands, widely distributed and abundant, occurring even in areas of high species richness, which indicates that it does not reduce diversity in these ecosystems (Menezes et al. 2018). While this species may help to accelerate vegetation cover development, full restoration requires the reintroduction of a broader diversity of native species from southern Brazil, especially those contributing to structural and functional diversity (Andrade et al. 2015; Rolim et al. 2022). An initial list of priority species already exists, but further studies are needed on their management and commercial seed availability (Rolim et al. 2022; Dutra-Silva et al. 2024; Michel & Overbeck 2024). Mechanized seed collection with adapted harvesters has shown good results (Pereira Machín 2017; Panella 2022), and in scenario 3 the use of this equipment—available on the market for about USD 6700.00—is proposed as a promising strategy for large-scale restoration. Use of this equipment is not yet a consolidated practice in the Pampa grasslands but has contributed to restoration success in different grassland regions worldwide (e.g. Edwards et al. 2007; Siota et al. 2020). Recent research in the Pampa region indicates high success in seed collection and high germinability of collected seeds (UFRGS; for germination, see Thomas et al. 2025). Certainly, more research is needed to fully understand the seed biology and germination of grassland species and to support the development of seeding plans (Shaw et al. 2020), but current knowledge points to this collection and use method as a pragmatic solution, which needs to be improved based on knowledge generated through restoration project monitoring.

For the cost estimation, two seed collections per year were considered, followed by simple drying, removal of residual material, quality verification, and viability testing, conducted by a specialized technician. Then, approximately 40 kg/ha of the native seed mix is proposed to be introduced through manual overseeding over 3 years of continuous management. The estimated cost does not include seed value, but covers the entire process from collection to introduction, totaling USD 1914.80, considering two collections and seedings per year over 3 years. This amount falls within the cost range observed by Kimball et al. (2015) in a study conducted in the Santa Ana Mountains, California, United States, where costs ranged from USD 816.34 to USD 5334.84/ha, depending on the seeding method, seed density and type, soil preparation, topography, vegetation diversity, and post-seeding maintenance. The use of local native species can enhance restoration effectiveness due to their environmental adaptation. However, seed diversity and density directly influence both costs and restoration success (Schaub et al. 2021; Kaulfuß et al. 2022). Thus, further research can help improve seed collection and use protocols, which will likely lead to adjustments in cost estimates. Similarly, Figueiredo et al. (2019), in *campo rupestre* areas degraded by mining, estimated that direct seeding combined with the incorporation of litter into the substrate resulted in an average establishment of 49 individuals/m^2, with a unit cost between USD 0.006 and USD 0.09 per seedling established after 1 year. Despite low establishment rates for some species, these per-plant values were 60 times lower than the average costs of planted seedlings in other Brazilian biomes, highlighting the economic potential of the technique also in grassland ecosystems, even under more severe edaphic conditions than in the *Campos Sulinos*.

Grassland restoration in scenario 3 showed a high cost, estimated at USD 4697.77/ha over 3 years, due to the integration of multiple methods. This value is similar to that reported by Benini et al. (2021) and includes soil preparation, direct seeding of native species, and herbicide application, totaling USD 4355.97/ha for converted areas. Results consistent with this magnitude were also observed by Raupp et al. (2020) for 57 tree species from forests and savannas in central Brazil. In that study, direct seeding had an average cost of USD 0.36 per established seedling (density of 2500 seedlings/ha), being 2.3–4.8 times cheaper per hectare than seedling planting, depending on the establishment rate. Importantly, costs for seeding native species are not much higher than the cost of using exotic forage species in scenario 2; native species could be considered in scenario 2 as an alternative, likely with faster positive biodiversity effects.

As a complement to the introduction of native species, rotational grazing contributes to stocking rate management, promotes biodiversity, and increases forage productivity (Boavista et al. 2019), and can be applied in all scenarios. Subdividing paddocks with electric fencing makes management more efficient and cost-effective (Nabinger et al. 2009). Resting areas, combined with grazing deferment, support species diversity recovery, improve water infiltration, reduce soil compaction, and enhance root depth (Castagna et al. 2008), aiding both grassland restoration and livestock productivity (Fedrigo et al. 2018). Practices such as grazing management adjustments promoted by rotational grazing can generate significant productivity gains, even with low investments. According to Nabinger et al. (2009), the regional average of 70 kg of live weight/ha/year (approximately USD 134.42/ha) can increase to 200–230 kg/ha/year (USD 441.65/ha) solely by adjusting stocking rates, representing a 228.6% increase without additional inputs. Despite these benefits, many family farmers remain resistant due to technical limitations and the perception of livestock as a form of financial security (Ribeiro 2009; Matte & Waquil 2021). Continuous training and clear communication of the economic and environmental benefits are essential to promote broader adoption of these practices (Ash & Smith 1996).

In addition to these direct benefits for livestock farmers due to restoration and improved management, the development of a restoration supply chain also brings economic gains. In the United States, restoration regulation and the growth of ecosystem service markets generate around 126,000 direct jobs and USD 9.5 billion annually, as well as 95,000 indirect jobs and USD 15 billion in related activities (BenDor et al. 2015). For the *Campos Sulinos* region, there are still no estimates of the economic potential of such a chain, but the need for its development is evident—for example, to provide native seeds for restoration. Nonetheless, despite these regional economic benefits, the high costs presented here highlight the importance of public

policies and support for restoration. At current beef cattle prices, restoration costs in scenarios 2 and 3 (around USD 5000) would take around 15 years to be amortized, making it unlikely that producers will adopt such practices spontaneously without external incentives, unless legally required. Restoration supply chains, financial incentives, and market mechanisms must be coupled with government support to ensure that the economic burden does not fall solely on producers. The cost estimates we developed here will be helpful to provide a more reliable basis for restoration planning. As scientific knowledge and practical experience in restoration in the region increase and new techniques are developed, the cost estimates presented here should be developed further.

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LITERATURE CITED

Abagandura GO, Mamo, M., Schacht, W. H., Shropshire, A., & Volesky, J. D. (2024) Soil carbon and nitrogen after eight years of rotational grazing in the Nebraska Sandhills meadows. Geoderma 442:116776. doi:https://doi.org/10.1016/j.geoderma.2024.116776 (accessed 13 Jul 2025)

Adelino JRP, Heringer G, Diagne C, Courchamp F, Faria LDB, Zenni RD (2021) The economic costs of biological invasions in Brazil: a first assessment. NeoBiota 67:349–374. https://doi.org/10.3897/neobiota.67.59185

Andrade BO, Bonilha CL, Overbeck GE, Vélez-Martin E, Rolim RG, Bordignon SAL, et al. (2018) Classification of South Brazilian grasslands: implications for conservation. Applied Vegetation Science 21:298–311. https://doi.org/10.1111/avsc.12367

Andrade BO, Koch C, Boldrini II, Vélez-Martin E, Hasenack H, Hermann J-M, Kollmann J, Pillar VD, Overbeck GE (2015) Grassland degradation and restoration: a conceptual framework of stages and thresholds illustrated by southern Brazilian grasslands. Natureza & Conservação 13:95–104. https://doi.org/10.1016/j.ncon.2015.08.002

Andrade BO, Zanin M, Rolim RG, Bonilha CL, Ferreira PMA, Lucas DB, et al. (2023) 12,500 and counting: a database of vascular plants of the South Brazilian grasslands. Biodiversity and Conservation 32:2343–2362. https://doi.org/10.1007/s10531-023-02574-2

Andres SE, Mills CH, Gallagher RV, Adams VM (2024) A framework for ecological restoration cost accounting across context and scale. Biological Conservation 295:110671. https://doi.org/10.1016/j.biocon.2024.110671

Ash AJ, Smith DMS (1996) Evaluating stocking rate impacts in rangelands: animals don't practice what we preach. The Rangeland Journal 18:216–243. https://doi.org/10.1071/RJ9960216

Assis GB, Pilon NAL, Siqueira MF, Durigan G (2020) Effectiveness and costs of invasive species control using different techniques to restore cerrado grasslands. Restoration Ecology 28:879–889. https://doi.org/10.1111/rec.13219

Baeza S, Vélez-Martin E, de Abelleyra D, Banchero S, Gallego F, Schirmbeck J, et al. (2022) Two decades of land cover mapping in the Río de la Plata grassland region: the MapBiomas Pampa initiative. Remote Sensing Applications: Society and Environment 28:100834. https://doi.org/10.1016/j.rsase.2022.100834

Baggio MA, Ferreira PMA, Andrade BO, Lucas DB, Koch C, Overbeck GE (2021) To graze or not to graze: ecological restoration of southern Brazilian grasslands with native grass seed addition. Restoration Ecology 29:e13361. https://doi.org/10.1111/rec.13361

Baggio MS, Medeiros RB, Focht T, Boavista LR, Pillar VD, Müller SC (2018) Effects of initial disturbances and grazing regime on native grassland invasion by *Eragrostis plana* in southern Brazil. Perspectives in Ecology and Conservation 16:158–165. https://doi.org/10.1016/j.pecon.2018.06.004

Bai Y, Cotrufo MF (2022) Grassland soil carbon sequestration: Current understanding, challenges, and solutions. Science 377:603–608. https://doi.org/10.1126/science.abo2380

Barbosa CMP, Nabinger C, Freitas AK, Carvalho PCF, Genro TCM, Jacques AVA (2008) Effect of grazing methods and intensities on the botanical composition of native grassland in southern Brazil. Revista Brasileira de Zootecnia 37:35–42. https://doi.org/10.4025/actascianimsci.v30i4.6463

Bayerisches Landesamt für Umwelt (2022) Kostendatei für Maßnahmen des Naturschutzes und der Landschaftspflege. Bayerisches Landesamt für Umwelt, Augsburg, Germany. https://www.lfu.bayern.de/natur/landschaftspflege_kostendatei/doc/kostendatei_kurz.pdf (accessed 11 Feb 2025)

BenDor T, Lester TW, Livengood A, Davis A, Yonavjak L (2015) Estimating the size and impact of the ecological restoration economy. PLOS ONE 10(6): e0128339 (accessed 18 Feb 2025)

Benini RM, Lenti FEB, Tymus JRC, Silva APM, Isernhagen I (2021) Costs of restoring native vegetation in Brazil: new studies estimate the financial values of the activity to guide policies and investments. Pages 20–37. In: Benini RM, Adeodato S (eds) Forest restoration economy. The Nature Conservancy, São Paulo, Brazil

Bittencourt HVH, Bonome LTS, Trezzi MM, Vidal RA, Lana MA (2017) Seed germination ecology of *Eragrostis plana*, an invasive weed of South American pasture lands. South African Journal of Botany 109:246–252. https://doi.org/10.1016/j.sajb.2017.01.009

Boavista LR, Trindade JPP, Overbeck GE, Müller SC (2019) Effects of grazing regimes on the temporal dynamics of grassland communities. Applied Vegetation Science 22:328. https://doi.org/10.1111/avsc.12432

Bodin B, Garavaglia V, Pingault N, Ding H, Wilson S, Meybeck A, Gitz V, d'Andrea S, Besacier C (2021) A standard framework for assessing the costs and benefits of restoration: introducing the economics of ecosystem restoration. Restoration Ecology 29:e13515. https://doi.org/10.1111/rec.13515

Boldrini IL (2009) A flora dos Campos do Sul do Brasil. Pages 63–77. In: Pillar VP, Müller SC, Castilhos ZMS, Jacques AVA, et al. (eds) Campos Sulinos: conservação e uso sustentável da biodiversidade. Ministério do Meio Ambiente, Brasília, Brazil

Brancalion PHS, Melia P, Tymus JRC, Lentic FEB, Benini RM, Silva APM, Isernhagen I, Holle KD (2019) What makes ecosystem restoration expensive? A systematic cost assessment of projects in Brazil. Biological Conservation 240:108274. https://doi.org/10.1016/j.biocon.2019.108274

Briske DD, Derner JD, Brown JR, Fuhlendorf SD, Teague WR, Havstad KM, Gillen RL, Ash AJ, Willms WD (2008) Rotational grazing on rangelands: reconciliation of perception and experimental evidence. Rangeland Ecology & Management 61:3–17. https://doi.org/10.2111/06-159R.1

Carvalho PCF, Santos DT, Neves FP (2007) Forage allowance as a regulator of sward structure and animal performance. In: Dall'Agnol M, Nabinger C, Santana DM, Santos RJ (eds) Sustainable Productivity of the Pampa Biome. Proceedings of the II Symposium on Forage Species and Animal Production, Porto Alegre, Brazil, pp. 23–60. Available at: https://www.bibliotecaagptea.org.br/zootecnia/forragens/artigos/OFERTA%20DE%20FORRAGEM%20COMO%20CONDICIONADORA%20DA%20ESTRUTURA%20DO%20PASTO%20E%20DO%20DESEMPENHO%20ANIMAL.pdf. Accessed 15 Feb 2024.

Castagna AA, Aronovich M, Rodrigues E (2008) Pastoreio racional Voisin: manejo agroecológico de pastagens. Manual Técnico, 10. Programa Rio Rural, Niterói, Brazil https://ibeasa.org/wp-content/uploads/2021/01/Pastoreio-Racional.pdf (accessed 3 Feb 2025)

Dong S, Xu Y, Li S, Shen H, Yang M, Xiao J (2024) Restoration actions associated with payment for ecosystem services promote the economic returns of

alpine grasslands in China. Journal of Cleaner Production 458:142439. https://doi.org/10.1016/j.jclepro.2024.142439

Dresseno ALP, Guido A, Balogianni V, Overbeck GE (2018) Negative effects of an invasive grass, but not of native grasses, on plant species richness along a cover gradient. Applied Ecology and Environmental Research 43:949–954. https://doi.org/10.1111/aec.12644

Dutra-Silva R, Overbeck GE, Müller SC (2024) How can Brazilian legislation on native seeds advance based on good practices of restoration in other countries? Perspectives in Ecology and Conservation 22:224–231. https://doi.org/10.1016/j.pecon.2024.08.002

Edwards AR, Mortimer SR, Lawson CS, Westbury DB, Harris SJ, Woodcock BA, Brown VK (2007) Hay strewing, brush harvesting of seed and soil disturbance as tools for the enhancement of botanical diversity in grasslands. Biological Conservation 134:372–382. https://doi.org/10.1016/j.biocon.2006.08.025

Fachinetto JM (2010) Caracterização agronômica, molecular, morfológica e determinação do nível de ploidia em uma coleção de acessos de *Paspalum notatum* Flügge. MSc dissertation. Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil.

FAO (Food and Agriculture Organization of the United Nations) (2021) Principles for ecosystem restoration to guide the United Nations Decade 2021–2030. Food and Agriculture Organization of the United Nations, Rome, Italy. https://openknowledge.fao.org/server/api/core/bitstreams/b234f058-9f77-4481-b870-a7fa2e7ad5f8/content (accessed 3 Feb 2025)

Fedrigo J, Ataide P, Azambuja J, Oliveira L, Jaurena M, Laca E, Overbeck G, Nabinger C (2018) Temporary grazing exclusion promotes rapid recovery of species richness and productivity in a long-term overgrazed Campos grassland. Restoration Ecology 26:677–685. https://doi.org/10.1111/rec.12635

Ferreira PMA, Andrade BO, Podgaiski LR, Dias AC, Pillar VD, Overbeck GE, Mendonça MS Jr, Boldrini II (2020) Long-term ecological research in southern Brazil grasslands: effects of grazing exclusion and deferred grazing on plant and arthropod communities. PLoS One 15:e0227706. https://doi.org/10.1371/journal.pone.0227706

Figueiredo MA, Messias MCTB, Leite MGP, Kozovits AR (2019) Direct seeding in the restoration of post-mined campo rupestre: germination and establishment of 14 native species. Ecological Engineering 132:30–37. https://doi.org/10.1016/j.ecoleng.2019.04.016

Guerra A, Reis LK, Borges FLG, Ojeda PT, Pinedo LB, Miranda CO, Santos TM, Shimbo JZ, Rodrigues RR (2020) Ecological restoration in Brazilian biomes: identifying advances and gaps. Forest Ecology and Management 458:117802. https://doi.org/10.1016/j.foreco.2019.117802

Guido A, Pillar VD (2017) Invasive plant removal: assessing community impact and recovery from invasion. Journal of Applied Ecology 54:1230–1237. https://doi.org/10.1111/1365-2664.12848

Herrick AL, Mogensen N, Svenning J-C, Buitenwerf R (2023) Rotational grazing with cattle-free zones supports the coexistence of cattle and wild herbivores in African rangelands. Journal of Applied Ecology. 60. https://doi.org/10.1111/1365-2664.14493 (accessed 13 Jul 2025)

Herrero-Jáuregui C, Oesterheld M (2018) Effects of grazing intensity on plant species richness and diversity: a meta-analysis. Restoration Ecology 26:994–1002. https://doi.org/10.1111/oik.04893

Kaulfuß F, Rosbakh S, Reisch C (2022) Grassland restoration by local seed mixtures: New evidence from a practical 15-year restoration study. Applied Vegetation Science 25:e12652. https://doi.org/10.1111/avsc.12652 (accessed 16 Feb 2025)

Kiehl K, Kirmer A, Donath TW, Rasran L, Hölzel N (2010) Species introduction in restoration projects – evaluation of different techniques for the establishment of semi-natural grasslands in central and northwestern Europe. Basic and Applied Ecology 11:285–299. https://doi.org/10.1016/j.baae.2009.12.004

Kimball S, Lulow M, Sorenson Q, Balazs K, Fang YC, Davis SJ, O'Connell M, Huxman TE (2015) Cost-effective ecological restoration. Restoration Ecology 23:800–810. https://doi.org/10.1111/rec.12261

Knight ML, Overbeck GE (2021) How much does it cost to restore a grassland? Restoration Ecology 29:e13463. https://doi.org/10.1111/rec.13463

Koch C, Conradi T, Gossner MM, Hermann JM, Leidinger J, Meyer ST, Overbeck GE, Weisser WW, Kollmann J (2016) Management intensity and temporary conversion to other land-use types affect plant diversity and species composition of subtropical grasslands in southern Brazil. Applied Vegetation Science 19:589–599. https://doi.org/10.1111/avsc.12262

Kreuter UP, Workman JP (1994) Costs of overstocking on cattle and wildlife ranches in Zimbabwe. Ecological Economics 11:237–248. https://doi.org/10.1016/0921-8009(94)90204-6

Krob PM, Zortea RB, Bourscheid MRC, Ferreira PMA, Andrade BO, Overbeck GE (2021) The contribution of southern Brazil to the climate and biodiversity agenda: a synthesis of the Campos Sulinos. Bio Diverso 1:132–144

Lyons KG, Török P, Hermann JM, Kiehl K, Kirmer A, Kollmann J, et al. (2023) Challenges and opportunities for grassland restoration: a global perspective of best practices in the era of climate change. Global Ecology and Conservation 46:e02612. https://doi.org/10.1016/j.gecco.2023.e02612

MapBiomas (2023) Pampa – Appendix. Collection 8, Version 1. São Paulo: MapBiomas. 34 p. Available at: https://github.com/mapbiomas-brazil/pampa (accessed 15 Oct 2025)

MapBiomas (2024) RAD2023: annual deforestation report in Brazil 2023. MapBiomas, São Paulo, Brazil. http://alerta.mapbiomas.org. https://doi.org/10.1088/1748-9326/ac5193 (accessed 15 Oct 2025)

Matte A, Waquil PD (2021) Changes in markets for lamb in livestock family farming in Brazil. Small Ruminant Research 205:106535. https://doi.org/10.1016/j.smallrumres.2021.106535

McDonald S, Whitehead J, Dalal RC, Sanderman J, Bray SG, McCosker T, Arndt C, Baldock J, Cowie AL (2025) Grazing management for soil carbon in Australia: a review. Restoration Ecology 33:e14022. https://doi.org/10.1016/j.jenvman.2023.119146

Medeiros RB, Ferreira NR (2011) Control of biological invasion by South African lovegrass on a roadside by introducing grasses. Revista Brasileira de Zootecnia 40:260–269. https://doi.org/10.1590/S1516-35982011000200005

Menezes LS, Ely CV, Lucas DB, Minervini-Silva GH, Boldrini II, Overbeck GE (2018) Plant species richness record in Brazilian Pampa grasslands and implications. Brazilian Journal of Botany 41:817–823. https://doi.org/10.1007/s40415-018-0491-2

Menezes LS, Ely CV, Lucas DB, Minervini-Silva GH, Vélez-Martin E, Hasenack H, Trevisan R, Boldrini II, Pillar VD, Overbeck GE (2022) Reference values and drivers of diversity for South Brazilian grassland plant communities. Anais da Academia Brasileira de Ciências 94:e20201079. https://doi.org/10.1590/0001-3765202220201079

Mezzalira JC, Carvalho PCDF, Fonseca L, Bremm C, Reffatti MV, Poli CHEC, Trindade JKD (2011) Methodological aspects of ingestive behavior of grazing cattle. Revista Brasileira de Zootecnia 40:1114–1120. https://doi.org/10.1590/S1516-35982011000500024

Michel T, Overbeck GE (2024) Review of ecological restoration in the Brazilian Pampa. Anais da Academia Brasileira de Ciências 96:e20231283. https://doi.org/10.1590/0001-3765202420231283

Minervini-Silva GH, Overbeck GE (2020) Soil seed bank in a subtropical grassland under different grazing intensities. Acta Botanica Brasilica 34:298–307. https://doi.org/10.1590/0102-33062019abb0297

Nabinger C, Carvalho PCF (2009) Ecophysiology of pastoral systems: applications for their sustainability. Agrociencia Uruguay 13:18–27 http://hdl.handle.net/10183/273500

Nabinger C, Ferreira ET, Freitas AK, Carvalho PCF, Sant'Anna DM (2009) Animal production based on native grasslands: applications of research results. Pages 237–247. In: Pillar VD (ed) Southern Brazilian grasslands: conservation and sustainable use of biodiversity. Ministry of the Environment (MMA), Brasília, Brazil

Nunes CLR, Lucas M, Leitão FL, Perez NB, Trentin G (2012) Overseeding of ryegrass (Lolium multiflorum L.) in native grassland after post-flowering control of Eragrostis plana using the Campo Limpo machine. In:

Proceedings of the 21st Scientific Initiation Congress and 4th Scientific Exhibition, Federal University of Pelotas (UFPel), Pelotas, Brazil. http://www.alice.cnptia.embrapa.br/alice/handle/doc/941853 (accessed 23 Nov 2024)

Overbeck GE, Müller SC, Fidelis A, Pfadenhauer J, Pillar VD, Blanco CC, Boldrini II, Both R, Forneck ED (2007) Brazil's neglected biome: the South Brazilian Campos. Perspectives in Plant Ecology, Evolution and Systematics 9:101–116. https://doi.org/10.1016/j.ppees.2007.07.005

Overbeck GE, Scasta JD, Furquim FF, Boldrini II, Weir JR (2018) The South Brazilian grasslands – a South American tallgrass prairie? Parallels and implications of fire dependency. Perspectives in Ecology and Conservation 16:24–30. https://doi.org/10.1016/j.pecon.2017.11.002

Overbeck GE, Toma TSP, da Silveira-Filho RR, Dechoum MS, Fonsêca NC, Grelle CEV, et al. (2024) Brazil's natural grasslands under attack. Science 384:168–169. https://doi.org/10.1126/science.adp4923

Overbeck GE, Vélez-Martin E, Menezes LS, Anand M, Baeza S, Carlucci MB, et al. (2022) Placing Brazil's grasslands and savannas on the map of science and conservation. Perspectives in Plant Ecology, Evolution and Systematics 56:125687. https://doi.org/10.1016/j.ppees.2022.125687

Packard S, Mutel CF (2005) The tallgrass restoration handbook: for prairies, savannas, and woodlands. 2nd ed. Island Press, Washington, D.C.

Panella L (2022) Perspectiva de restauración espontánea y asistida en pastizales del Uruguay. PhD thesis. Universidad de la República, Facultad de Agronomía, Montevideo, Uruguay. https://www.colibri.udelar.edu.uy/jspui/handle/20.500.12008/34663 (accessed 31 Nov 2024)

Pereira Machín M (2017) Taita: uma colhedora de sementes de campo natural. Plan Agropecuario, Montevidéu, Uruguay. https://planagro.uy.planagropecuario.org.uy/uploads/magazines/articles/173_2670.pdf (accessed 17 Jan 2025)

Perez NB (2010) Controle de plantas indesejáveis em pastagens: uso da tecnologia campo limpo (Comunicado técnico, 72). Embrapa Pecuária Sul, Bagé, Brazil. http://ainfo.cnptia.embrapa.br/digital/bitstream/item/31725/1/CO-72-online.pdf (accessed 23 Nov 2024)

Perez NB (2015) Integrated method of pasture restoration MIRAPASTO: focus on Annoni grass. Embrapa Pecuária Sul, Brasília, DF, Brazil. https://www.embrapa.br/pecuaria-sul/busca-de-publicacoes/-/publicacao/1023496/metodo-integrado-de-recuperacao-de-pastagens-mirapasto-foco-capim-annoni (accessed 17 Aug 2024)

Pillar VD, Lange O (eds) (2015) Os Campos do Sul. Rede Campos Sulinos – Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil. https://doi.org/10.13140/RG.2.1.3873.3922

Pillar VD, Vélez E (2010) Extinção dos Campos Sulinos em Unidades de Conservação: um fenômeno natural ou um problema ético? Natureza & Conservação 8:84–86. https://doi.org/10.4322/natcon.00801014

Pyšek P, Pergl J, van Kleunen M, Dawson W, Essl F, Kreft H, Weigelt P, Wilson JR, Winter M, Richardson DM (2020) South Africa as a donor of naturalized and invasive plants to other parts of the world. In: van Wilgen BW, Measey J, Richardson DM, Wilson JR, Zengeya TA (eds) Biological invasions in South Africa. Invading nature – Springer series in invasion ecology. Vol 14. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-030-32394-3

Rai PK (2022) Environmental degradation by invasive alien plants in the Anthropocene: challenges and prospects for sustainable restoration. Anthropocene Science 1:5–28. https://doi.org/10.1007/s44177-021-00004-y

Raupp PP, Ferreira MC, Alves M, Campos-Filho EM, Sartorelly PAR, Consolaro HN, Vieira DLM (2020) Direct seeding reduces the costs of tree planting for forest and savanna restoration. Ecological Engineering 148:105788. https://doi.org/10.1016/j.ecoleng.2020.105788

Ribeiro CM (2009) Estudo do modo de vida dos pecuaristas familiares da Região da Campanha, Rio Grande do Sul. PhD dissertation. Universidade Federal do Rio Grande do Sul, Faculdade de Ciências Econômicas, Programa de Pós-Graduação em Desenvolvimento Rural, Porto Alegre, Brazil. https://lume.ufrgs.br/handle/10183/17261 (accessed 21 Nov 2024)

Rickert KG (1996) The influence of stocking rate on the ecological and economic sustainability of grazing systems. In: Elgersma A, Struik PC, van der Maesen LJG (eds) Grassland science in perspective. Wageningen Agricultural University Papers 96–4, International Farewell Symposium "Grassland Science in Perspective," Wageningen Agricultural University, The Netherlands, June 20, 1996. Wageningen Agricultural University, Wageningen, the Netherlands

Rolim RG, Rosenfield MF, Overbeck GE (2022) Are we ready to restore South Brazilian grasslands? Plant material and legal requirements for restoration and plant production. Acta Botanica Brasilica 36:e2021abb0155. https://doi.org/10.1590/0102-33062021abb0155

RS (Rio Grande do Sul) (2021) Atlas Socioeconômico do Rio Grande do Sul. 6th ed. Secretaria de Planejamento, Governança e Gestão, Porto Alegre, RS, Brazil

Schaub S, Finger R, Buchmann N, Steiner V, Klaus VH (2021) The costs of diversity: higher prices for more diverse grassland seed mixtures. Environmental Research Letters 16:094011. https://doi.org/10.1088/1748-9326/ac1a9c

Shaw N, Barak RS, Campbell RE, Kirmer A, Pedrini S, Dixon K, Frischie S (2020) Seed use in the field: delivering seeds for restoration success. Restoration Ecology 28:S276–S285. https://doi.org/10.1111/rec.13210

Silva JC (2014) Germination power of Pensacola (*Paspalum notatum Fluegge var. saurae* Parodi) and Pega-pega (*Desmodium incanum* DC) seeds. Undergraduate thesis. Bachelor in Animal Science, Universidade Federal do Pampa (UNIPAMPA), campus Dom Pedrito, RS, Brazil. http://dspace.unipampa.edu.br:8080/jspui/handle/riu/3011 (accessed 15 Feb 2025)

Silva TJM, Nabinger C, Mezzalira JC, Trindade JK, Silva CEG, Veiga GV, et al. (2007) Effect of deferred grazing on natural pastures on animal production. In: 19th Scientific Initiation Meeting, 21–26 October 2007, Porto Alegre, RS, Brazil. Book of abstracts. Federal University of Rio Grande do Sul, Porto Alegre, Brazil

Siota FP, Petruzzi H, Sawczuk N, et al. (2020) Rehabilitación de pastizales semiáridos: desarrollo de una cosechadora de semillas de gramíneas nativas. Multequina 29:157–164 (accessed 3 Feb 2025)

Soares AB, Carvalho PCF, Nabinger C, Trindade JPP, Trindade JK, Mezzalira JC (2011) Dynamic botanical composition in rangeland under forage allowances. Ciência Rural 41(8):1459–1465. https://doi.org/10.1590/S0103-84782011000800026 (accessed 13 Jul 2025)

Teague WR, Dowhower SL (2003) Patch dynamics under rotational and continuous grazing management in large, heterogeneous paddocks. Journal of Arid Environments 53:211–229. https://doi.org/10.1006/jare.2002.1036

Thomas PA, Müller SC, Dutra-Silva R, Brunes A, Nabinger C, Minervini-Silva GH, Marins T, Rolim R, Overbeck GE (2025) Germination of South Brazilian grassland species: state of knowledge and research needs for advancing grassland restoration. Acta Botanica Brasilica 39:e20250006. https://doi.org/10.1590/1677-941X-ABB-2025-0005

Thomas PA, Overbeck GE, Pillar VDP, Müller SC, Bencke GA (2024) Ecological restoration of Campos Sulinos grasslands. In: Overbeck GE, Pillar VDP, Müller SC, Bencke GA (eds) South Brazilian grasslands. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-031-42580-6_20

Thomas PA, Schüler J, Boavista LR, Torchelsen FP, Overbeck GE, Müller SC (2019) Controlling the invader *Urochloa decumbens*: subsidies for ecological restoration in subtropical Campos grassland. Applied Vegetation Science 22:1–12. https://doi.org/10.1111/avsc.12407

Vélez E, Chomenko L, Schaffer W, Madeira M (2009) An overview of conservation initiatives in the Southern Brazilian Grasslands. Pages 237–247. In: Pillar VDP (ed) Southern Brazilian Grasslands: Conservation and Sustainable Use of Biodiversity. Ministry of the Environment (MMA). Available at:. http://antigo.mma.gov.br/publicacoes/biomas/category/64-pampa.html?download=1060:campos-sulinos-conservacao-e-uso-sustentavel-da-biodiversidade

Vieira MS, Overbeck GE (2020) Small seed bank in grasslands and tree plantations in former grassland sites in the South Brazilian highlands. Biotropica 52:718–726. https://doi.org/10.1111/btp.12785

Wilson JB, Peet RK, Dengler J, Pärte M (2012) Plant species richness: the world records. Journal of Vegetation Science 23:796–802. https://doi.org/10.1111/j.1654-1103.2012.01400.x

Zabala-Pardo D, Lamego FP (2024) Biology of the invasive species *Eragrostis plana* in southern Brazil: what have we learned and how may this help us manage it? Weed Research 64:107–118. https://doi.org/10.1111/wre.12615

Supporting Information

The following information may be found in the online version of this article:

Table S1. Detailed restoration costs by step across different scenarios Rev1.

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