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Short-term effectiveness of *Ulex europaeus* control measures in Uruguay

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Case Study

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Abstract

Gorse (*Ulex europaeus* L.) is a leguminous shrub native to western Europe, voluntarily introduced into Uruguay for ornamental purposes. It is considered among the 100 most problematic invasive species in the world. In Uruguay, it seriously affects both livestock and forestry systems. We evaluated different weed management techniques on a cattle farm invaded by *U. europaeus*, in the region of Lavalleja. In spring 2020, three treatments were applied—cutting only (C); cutting and grazing (CG); and cutting, applying herbicide, and grazing (CHG)—to 18 plots ranging from 25 m^2 to 50 m^2. Following treatment, *U. europaeus* regrowth and the height and the perimeter of five plants per plot, as well as seedling recruitment, were assessed over 16 mo. The livestock were cattle (*Bos* sp.) and sheep (*Ovis* sp.). The CHG treatment was the most effective in inhibiting the regrowth of *U. europaeus*, while grazed plants grew less in height compared with those excluded from grazing (CG = 62.3 cm ± 1.9, C = 84.8 cm ± 2.0, $P < 0.05$). However, by the end of the study, seedling recruitment was lower in the C treatment (C = 0.3 ± 0.3, CG = 3.1 ± 1.8, CHG = 8.6 ± 4.6 seedlings m^{-2}, $P < 0.05$), where increased height of herbaceous vegetation may have reduced the success of the emergence and establishment of regenerants. These results encourage further long-term study of this invasive species' response, as well as an evaluation of the potential impacts of these control measures on non-target species.

Introduction

Gorse (*Ulex europaeus* L.) is a leguminous shrub native to western Europe, belonging to the Fabaceae family. It is considered to be among the 100 most problematic invasive species in the world (Lowe et al. 2000). *Ulex europaeus* is highly successful in occupying degraded, low-fertility, or eroded soils, and its dense thickets inhibit the colonization and establishment of native species (Beltrán et al. 2014). Land abandoned after agricultural and livestock use presents ideal conditions for *U. europaeus* establishment (Altamirano et al. 2016). Degraded environments produce changes in the composition, abundance, and distribution of native species (Hobbs and Huenneke 1992; Ranyard et al. 2018). Factors such as road and highway density, natural grassland cover, and aridity affect the invasion level in grasslands (Guido et al. 2016). In a study conducted in Rio Grande do Sul (Brazil), Leon Cordero et al. (2016) detected a high invasion in overgrazed grasslands and silvicultural production, while they did not record any invasion in native forests. *Ulex europaeus* has become a successful invasive species, because in addition to fixing nitrogen, it is tolerant to various edaphic conditions, produces a large number of seeds tolerant to high temperatures, and has the ability to resprout from stumps following mechanical or physical damage (Broadfield and McHenry 2019). Additionally, it is notorious for rapid fuel accumulation and high flammability, which increase the risk of wildfire (Anderson and Anderson 2010).

In Uruguay, *U. europaeus* was voluntarily introduced at the end of the 19th century for ornamental and living fence purposes (Porcile 2001). The current situation in the country is a growing concern, impacting multiple sectors of society, including agriculture and related institutions. In this sense, the Invasive Exotic Species Committee of Uruguay (Comité de Especies Exóticas Invasoras) has defined this species as one of the 42 invasive species nationwide (Aber et al. 2014). Guido et al. (2024) identified it as the most frequent and abundant invasive species in the eastern region of the country. Areas heavily infested with *U. europaeus* are nearly impassable due to its dense, spiny growth. This harms pastoral activity, significantly affecting family producers with smaller farms, as it interferes with herd management and forage availability (Tassano et al. 2024). In silvicultural areas, *U. europaeus* has been observed to proliferate in the shrub layer, as a consequence of tillage, pruning, and thinning (Porcile 2001). Previous management approaches in eastern Uruguay include prescribed fire, cutting, and

Management Implications

Ulex europaeus (gorse) is a shrub of European origin that has spread across the eastern region of Uruguay, invading grasslands and posing a challenge to the livestock and forestry production sectors. Farmers employ various control methods, often in combination, yet the outcomes remain highly variable and poorly systematized. While some national studies have suggested tools and techniques for control, publications assessing their effectiveness and impact are scarce. On a livestock farm, we implemented three of the most commonly used control practices in the region: cutting only, cutting followed by herbicide application on the stump (both performed once at the beginning of the study), and grazing, in an area with *U. europaeus* patches. The herbicide was highly effective in preventing resprouting and limiting the growth of the invasive species over the 16-mo study period. Grazing reduced the number of sprouts per stump and the height of resprouted stumps. In the case of *U. europaeus* seedlings, no consistent pattern was observed, likely due to the short study period. However, there was a tendency toward a decrease in seedling numbers in the plots excluded from grazing, where the height of the herbaceous vegetation was greater. Applying herbicide to cut stumps minimizes its impact on non-target plant species and reduces the need for frequent applications.

herbicides (Balero 2015; Castro 2011; Quiñones et al. 2015; Tassano et al. 2024). Tassano et al. (2024) reported that in a survey of 31 farmers and agricultural technicians in the eastern region, 97% considered the combination of chemical and mechanical controls to be the most effective. However, when defining the strategy for use, the majority opted for the individual application of chemical control or grazing management.

Mechanical methods, such as cutting, rapidly reduce *U. europaeus* biomass. However, this is only a short-term solution, as it causes the plants to quickly regrow (Hoshovsky 1986; Udo et al. 2018; Viljoen and Stoltsz 2007).

The use of herbicides is another widely employed control method, and their application can be foliar and on stumps. According to Viljoen and Stoltsz (2007), foliar application in this species may be less effective due to the characteristics of its thorny leaves, while application on freshly cut stems is better for herbicide absorption. Among the recommended herbicides are picloram, glyphosate, and triclopyr. In Uruguay, Castro (2011) made a series of recommendations for the use of triclopyr, glyphosate and vegetable oils at different stages of development of the invasive species in livestock and silvicultural systems. The effectiveness of these herbicides is high (between 80% and 100%); however, they can affect non-target species. This constitutes a problem for the restoration of vegetation cover, which would act as a barrier to the growth of *U. europaeus* seedlings (Broadfield and McHenry 2019).

Another approach to managing this invasive species is grazing (Radcliffe 1985; Roberts and Florentine 2021; Tassano et al. 2024). Grazing by domestic livestock negatively affects the growth and development of *U. europaeus* seedlings, and adjusting grazing pressure can improve the growth of desirable pasture species, so that they are more competitive and able to resist invasion (Popay and Field 1996; Roberts and Florentine 2021). However, this management may not enough to control the invasive and that combined measures are required to achieve this objective. Systematizing existing information on the effects of *U. europaeus* control methods is crucial, particularly in the eastern region, where its invasion has been most severe (Tassano et al. 2024). Uncertainties arise regarding management strategies, due to the numerous situations in which *U. europaeus* stands are found in relation to density, age, and spatial distribution, among other aspects.

In this context, this study aimed to assess the effects of integrated weed management on the regeneration and recruitment of *U. europaeus* within a grazed grassland on a family-run cattle farm in the country's eastern region. Specifically, we evaluated the effects of various management practices and their combinations on the growth, regrowth, and seedling recruitment of *U. europaeus*. The questions we sought to answer were: (1) Is the use of herbicide combined with grazing an effective method for managing adult *U. europaeus* plants? (2) What are the effects of these practices on *U. europaeus* recruitment?

The results obtained from the study are expected to assist farmers in successful management of this troublesome species as well as improve and increase the available grazing area for domestic livestock, thereby increasing productivity.

Materials and Methods

This experiment was carried out on a family farm invaded by *U. europaeus* located in Lavalleja, in the eastern region of Uruguay (34.07°S, 55.12°W; Figure 1), in grasslands under mixed cattle (*Bos* sp.) and sheep (*Ovis* sp.) grazing with a high stocking rate for most of the period under study, and a cattle to sheep relationship of 1:1.5. These grasslands are characterized by a predominance of native C_4 grasses [i.e., *Dichanthelium sabulorum* (Lam.) Gould & C.A. Clark (hemlock rosette grass), *Paspalum dilatatum* Poir. (dallisgrass), *Axonopus fissifolius* (Raddi) Kuhlm (common carpetgrass), followed by C_3 grasses (*Piptochaetium montevidense* (Spreng.) Parodi, *Nassella neesiana* (Trin. & Rupr.) Barkworth (Uruguayan needlegrass)] and forbs (i.e., *Oxalis* sp.). To quantify stocking rate, livestock unit (unidad ganadera [UG]) was calculated according to Boné and Perrugoria (2011). It represents the live weight of the animal according to breed and category. The livestock unit value for the farm under study was 2.03. The study site is located in a landscape dominated by rocky hill ranges, with a predominance of shallow soils with a grassland matrix. Eutrophic and Subeutrophic Brunosols are the dominant soils. An area invaded by numerous *U. europaeus* patches was selected on the middle and lower slopes of a hill. Total *U. europaeus* cover was 10%, in a total of 4.7 ha of grassland, and *U. europaeus* plants were approximately 15 to 25 yr old. Based upon the variation of patch size available for study, plots of two different sizes were selected. These included nine 25-m^2 plots and nine 50-m^2 plots. In spring (November 2020), for each plot size, three treatments were assigned and applied to plots according to a randomized complete block design: (1) cutting only (C), which served as an appropriate control to evaluate resprouting; (2) cutting + grazing (CG); and (3) cutting + herbicide + grazing (CHG). Each treatment was replicated on three plots in each plot size. The blocking factor was the site's topography. As foliar spraying of mature *U. europaeus* is complicated by its spiny, scale-like leaves and efficacy may vary with plant age and growth stage, this study concentrated on spraying freshly cut stumps as a more reliable application technique (Broadfield and McHenry 2019).

Cuts were made with a chainsaw at 20-cm height from the ground, just below the height at which the stems typically branch (Thevenoux et al. 2022). All cut shoots were then removed from the experimental area. For the grazing component of the study, C treatment plots were enclosed with an electric fence to prevent

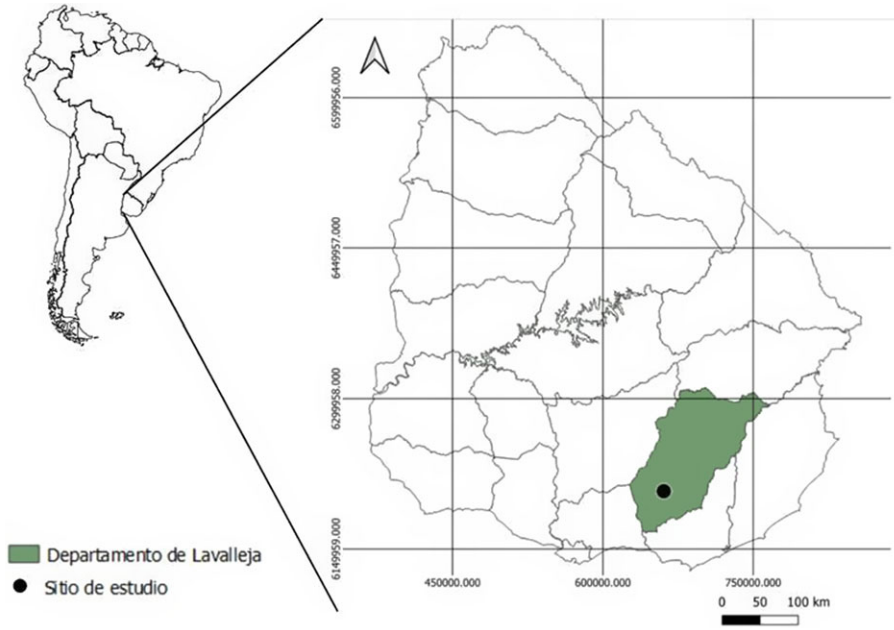

Figure 1. Location of the study site in Lavalleja, Uruguay.

grazing, while grazing was continuous throughout the entire study period for the CG and CHG treatments. Tordon® 101, containing 240 g ae L^{-1} 2,4-D and 64 g ae L^{-1} (picloram, Dow Agrosciences Argentina) was applied on the stumps immediately after cutting (Broadfield and McHenry 2019). Five stumps were subsequently marked in each plot to be monitored during the experiment. The mean stem diameter was 3.14 cm ± 0.11 (SD) for all stumps in the plots.

In spring 2020 (December), autumn (April) and spring (October) 2021, and autumn (April) 2022, the following variables were recorded for each marked stump: plant height, plant perimeter, and number of seedlings per square meter. Perimeter was measured at the edge of the shoots with the largest diameter parallel to the ground. For the number of seedlings per square meter (up to 15 cm in height), a 1-m^2 quadrat with the *U. europaeus* stump placed at its center was used. At each sampling time, seedlings were not removed in the area surrounding the adult *U. europaeus* plant. Because *U. europaeus* is a multistemmed plant, the proportion of stems that resprouted per stump and the number of resprouts per stump were only recorded on the first date.

Perimeter growth rate (PGR) was calculated for two periods (period 1: December 2020 to April 2021; period 2: October 2021 to April 2022) as PGR= $(P_f - P_i)/N_M$, where P_f is the final perimeter, P_i is the initial perimeter, and N_M is the number of months of each period. The height growth rate (HGR) was calculated in the same way. At the end of the study period, the average height of herbaceous vegetation (grasses, forbs, and graminoids) in each quadrat was also measured.

To further characterize the site, air temperature and humidity were continuously monitored throughout the study using a Hobo U23 Pro v2 automatic recorder (Nebraska, USA). Drought was characterized based on precipitation relative to the climatic mean precipitation value obtained from the Uruguayan Institute of Meteorology (Instituto Meteorológico n.d.). Data were grouped into two periods defined by growth rate: period 1 (from December 1, 2020, to April 13, 2021) and period 2 (from October 13, 2021, to April 6, 2022).

A generalized linear mixed-effects model (GLMM) accounting for subsampling error and/or repeated measures over time was used. Repeated measurements were accounted for by treating the plots as split-plot design over time. The plot was included as a random effect to account for the correlation between repeated measurements taken from the same plot. Perimeter, height, and growth rate were assumed to follow a normal distribution, while a Poisson distribution was assumed for the number of resprouts per stump and a negative binomial distribution for the number of seedlings per square meter (recruitment). Treatment, block, plot size, date, and their interactions were considered fixed effects, except for the proportion of stems resprouted and the number of resprouts per stump, which did not include the date effect, as it was measured only once (1 mo after treatments were applied). All fixed effects were tested using ANOVA or analysis of deviance (a generalization of the ANOVA for GLMMs), and multiple comparisons were conducted with Tukey's test ($P < 0.05$). Because plot size and its interactions were not significant in any case, mean comparisons were performed for treatment means or treatment by date interaction means. All statistical analyses were performed using R software (R Core Team 2023).

Results and Discussion

Recruitment and Growth of Ulex europaeus Plants

One month after the treatments were applied (December 2020), the mean proportion of stems that resprouted and the number of resprouts per stump were different among treatments (Table 1), with CHG treatment achieving significantly lower values for both variables. At the end of the study period, this was the only treatment to result in disintegrated stumps (18%) (Table 2).

For plant perimeter and height, treatments and date effects were significant, as well as their interaction ($P < 0.05$). In the case of perimeter, CHG was the only treatment that differed significantly from the C treatment, on all dates except for date 1 (Figure 2A). For plant height, from the third date onward, all treatments had different average height values (Figure 2B), with C and CHG treatments showing the most contrasting responses over time.

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Table 1. Means and standard errors (± SE) for the proportion of stems resprouted and the number of resprouts per stump 1 mo after the treatments (C, cutting; CG, cutting + grazing; CHG, cutting + herbicide + grazing) were applied[a].

Treatment	Proportion of stems resprouted		No. of sprouts per stump	
C	0.9 ± 0.03	A	147.4 ± 24.5	a
CG	0.9 ± 0.03	A	125.5 ± 20.7	b
CHG	0.1 ± 0.03	B	7.9 ± 1.4	c

[a]Distinct letters in columns indicate significant differences between treatments according to Tukey's test ($P < 0.05$).

Table 2. Proportion of stumps resprouted and disintegrated 16 mo after the treatments (C, cutting; CG, cutting + grazing; CHG, cutting + herbicide + grazing) were applied.

	Proportion of stumps	
Treatment	Resprouted	Disintegrated
C	1.0	0
CG	1.0	0
CHG	0	0.18

Regarding monthly growth rates, in all cases, the CHG treatment had the lowest growth rate ($P < 0.05$), both in height and perimeter (Figures 3 and 4). In the case of HGR, during the first period, all treatments had different effects (CHG < CG < C), while in period 2, the effect of the CHG treatment was different from the effect of the other two (Figure 3). In the case of PGR, the CHG treatment resulted in significantly lower values than the other two treatments for both periods (Figure 4).

The number of seedlings was compared between treatments for each date, recording differences on the second and fourth sampling dates (Table 3), where the CHG treatment differed from the control at the end of the study period. All treatments indicated an abrupt reduction in seedling abundance in autumn 2022 (April).

The average height of herbaceous vegetation (cm) at the end of the study period was significantly higher ($P < 0.05$) in the C treatment, compared with the other two treatments (C = 13.01 ± 1.97, CG = 5.31 ± 1.95, CHG = 2.99 ± 1.95, mean and SE of each treatment).

Environmental Variables

Total rainfall amounted to 490 mm in period 1 and 450 mm in period 2, with drought conditions occurring in both periods. Compared with the average climatic rainfall for each period, the precipitation deficit was 110 mm in period 1 and 364 mm in period 2. Additionally, period 2 exhibited higher maximum air temperatures and greater thermal amplitude than period 1 (Table 4).

The control strategies tested were partially successful, depending on the variable of interest. Thus, a control strategy including an herbicide application, preliminarily confirms the efficacy in reducing and preventing plant regrowth, as reported by Roberts and Florentine (2021). CG was, in general, less effective than the cutting + herbicide + grazing treatment in reducing the proportion of resprouted plants (Thevenoux et al. 2022). However, this treatment reduced the number of resprouts per stump and HGR compared with the C treatment in the first sampling period.

Applying herbicide immediately after cutting negatively affected the regrowth of plants in the proportion of stems resprouted and the number of resprouts per stump. After 16 mo, 18% of the herbicide-treated plants disintegrated completely or partially, and the number of plants that resprouted was zero. Likewise, the growth rates in perimeter and height were zero or even negative for both periods. These results align with those obtained by Balero (2015) in a *U. europaeus*–invaded pasture, where the same integrated stump management measures were applied, leading to successful control of the invader. However, 12 mo after the treatments, plant regrowth was observed (R Balero, personal communication). This regrowth is attributed to the capacity of underground stems to regenerate, drawing on carbohydrates stored in the lignotuber, a structure adapted to disturbances (Canadell and López-Soria 1998; Perry et al. 2014; Thevenoux et al. 2022). Long-term monitoring is essential to assess the regrowth from stumps.

From the first year after cutting, *U. europaeus* plants subjected to grazing had lower height than those excluded from grazing, which suggests that livestock were utilizing the tender new regrowth at the shoot apex. Within the study period, we found that grazing influenced the number of shoots per stump and plant height growth; however, there is insufficient evidence to determine whether these effects would be significant in the long term (Broadfield and McHenry 2019). Although our study employed a mixed continuous grazing regime, the literature suggests that intensive sheep grazing can reduce *U. europaeus* regeneration (Leon Cordero et al. 2016). Furthermore, different classes of livestock selectively graze various life stages of *U. europaeus*: cows tend to graze seedlings, while sheep and horses (*Equus* sp.) graze adult plants (Leon Cordero et al. 2016; Roberts and Florentine 2021). Although we did not monitor livestock behavior, we did observe sheep consuming the apices of the new branches of *U. europaeus* plants on several occasions.

Regarding the abundance of seedlings, all treatments showed an abrupt reduction in autumn 2022 (April), likely in response to the drought and a greater temperature range in the period from October 2021 to April 2022. Extreme water stress, associated with low seedling survival in winter, could influence establishment success (Christina et al. 2022). Concerning the effect of treatment, ungrazed plots (C) ended up with fewer seedlings than those of the herbicide treatment (CHG), contrary to what has been reported by other studies (Ghanizadeh and Harrington 2019; Leon Cordero et al. 2016). These authors suggest that grazing can reduce seedling emergence and establishment. In ungrazed plots, the average height of the forb and grass cover was three and four times higher than CG and CHG, respectively. These conditions may have resulted in lower light availability and increased competition with grasses and forbs present, which may have reduced seed germination and seedling survival (Thevenoux et al. 2022). In grazed plots, the animal load was high (2.03 UG) during the study period. For the study region, recommended animal load values are reported to range between 0.65 and 0.70 UG (Boné and Perrugoria 2011). High and continuous grazing pressure on the system could lead to sparse and low herbaceous vegetation cover, thereby reducing the competitive capacity of the species that comprise it (Broadfield and McHenry 2019). Maintaining vegetation cover can help prevent or reduce *U. europaeus* invasion. To enhance the competitiveness of the vegetation cover, one management measure is to sow forage crops such as white clover (*Trifolium repens* L.) and perennial ryegrass (*Lolium perenne* L.), which can compete with *U. europaeus* seedlings for light (Hartley and Phung Hong 1979). However, it would be beneficial to test this effect using native grasses typical of the region's grasslands, particularly those present in the study area's species mix (León Cordero et al. 2016), such as *Axonopus fissifolius* Chase, *Axonopus argentinus* Parodi, *Paspalum notatum* Flueggé (bahiagrass), or *P. dilatatum*. Likewise, grazing plus a regime that allows

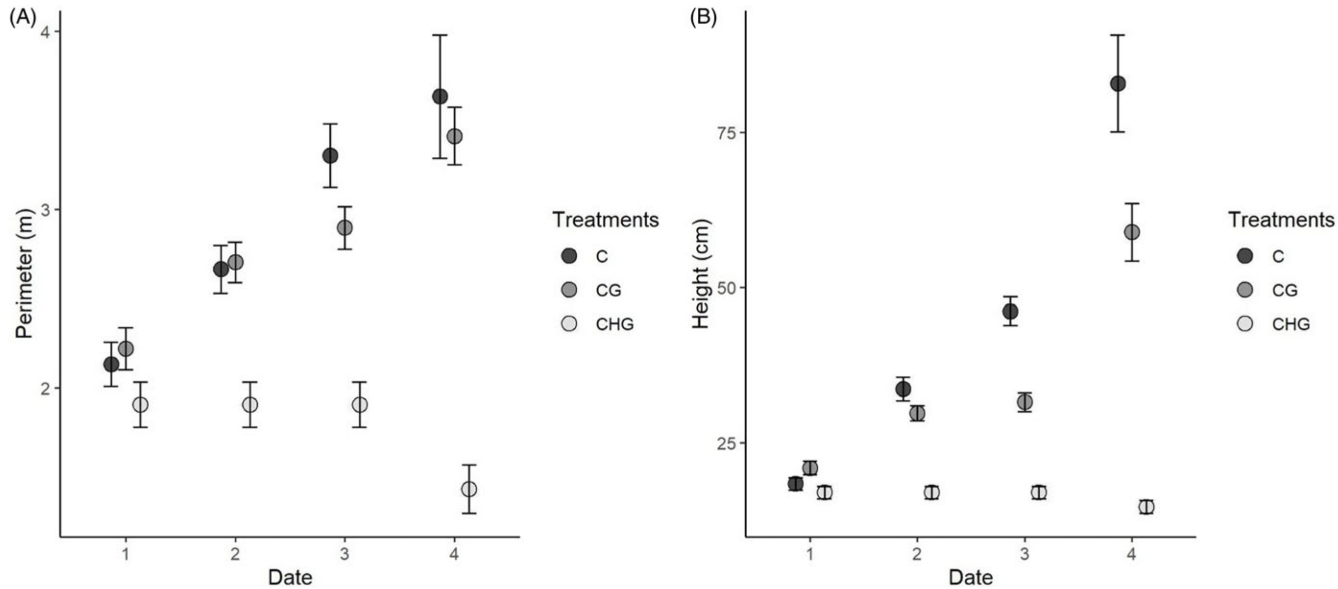

Figure 2. Mean (circles) ± SE (error bars) of perimeter (A) and height (B) average of *U. europaeus* plants in each treatment (C, cutting; CG, cutting + grazing and CHG, cutting + herbicide + grazing) for each sample date (1, Spring 2020; 2, Autumn 2021; 3, Spring 2021; 4, Autumn 2022).

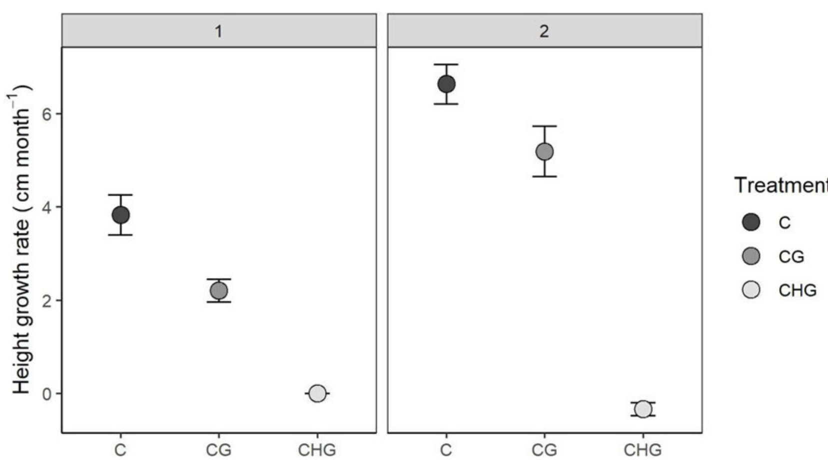

Figure 3. Mean (circles) ± SE (error bars) of height growth rate (cm mo^{-1}) of *Ulex europaeus* plants in each treatment (C, cutting; CG, cutting + grazing; CHG, cutting + herbicide + grazing) for period 1 (1: spring 2020–autumn 2021) and period 2 (2: spring 2021–autumn 2022).

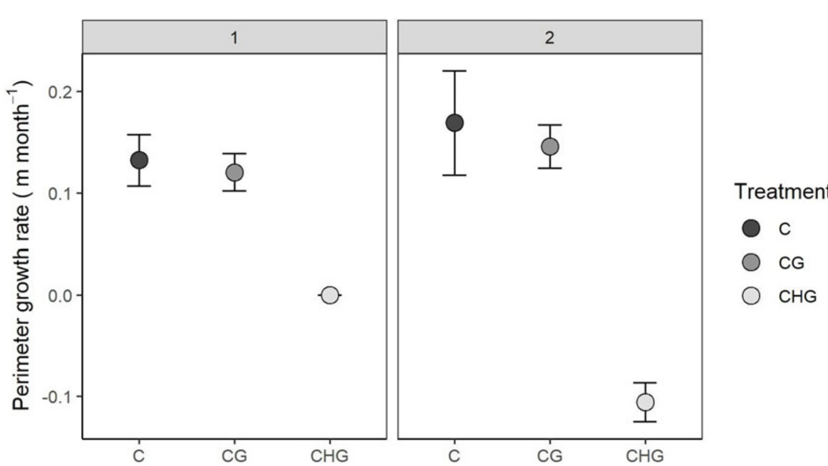

Figure 4. Mean (circles) ± SE (error bars) of perimeter growth rate (m mo^{-1}) of *Ulex europaeus* plants in each treatment (C, cutting; CG, cutting + grazing; CHG, cutting + herbicide + grazing) for period 1 (1: spring 2020–autumn 2021) and period 2 (2: spring 2021–autumn 2022).

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Table 3. Number of *Ulex europaeus* seedlings (± SE) per square meter (n m^{-2}) recruited by treatment (C, cutting; CG, cutting + grazing; CHG, cutting + herbicide + grazing) in the four sampling seasons in Lavalleja, Uruguay[a].

	Sampling season							
Treatment	Spring 2020		Autumn 2021		Spring 2021		Autumn 2022	
C	0.9 ± 0.5	a	65.5 ± 23.5	ab	37.3 ± 21.0	a	0.3 ± 0.3	a
G	3.3 ± 2.0	a	119.9 ± 37.9	b	94.1 ± 36.0	a	3.1 ± 1.8	ab
CHG	0.6 ± 0.3	a	30.1 ± 9.4	a	83.4 ± 31.9	a	8.6 ± 4.6	b

[a]Distinct letters in columns indicate significant differences between treatments for each sampling season (P < 0.05).

Table 4. Mean, maximum and minimum temperature, temperature range, and relative humidity for period 1 (1 December 2020 - 13 April 2021) and period 2 (13 October 2021 - 6 April 2022) in the study area.

Period	Mean temperature	Maximum temperature	Minimum temperature	Temperature range	Relative humidity
	------------------------°C------------------------				%
Period 1	21.1	27.8	15.2	12.6	74.9
Period 2	21.5	29.0	14.2	14.9	73.6

the maintenance of a competitive herbaceous cover, which favors the biotic resistance of the resident community, constitutes an integral management strategy that has given auspicious results in the control and spread of invasive species (Bakker et al. 2019).

In summary, the results obtained in our study show that combined management strategies would be the most effective way to prevent the establishment and growth of *U. europaeus* plants (Roberts and Florentine 2021). Our results suggest that in relation to adult *U. europaeus* plants, the treatment combining herbicide and grazing (CHG) is the most effective in inhibiting regrowth, even causing plant death.

Regarding the effects of treatment on recruitment, no consistent or sustained pattern was observed over time, indicating the need for a longer evaluation period. The resident plant community, particularly pasture height, may play an inhibitory role in *U. europaeus* germination, emergence, and seedling establishment by competing for resources (e.g., light). In our study, a trend of decreased seedling abundance was observed in the control treatment plots at the end of the study period. This suggests a potential inhibitory effect of vegetation cover on the emergence and establishment of *U. europaeus* seedlings.

Final Considerations

This study aimed to systematize the results of *U. europaeus* management strategies in a region where it presents a significant challenge for both the livestock sector and grassland conservation. We recognize that, in addition to assessing the effects on the invasive species, it is crucial to understand the impacts of these methods on the herbaceous community that forms the matrix of these sites. This information is essential for developing strategies to restore native vegetation.

Control measures to contain or reduce the invasion may vary depending on the density, spatial distribution, and age of the invasive plants; the conditions of the receiving environment, such as the state of the resident community, land use, and topographical variables; and the socioeconomic dimension. It is essential for the local community to be organized in order to carry out control efforts in the affected area. Institutional support facilitates the organizational and operational aspects of controls and monitoring (material and logistical), which will allow more sustained successes over time.

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Competing interests. The authors declare no conflicts of interest.

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