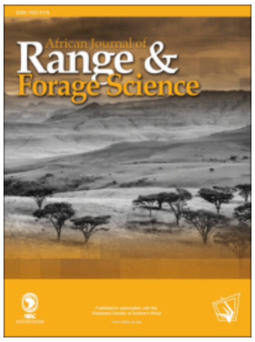

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Research Note

The control of the encroaching shrub *Seriphium plumosum* (*L.*) Thunb. (Asteraceae) and the response of the grassy layer in a South African semi-arid rangeland

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Large-scale bush encroachment within rangelands is of increasing concern for land users. The aggressive encroachment of the woody shrub *Seriphium plumosum* (*L.*) Thunb. (Asteraceae), previously known as *Stoebe plumosa*, has resulted in a reduction in productivity, causing large socio-economic challenges, such as loss of productive land. In this study, we evaluated the efficacy of four herbicides in combination with mechanical removal of *S. plumosum*. We measured shrub mortality, regrowth and examined the grass species richness and cover after the execution of the control methods. Furthermore, we compared the productivity of the paddock where *S. plumosum* had been controlled with a neighbouring unencroached paddock. Five months after herbicide application, the total mortality of all shrubs was recorded. Grass species richness and cover were higher when shrubs had been mechanically removed before herbicide application. Additionally, the use of the non-species-specific herbicide (tebuthiuron) resulted in lower species richness and cover, compared to application of a species-specific herbicide (metsulfuron-methyl). The productivity of the treated area increased in the year after application. Our results show that when controlling *S. plumosum* the manual removal of shrubs before applying herbicides can improve the regeneration of the grass layer. This combination of mechanical and chemical control is effective in combating *S. plumosum* encroachment and increases forage yields in semi-arid rangelands.

Keywords: bankrupt bush, bush encroachment, control method, herbicide, Stoebe plumosa

The increase in woody plant density (i.e. bush and shrub encroachment) has become a problem in grasslands and savannas as it has consequences for net primary productivity, vegetation structure, and the diversity of these ecosystems (Ward 2005; Archer et al. 2017; Russel et al. 2019). Woody plant encroachment is caused by the simultaneous occurrence of a variety of factors (Archer et al. 2017), including climate variability and change, lack of fire and browsing regimes, management practices, and specific plant species adaptation (Kgosikoma and Mogotsi 2013; Archer et al. 2017). This shift in the vegetation type and structure within rangelands often leads to decreased grazing capacity, reduced land value and a loss in biodiversity (Chief et al. 2012). Over the past decade, the woody shrub *Seriphium plumosum* (Asteraceae) (previously known as *Stoebe plumosa*), commonly known as ‘bankrupt bush’, has encroached primarily into semi-arid rangelands in South Africa (Bezuidenhout 2012; Adepoju et al. 2020). *Seriphium plumosa* is a grey, perennial shrub with a height and spread of approximately 1 m. The shrub has thin, wiry stems that have bundles of small, heather-like leaves with small flowers surrounded by pale brown bracts with purple disc florets arranged in large plumes (Van Wyk et al. 1988). Even though the specific habitat preferences of *S. plumosum* are not well known, Adepoju et al. (2020) found that it occurs in high densities in areas with low rainfall, high diurnal temperature variation and high livestock grazing activity.

The Department of Agriculture, Land Reform and Rural Development found evidence of encroachment by *S. plumosum* in seven of South Africa’s nine provinces (Graham et al. 2020). This is of major concern since studies conducted by Snyman (2012a), Avenant (2015) and Nkosi et al. (2018) found that this woody shrub is mostly unpalatable to livestock, has no natural enemies and can outcompete palatable grass species. If encroachment of this aggressive shrub becomes unmanageable, it has the potential to cause great economic loss to South African livestock production. The encroachment of *S. plumosum* can lead to land degradation that impacts food security and natural resource conservation strategies, and lead to declines in biodiversity and ecosystem functioning (Archer 2010; Graham et al. 2020).

Du Toit and Sekwadi (2012) have reported that the chemical methods that are commonly used to control woody shrubs are often economically unfeasible and can cause long-term damage to the ecosystem due to the high mortality of non-target species and the long-term retention of the active ingredient in the soil. To ensure the sustainability of rangelands, it is imperative to find effective, environmentally compatible methods to control the expansion of *S. plumosum* effectively. In addition, the response of the grass layer to *S. plumosum* encroachment and its subsequent control is of key importance in rangelands, as grasses are the main sustenance for livestock (Avenant 2015; Pule et al. 2016; Hadebe et al. 2021).

Avenant (2015) and Nkosi et al. (2018) found that the use of environmentally compatible herbicides, in combination with mechanical control methods, showed promising results for controlling *S. plumosum.* One of the main concerns when using chemical controls for woody plant encroachment is the impact these herbicides have on the livestock fodder production and management systems (Du Toit and Sekwadi 2012). In many cases, chemical control must be enforced multiple times before effective results can be seen. Spot spraying may also be necessary in the year following treatment in the event of regrowth, as well as the treatment of individuals that were overlooked during the initial herbicide application.

In this study, the effectiveness of a combination of mechanical and chemical control on *S. plumosum* mortality was investigated. In addition, we examined how mechanical and chemical control of shrubs affected the grass species richness and cover. Furthermore, we compared the grass production and grazing capacity pre- and post-shrub control, with an area not encroached by *S. plumosum*.

The study was conducted between November 2019 and March 2021 on the farm Booyskraal (26°00′49″ S, 27°10′58″ E, altitude 1 533 m above sea level) in the North-West province, South Africa. The study area is in a semi-arid region with an approximate average annual rainfall of 600 mm, typically occurring in the summer months from November to April. Mucina and Rutherford (2006) classified the study area as Rand Highveld Grassland, with the dominant perennial grass species identified as *Setaria sphacelata var. torta, Eragrostis curvula, Diheteropogon amplectens* and *Melinis repens.*

The study area is underlain by the rocks of the volcano–sedimentary Ventersdorp Supergroup (McCarthy and Rubidge 2006), which typically form shale and rocky quartzite hills and ridges. The study area has a Glenrosa soil type with a sandy soil texture and an average pH of 4.88 (Soil Classification Work Group 1991).

In one paddock of approximately 0.02 km^2 that was heavily encroached by *S. plumosum*, 27 plots of 9 m^2 were randomly placed with a minimum distance of 10 m between plots. The density of *S. plumosum* ranged from 5 to 10 individuals per plot. Each plot was assigned a combination of a herbicide application (i.e. tebuthiuron, metsulfuron, triclopyr A and B), and mechanical treatment in which all shrubs were either cut and removed or left in place, following a full factorial design with three replicates per treatment combination. An additional three plots were left untreated and served as controls [4 herbicides × 2 mechanical treatments (cut vs uncut) × 3 replicates + 3 controls = 27 individual plots].

Mechanical control was implemented by cutting all the shrubs in a plot to a height of 5 cm above the ground and removing the cut shrubs from the plot to expose the ground surface. The herbicides as well as an adjuvant (Actipron Oil) were applied after a 28-day holding period to ensure sufficient shrub regrowth after mechanical control (De Ruiter et al. 1997).

In this study, four different herbicides with the respective active ingredients tebuthiuron, metsulfuron-methyl, triclopyr A and triclopyr B were used. Tebuthiuron is a non-selective, broad-spectrum herbicide that is applied as granules, which are absorbed by plant roots after a rain event. Over-dosage is a huge risk and usually leads to soil sterilisation, which is why tebuthiuron is often not recommended to control high densities of encroaching shrubs. Metsulfuron-methyl is a foliar herbicide that is applied as a water-based solution to actively growing plants. Triclopyr is a systemic herbicide that, when applied to actively growing plants, acts by mimicking the plant enzyme auxin, causing the plant to rapidly take up triclopyr through its roots and leaves, resulting in uncontrolled plant growth and death within a few weeks (Ecoguard 2021). Two types of herbicides with the active ingredient triclopyr were used in this study. The differences between these two herbicides are the formulation of the generic products.

Mortality of all *S. plumosum* shrubs was assessed two and five months after herbicide application. Both leaf and branch mortality were estimated as percentages. Standard industry practice was used to identify shrub mortality where a shrub showing no leaf discoloration, deformation or necrotic tissue was assigned a value of 0%. Shrubs showing gradual unnatural discoloration, deformation or necrotic tissue were assigned values between 5% and 100%, using 5% increments depending on the extent of leaf mortality. These percentage increments were assigned a score ranging from one to five: 1 (0–10% mortality), 2 (10–30%), 3 (30–60%), 4 (60–90%) and 5 (+90%). The mortality scores were given based on the total percentage of the shrub that showed severe discoloration, deformation and necrotic tissue. The necrotic tissue was evaluated based on whether the stems break and crumble off. The total mortality of the shrub was noted when the basal stem easily broke off from the root and crumbled in your hand.

Regrowth or coppicing of *S. plumosum* was recorded 12 months after herbicide application. All shrubs in the plots were monitored for any signs of new growth, especially around the stem area. The coppice rate was calculated as the ratio of shrub individuals that displayed regrowth to the total number of shrubs in the same plot. Seasonal mortality and regrowth of shrubs in untreated control plots were measured for comparison to account for effects of environmental conditions.

Grass vegetation was surveyed 12 months post-herbicide application in three randomly placed 0.5 m × 0.5 m quadrats per plot (Mueller-Dombois and Ellenberg 1974). In each quadrat total grass canopy cover was visually estimated in percent and all grass species were identified to obtain species richness.

To gain a general understanding of how *S. plumosum* control affects grass production and grazing capacity, a total of 20 0.5-m^3 herbivore exclusion cages were placed in the encroached paddock and in an adjacent control paddock with low shrub cover, with 10 exclusion cages in each paddock. The control paddock and encroached paddock were approximately the same size, with similar environmental characteristics. The two paddocks were located approximately 20 m apart, separated by a road. Livestock grazing in both paddocks was prevented during the two-year trial, but both paddocks received the same grazing treatment prior.

The exclusion cages were used to measure the grass biomass production. The cages were randomly placed in the highly encroached paddock between the experimental plots and in the neighbouring control paddock where less than 10 *S. plumosum* individuals had encroached. The cages were placed in January 2020 and the grass biomass was collected in July 2020 and June 2021. The dry-weight-rank method was used to determine the biomass based on the relative contribution of various species. It is expressed in percentages and does not quantify total biomass for each species (Barnes et al. 1982). This data was used to determine the grazing capacities of both areas (Mannetje and Haydock 1963).

We used aligned rank transformed mortality scores, followed by a two-way nonparametric analysis of variance to test for the effects of herbicide type and cutting of shrubs on shrub mortality two months after application. We used linear two-way interaction models to test for the effects of the different herbicides and mechanical control and the interaction between these two independent variables on grass cover and grass species richness. Non-significant variables or interactions were removed stepwise from the maximal models according to Akaike information criterion (AIC) values. For significant factors with multiple levels (i.e. herbicides), pairwise comparisons were performed using Tukey's honestly significant difference (HSD) post hoc tests to detect significant differences between group means. The assumptions for linear models (homogeneity of variance, normality of residuals) were tested visually using respective plotting functions provided in R (qq-plots, residuals vs fitted values, etc.). All analyses were performed using R Version 4.0.0 (R Core Team 2020). The significance level of all test statistics was $p < 0.05$; however, $p < 0.1$ was regarded as a tendency.

Five months after the herbicide application, complete mortality of all shrubs was recorded, regardless of mechanical cutting and removal of shrubs or herbicide type. However, two months after herbicide application, higher mortality was recorded in the cut treatments, which was on average 0.9 higher on the assigned score compared to uncut treatments (Uncut = 3.1; Cut = 4.0; $F_{(1,16)} = 15.9$; $p < 0.01$; Table 1). Different herbicides also significantly affected the mortality two months after application, with metsulfuron-methyl and triclopyr B resulting in a one unit increase in mortality score compared to triclopyr A and tebuthiuron ($F_{(3,16)} = 6.3$; $p < 0.01$; Table 1). In the treated plots coppicing of shrubs only occurred in very low numbers with the use of triclopyr A for both cut and uncut treatments (~1% of stems) and at slightly higher rates in the uncut tebuthiuron treatment (~4% of stems), while in the untreated controls 23% of stems showed regrowth (Table 1).

Table 1: Average mortality and coppicing rates of *Seriphium plumosum* for the combination of chemical control (herbicides) and mechanical control (cutting and removal of shrubs). Mortality scores were recorded two months after application, and regrowth 12 months after application

Herbicide	Cutting	Mortality	Coppicing (%)
Control		1.0 ± 0.0	23.3
Metsulfuron-methyl	Cut	4.7 ± 0.2	0
Triclopyr A		3.8 ± 0.6	1.3
Tebuthiuron		3.0 ± 0.0	0
Triclopyr B		4.5 ± 0.0	0
Metsulfuron-methyl	Uncut	3.5 ± 0.6	0
Triclopyr A		2.3 ± 0.4	0.7
Tebuthiuron		3.0 ± 0.3	3.7
Triclopyr B		3.7 ± 0.2	0

Grass canopy cover was best explained by the maximal model including the interaction between mechanical and chemical control ($F_{(7,64)} = 3.4$; $R^2 = 0.19$; $p < 0.01$; AIC with interaction: 461.62; AIC only main effects: 461.92).

Grass canopy cover was significantly affected by both the different herbicides tested ($F_{(3,67)} = 3.4$; $p < 0.05$) and cutting before herbicide application ($F_{(1,67)} = 7.2$; $p < 0.01$), while an interaction between both factors (i.e. herbicide application and cutting) did not significantly explain changes in grass cover (Figure 1). Mechanical control before herbicide application led to a 15.1% increase in grass canopy cover across the four different herbicides. Pairwise comparisons between herbicides showed that the use of metsulfuron-methyl resulted in 23% higher grass cover compared to tebuthiuron ($p < 0.05$), while the 20% higher grass cover in the triclopyr A treatments compared to tebuthiuron was not statistically significant, but can still be considered a trend ($p = 0.06$). Grass species richness could best be explained by the model with the two main effects (cutting and herbicides) after the interaction parameter was excluded ($F_{(4,67)} = 5.1$; $p < 0.01$; AIC with interaction: 32.8; AIC only main effects: 31.5) (Figure 1).

We found 0.9 more species on average in plots that were mechanically controlled prior to herbicide application compared to the plots where only herbicides were applied ($F_{(1,67)} = 10.4$; $p < 0.01$). The use of different herbicides significantly affected grass richness ($F_{(3,67)} = 3.3$; $p < 0.05$). Pairwise comparisons showed that on average 1.2 more grass species occurred in metsulfuron-methyl treatments compared to plots treated with tebuthiuron ($p < 0.05$), while no other pairwise comparisons showed evident differences in species richness (Figure 1). In summary, our results show that metsulfuron-methyl and triclopyr A were the most effective herbicides with a 100% mortality rate five months post herbicide application, and led to the highest grass cover and grass species richness. Tebuthiuron was not as effective for *S. plumosum* control and had a negative effect on the grassy layer, as it not only killed the bushes but also grasses. Furthermore, the removal of shrubs had an additional positive effect on the regeneration of the grass layer.

Data from the grazing exclusion cages indicated a difference in the grass dry weight between the paddock encroached by *S. plumosum* and the control paddock (Table

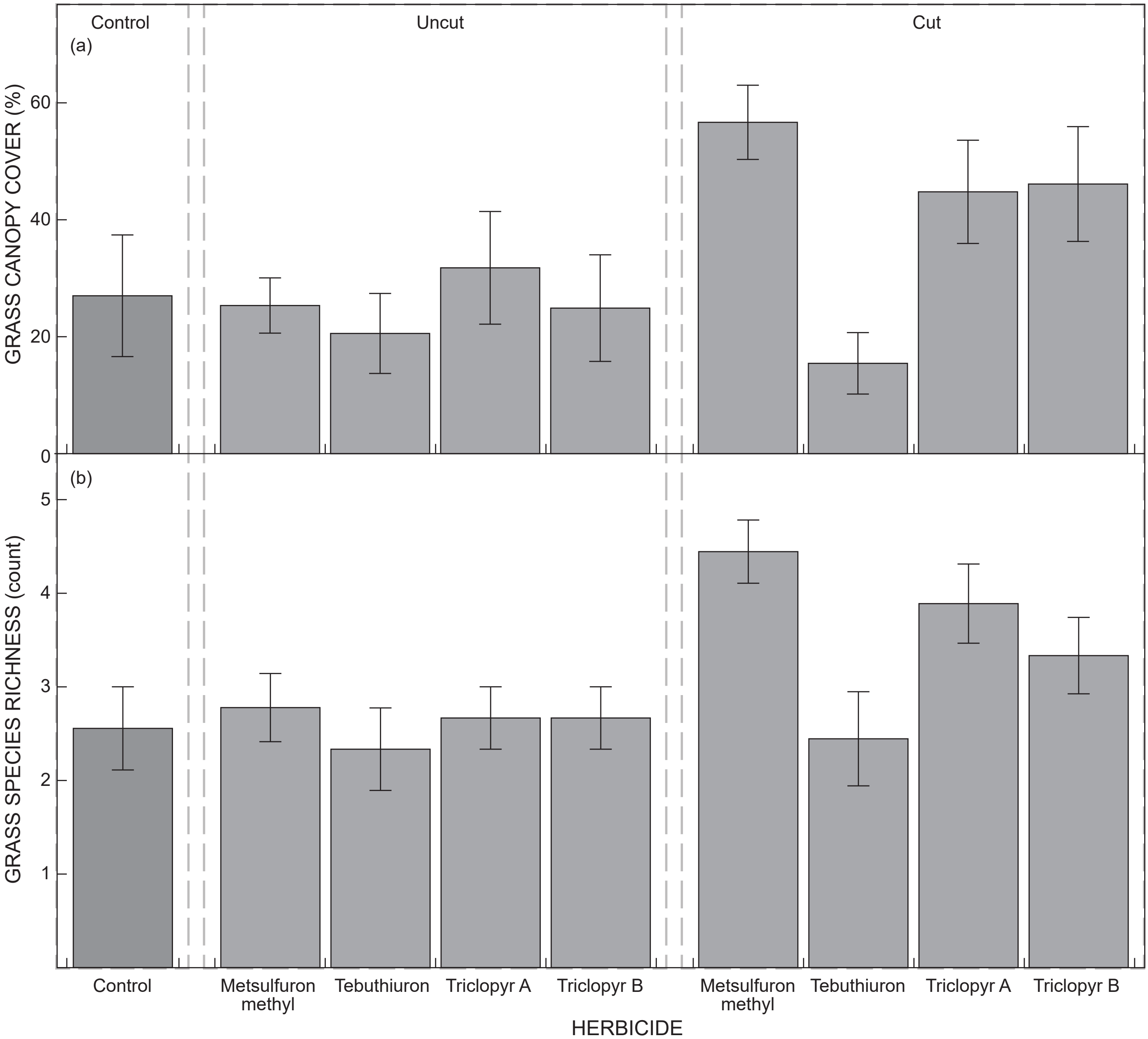

Figure 1: (a) Grass canopy cover (%) and (b) grass species richness (count) after different herbicide applications for cut plots and uncut plots (chemical control only). Error-bars indicate the standard error of the mean

2). Dry biomass yield was higher in the unencroached control paddock compared to the encroached paddock in both 2020 and 2021. However, dry biomass yield increased by approximately 1 000 kg ha^{-1} in the encroached paddock from 2020 to 2021, while the control paddock showed a decrease of approximately 500 kg ha^{-1}. In the control paddock production decreased from 6.7 kg mm^{-1} in 2020 to 6.2 kg mm^{-1} in 2021. This led to a decrease in grazing capacity from 2020 to 2021 for both the encroached and control paddock, which was more pronounced in the encroached paddock (from 11.1 to 6.9 ha LSU^{-1}) than the control (from 6.7 to 6.1 ha LSU^{-1}). However, these results stem from a single comparison between two paddocks and must therefore be considered as indicative of an effect of shrub treatment on rangeland productivity.

This study showed that chemical control, in combination with mechanical cutting, is an effective method that can be considered to combat the encroachment of *S. plumosum*. We found that the use of metsulfuron-methyl and triclopyr A led to the fastest and highest mortality of *S. plumosum.* Tebuthiuron, on the other hand, also led to a complete mortality of shrubs, but it took longer for the effect to take hold. In addition, 12 months after application, regrowth occurred very infrequently in all herbicide plots, but occurred mainly with tebuthiuron application. This was surprising, because tebuthiuron remains in the soil for multiple years, and is meant to inhibit a re-establishment of shrubs in the subsequent years (Du Toit and Sekwadi 2012). Metsulfuron-methyl and tebuthiuron are the two most used herbicides to combat *S. plumosum* (Avenant

Table 2: Grazing capacity (ha LSU^{-1}), dry biomass yield (kg ha^{-1}) and production (kg mm^{-1}) in the encroached and control paddock over the two years of the experiment

	Encroached paddock		Unencroached paddock	
	2020	2021	2020	2021
Dry biomass yield (kg ha^{-1})	1 635.5	2 815.2	3 932.9	3 374.9
Production (kg mm^{-1})	3.1	6.1	7.6	7.4
Grazing capacity (ha LSU^{-1})	11.1	6.9	6.1	6.7

2015). A number of studies have reported on the effectiveness of the latter (Du Toit and Sekwadi 2012; Snyman 2012; Wepener 2007). However, in addition to control of the shrubs, it negatively affects the surrounding vegetation, given that it is not a species-specific herbicide (Du Toit 2012). This negative impact is in accordance with our results, where the grass layer was heavily diminished in the tebuthiuron plots. Metsulfuron-methyl is the most used herbicide to combat *S. plumosum* (Avenant 2015) and led to the highest grass richness and cover, but triclopyr which is not as commonly used also led to comparably good results regarding grass recovery. This positive effect on the grass layer was most apparent when shrubs had been removed prior to chemical control. According to Snyman (2012a) many additional seeds are being dispersed during the removal process, which supposedly leads to mass recruitment in the following season. This could not be verified in our study, as we did not encounter any new seedlings 12 months after the application. However, the establishment of new seedlings would have to be monitored over a longer period to draw final conclusions.

Cutting and removal, coupled with the use of metsulfuron-methyl and triclopyr A, led to the highest grass species richness and grass cover. *Seriphium plumosum* suppresses grass growth through shading, change in soil moisture and allelopathic properties, which inhibit grass seed germination and growth (Snyman 2010). It can therefore be assumed that the combination of chemical control and shrub removal can benefit the grass layer by eliminating competition for light and the release of allelopathic exudates simultaneously.

The comparison of the two paddocks indicated that removal of *S. plumosum* increased dry grass biomass and thereby, decreased grazing capacity. Even though no final conclusion can be drawn due to missing replication, it is likely that the above-mentioned effects led to an area-wide improvement of the encroached rangeland. Grazing capacity results paired with the results of grass species richness and cover indicate that the removal of *S. plumosum* is beneficial for increased fodder production in livestock management systems.

For the most effective control of *S. plumosum,* an adaptive management approach should be incorporated after control, with consistent monitoring of the progress during and after the period of chemical application. Adaptive management that includes the use of environmentally compatible herbicides like metsulfuron-methyl or triclopyr A, coupled with mechanical control and long-term monitoring for seedlings, is an effective method with which *S. plumosum* could possibly be controlled in South African semi-arid rangelands. Moreover, Mndela et al. (2022) concur long-term studies on a large-scale should be conducted to investigate the long-term efficacy of the control methods, as well as their effects on the grassy layer and the overall species composition.

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