Colegio de Postgraduados

Changes in grassland structure in Sierra de Organos National Park associated with a 14-year grazing exclusion

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ABSTRACT

Objective. To evaluate the effect of 14-year grazing exclusion on land cover and on the dynamics of plant functional groups in the grassland of the Sierra de Organos National Park.

Design/Methodology/Approach. In 2008, at the beginning of the grazing exclusion, four transects were established to measure land cover and plant functional groups. The measurements were repeated in 2010, 2012, 2014, 2018 and 2022.

Results. During the first ten years of grazing exclusion, basal cover increased by 201%, as well as by 228.7% in litter accumulation and 219% in soil cover. In other words, bare soil was significantly reduced. However, in the following period of the evaluation, basal cover and soil cover decreased, which meant an increase in bare soil. In addition, during the first decade of grazing exclusion, grasses maintained a clear dominance in the plant community. However, since 2018 those decreased, which coincided with an increase in herbaceous plants and shrubs.

Limitations/Implications of the study. The study generated practical information applicable both in the study area and in livestock ranches in the Central-North Region of Mexico.

Findings/Conclusions. Grazing exclusion should be limited to a period of less than ten years, since during that time the vegetation cover increases and bare soil is reduced; however, as it continued, a degradation of the pasture and the substitution of grasses for other herbaceous and shrubs were observed.

Keywords: leaf litter, basal cover, plant functional groups.

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INTRODUCTION

Mexico's National Park "Sierra de Organos" (SONP) is an outstanding national ecotourism destination and an area of scientific interest due to its unique landscape and great biodiversity, which includes endemic and threatened species. However, the inadequate management of extensive livestock farming for decades led to overgrazing, which caused the deterioration of vegetation and soil degradation, affecting landscapes in the Park. To conserve its natural resources and encourage ecotourism, the SONP was declared a Protected Natural Area (ANP, in Mexico) in 2000. As part of management practices, during the second half of 2008 cattle grazing was excluded, with the aim of restoring vegetation, improving the soil and ensuring the ecological and tourist sustainability of the park in the long term.

Grazing exclusion (GE) has been promoted worldwide as an effective strategy for the restoration of grasslands degraded by overgrazing (Shu *et al.*, 2024). However, several studies have shown that its effects can vary significantly depending on the length of the exclusion period (Lian *et al.*, 2024). On the one hand, grazing exclusion in the short term (three to five years) tends to favour an increase in biomass and plant diversity (Zhan *et al.*, 2022; Yang *et al.*, 2023). On the other hand, prolonged periods of exclusion (eight years or more) can decrease vegetation cover and species richness, thereby reducing the expected benefits of restoration (Liu *et al.*, 2020; Zhan *et al.*, 2022; Yang *et al.*, 2023).

Prolonged grazing exclusion in grasslands favors the excessive accumulation of leaf litter on the soil surface. Studies have shown that this increase in organic material hinders the ecological restoration of degraded or poorly managed grasslands (Song *et al.*, 2025). One of the main negative effects of abundant leaf litter is that it forms a layer on the ground that acts as a physical barrier and reduces the amount of light available, which hinders the recruitment of plants from seed and limits the emergence and development of seedlings and shoots of perennial species (Facelli & Pickett, 1991; Jessen *et al.*, 2023). Another relevant impact is the increase in the number of native shrubs, which alters the original structure and composition of the plant community (Zhang *et al.*, 2024).

On the other hand, excessive litter accumulation increases the risk of fires, posing an additional threat to ecosystem stability and resilience (Vermeire *et al.*, 2018). Although leaf litter in moderate amounts benefits the ecosystem by attenuating the thermal oscillation of the soil, improving infiltration, decreasing evapotranspiration, reducing erosion and contributing organic matter to the in situ nutrient cycle (Pellant *et al.*, 2020).

During the first six years of grazing exclusion in the SONP (2008-2014), leaf litter cover increased from 17.8% to 39.9% (Valdez-Cepeda *et al.*, 2021), evidencing a considerable accumulation of surface organic material due to the absence of grazing. As a result, the authors recommended reviewing and adjusting the length of exclusion periods to avoid negative impacts associated with excess of litter and to achieve sustainable grassland management. However, as this strategy has not been modified to date, it is considered essential to re-evaluate grazing exclusion effectiveness to ensure the conservation and functionality of the ecosystem.

In order to address this problem and with the consideration of the environmental, ecotourism and socioeconomic importance of the SONP, this research was proposed to generate practical information that guides decision-making towards the sustainable management of this Mexico's natural protected area; and to provide elements with value for the conservation of grasslands in the regional livestock sector. Therefore, the objective was to evaluate the effect of 14-year grazing exclusion on soil cover and on the dynamics of plant functional groups in the grassland of the Sierra de Organos National Park.

MATERIALS AND METHODS

Study Area

The study was implemented in the Sierra de Organos National Park —SONP, part of Mexico's national system of protected natural areas (known as ANP), which is located in the northwest of the municipality of Sombrerete, Zacatecas, Mexico; with extreme coordinates 23° 46' 54.31" N and 103° 46' 37" W, 23° 48' 06.39" N and 103° 49' 08.66" W, 23° 46' 07.71" N and 103° 47' 01.26" W and 23° 48' 28.80" N and 103° 48' 57.93" W (SEMARNAT, 2013). The National Park covers an area of 1124.65 hectares under Ejido's property. The climate is temperate sub-humid [C(w_0) (w) a (e)], with rainfall in summer; the annual averages of precipitation and temperature are 592.3 mm and 14.9 °C (INIFAP, 2025). The landscape is composite of a low mountain range of volcanic rock with escarpments, ridges and small valleys with flat-undulating topography and gentle slopes, where the altitude varies between 2120 and 2560 m (SEMARNAT, 2013). The vegetation present includes pine forest, oak forest, natural grassland, scrubland, riparian vegetation, as well as aquatic and subaquatic communities (SEMARNAT, 2013).

Rainfall

In the interannual variability of precipitation, from 2008 to 2022, four stages were identified in the area of influence of the SONP. A drought season (2008-2012) with values below the average (592.3 mm), with an extreme drought in 2011 (250 mm, 57.8% lower than the general average for the period). A sustained wet season (2013-2018) followed, with rainfall above the general average for the period and a maximum of 961 mm (in 2015, 62.2% higher than the general average for the period). Then, a brief return to dry conditions (2019-2020) and finally, a moderate wet season (2021-2022), the latter with records above the general average for the period (Figura 1). This information with annual records allowed us to explore the existence, or not, of associations between rainfall and the grassland variables analyzed in this study.

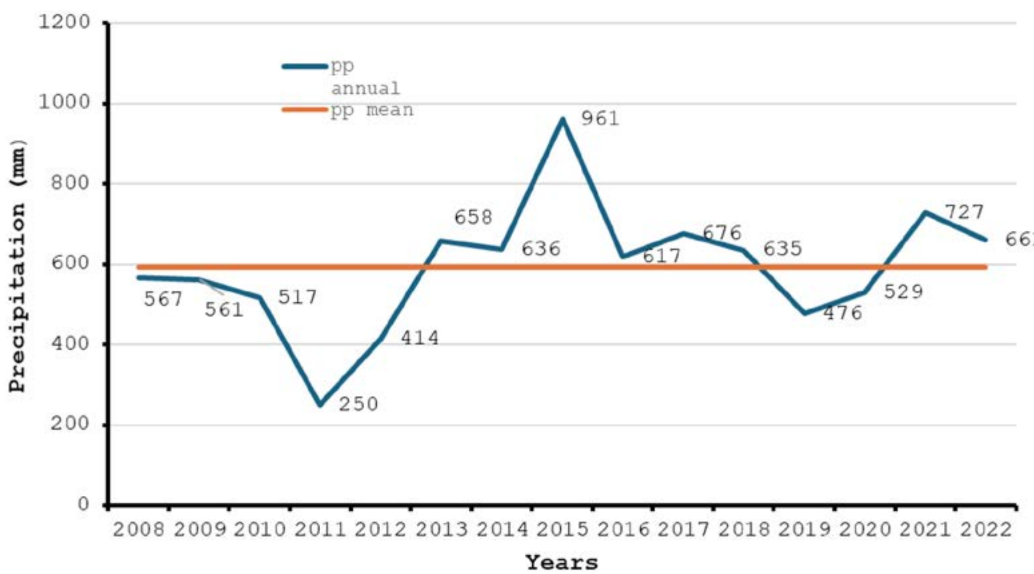

Figure 1. Annual rainfall (mm) recorded at the "Providencia" Meteorological Station during the period 2008-2022 (INIFAP, 2025). The orange horizontal line represents the general average for the period (592.3 mm), which represents the 23-year normalized climate value for rainfall in that Meteorological station (2000-2022).

Sampling procedure

This study was developed exclusively in the SONP grassland, which covers an area of 135 hectares (SEMARNAT, 2013). In this plant community, four transects were established for monitoring of variables, strategically distributed and identified as I, II, III and IV. In transects I, II and IV, 100 random measurement points were selected, while in transect III, due to physiographic conditions, 66 random points were established. The data collected at the measurement points allowed quantifying four variables of grassland soil cover, including the percentage of basal cover, leaf litter, soil cover and bare soil.

In addition, at each measurement point, the perennial plant species present were identified, which were grouped into four functional groups: trees, shrubs, grasses, and grasses. The first evaluation was done in 2008, to coincide with the beginning of the grazing exclusion. Subsequent evaluations were recorded in 2010, 2012, 2014, 2018 and 2022. Data were collected in the early fall of each of those years; the method 'Early Warning Biological Monitoring-Rangelands and Grasslands' of the Allan Savory Holistic Management Center was used (ASCHM, 1999).

Statistical analysis

The response variables used to evaluate the effect of grazing exclusion (GE), applied over 14 years in the grassland, included percentages of basal cover, leaf litter, soil cover, and bare soil, as well as the relative proportion of grasses, herbaceous plants, shrubs, and trees. To analyze these variables, an analysis of variance was performed for each; the number of years without grazing was considered as the source of variation. The statistical analysis, a one-way analysis of variance, was performed in Minitab® 2016 version. When significant differences were detected in any variable, a Tukey multiple mean comparison test was applied ($p \leq 0.05$).

RESULTS AND DISCUSSION

The length of the grazing exclusion (GE) period generated significant differences ($p \leq 0.001$) in the percentages of basal cover, leaf litter, soil cover and bare soil. As well as in the relative proportion of grasses, herbaceous plants and shrubs in the SONP grassland (Figure 2 and Figure 3); in contrast, the proportion of trees showed non-significant changes (Figure 3).

Basal cover

In the temporal dynamics of the percentage of basal cover of the grassland, three significant ($p \leq 0.001$) stages were distinguished (Figure 2). The first phase, called initial recovery (2008-2012), was associated with an 82.2% increase in the first two years, as basal cover rose from 9.0% to 16.4%; in 2012, value remained practically unchanged, which means that the GE favored the growth in diameter of the grass tillers during the first two years. The total length of this phase coincided with the dry period in the study area (reference in Figure 1).

The annual rainfall remained lower than the general average for the period, which generated a water deficit that reduced plant growth and prevented the grazing exclusion

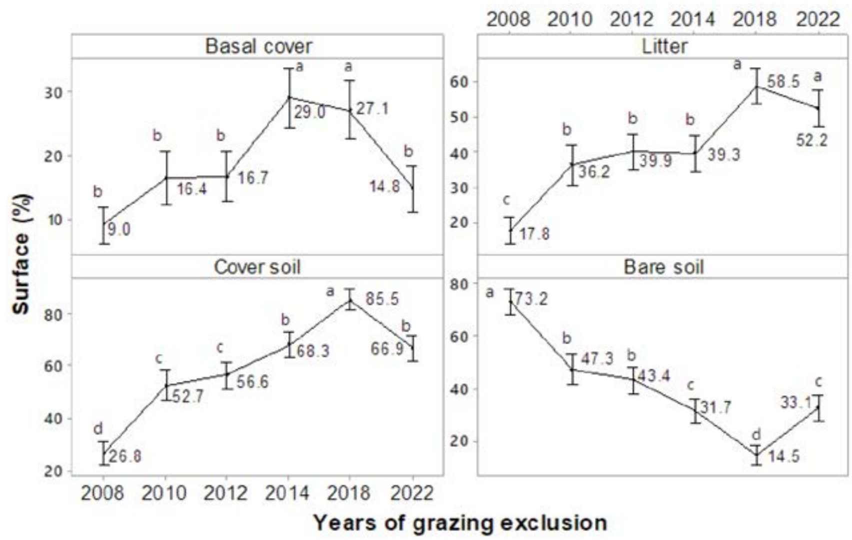

Figure 2. Percentages of area with basal cover, with leaf litter, with covered soil and in bare soil in the grassland of the Sierra de Organos National Park during 14-year grazing exclusion (2008-2022). Means with different letters indicate statistical difference (Tukey; $p \leq 0.05$). Lines represent the mean ± SE (1 unit of standard error).

to be reflected in only positive significant changes. During the second phase, we called peak and consolidation of basal cover (2013-2018), this variable reached its absolute maximum in 2014 (29%). This is more than triple its initial value, and decreased only to 27% in 2018, as an indication of a stabilization. This observed pattern indicates that, with six years of GE, the plant community reached its highest basal density and remained unchanged during the following four years. This stage coincided with a period of abundant annual rainfall, which favored both the recruitment of young plants and a greater development of grass tillers. As a result of this vegetative growth, a subsequent accumulation of leaf litter occurred.

Finally, during phase three, we defined as recent decline (2019-2022), basal cover showed a marked decrease up to 14.8%, this is a 45.4% decrease compared to that value in 2018. This decline is evidence that grazing exclusion alone does not ensure sustained increases for basal cover in the long-term. A moisture deficit was recorded during 2019-2020, while in 2021 and 2022, annual rainfall again exceeded the average. Despite the rebound in precipitation, basal cover did not recover; on the contrary, it decreased. This behaviour can be attributed, in part, to the lagging effects of the previous drought and, to a greater extent, to the grazing exclusion, since the prolonged absence of grazing limits grass regrowth and the removal of senescent biomass, which favors an excessive accumulation of leaf litter. This accumulation hinders both the development of plants already established, and the germination of seeds with establishment of new plants (Facelli & Pickett, 1991). According to our results, an optimal period of grazing exclusion is comprised between six and 10 years. After that time, the benefits began to reverse, as basal cover declined.

Overall, the results indicated that grazing exclusion acted as a trigger for the increase in basal cover, which peaked in 2014. However, the magnitude and duration of this response clearly depended on rainfall and litter accumulation. The sustained water volume between

2013 and 2018 boosted basal cover, while the increase in leaf litter reversed the growing trend. These facts show that the recovery of the grass stratum results from the interaction between the absence of grazing and the interannual availability of water. It is inferred that, after six years of grazing exclusion, it is advisable to suspend GE and to incorporate instead an adaptive pasture management system that integrates flexible grazing adjusted with rainfall variability. This means increasing grazing intensity in humid years and reducing animal load in dry seasons, in order to preserve both, productivity and vegetation cover (Derner *et al.*, 2022).

Leaf litter cover

The percentage of soil surface covered by leaf litter exhibited a pattern of four statistically different stages throughout the 14-year grazing exclusion ($p \leq 0.001$; Figure 2). During the first stage, we called initial accumulation (2008-2010), leaf litter cover was characterized by an increase from 17.8% to 36.2%, attributable to the absence of livestock grazing and trampling. In the second season, we identified as a transitional plateau (2011-2014), leaf litter cover showed almost constant values (39.9% in 2012 and 39.3% in 2014), suggesting a temporal balance between the fallen of leaf debris and their decomposition.

During the third stage, we defined as the maximum peak of accumulation (2015-2018), leaf litter cover reached its highest level in 2018, 58.5% which was three times the baseline. This value reflects the large basal cover of the period and the minimal biomass removal associated with the absence of grazing. Finally, during the fourth phase, we designated as the recent adjustment (2019-2022), leaf litter cover showed a slight decrease, up to 52.2% in 2022. The decrease in leaf litter observed in recent years is related to the parallel reduction of basal cover. Because less plant cover reduces leaf production and, consequently, the contribution of the material that compose the layer of leaf litter.

The results of our study are consistent with those of Song *et al.* (2025), who observed that, after four years of grazing exclusion, grasslands presented a notable accumulation of leaf litter. Similarly, Zhang *et al.* (2024) concluded that this accumulation in excluded grasslands weakened the biotic resistance of grasses, while favoring shrub growth and recruitment.

In general, the exclusion from grazing induced a sustained accumulation of leaf litter during the first decade, which was followed by a relative decrease during the following four years. In the initial stage, this increase implied a contribution of organic matter and a better retention of moisture in the soil (Pellant *et al.*, 2020). However, the accumulation of leaf litter also increased the fuel load and generated a physical barrier on the ground, especially when it reached its maximum value in 2018. That timing coincided with the onset of a marked decrease in basal cover.

This leaf litter barrier could negatively affect the regeneration processes and the dynamics of the vegetation in the grassland. According to Facelli & Pickett (1991), the reduction in light caused by leaf litter makes it difficult for seedlings to establish, and may even hinder the establishment of species with larger seeds. Chen *et al.* (2018) also observed that grass-leaves litter cover made it difficult to establish seedlings of invasive and native species coexisting in California grasslands. In addition, the layer of leaf litter represents a physical obstacle for seeds, seedlings and shoots, as it can delay or prevent their arrival into the soil, also inhibiting their emergence and development.

Soil cover

The percentage of area with soil cover presented a four-phase course during the 14-year grazing exclusion ($p \leq 0.001$; Figure 2). In the first phase that we called initial accumulation (2008-2010), soil cover doubled from 26.8% to 52.7%, thus showing the early response of herbaceous vegetation and the rapid accumulation of leaf litter once GE began. During the second phase, we called the moderate-growth plateau (2011-2014), soil cover was characterized by a more attenuated increase (52.7% to 68.3%) indicating a phase of dynamic balance between the increase in basal cover and the processes of accumulation and decomposition of leaf litter.

In the third phase, we described as the maximum peak (2015-2018), soil cover reached its highest value (85.5%), more than three times the initial level. This maximum coincided with the highest proportion of surface covered with leaf litter, and with the second highest basal cover value. The physical protection of the soil was favored, which tipically reduces vulnerability to erosion and improves hydrological function (Pellant *et al.*, 2020). During the fourth phase, we called the recent adjustment (2019-2022), soil cover showed a small decrease, a value of 66.9% soil cover was recorded. Despite this reduction, this value remained higher than that one measured at the start of GE.

In general terms, grazing exclusion promoted a sustained increase in soil cover during the first decade, but showed a slight decrease in the last four years. Our results corroborate the findings of Song *et al.* (2020), who demonstrated that prolonged exclusion from grazing induces a statistically significant reduction in total coverage. Based on our results, it is recommended that grazing exclusion does not exceed 10 years; while the following step is the reintroduction of livestock through adaptive management strategies. This practice would make it possible to conserve the soil cover achieved, and to ensure the functionality and sustainability of the grassland in the long term.

Bare soil

During the 14 years excluded from grazing, the percentage of land area with bare soil showed an inverse trend to those observed in basal cover, leaf litter and covered soil. The percentage of surface area with bare soil decreased as those variables increased, then it increased as those decreased. This behavior was divided into four phases ($p \leq 0.001$; Figure 2). During the first one that we called the initial decline (2008-2010), bare soil was reduced from 73.2% to 47.4%, which means a decrease of 25.8 percentage points after the immediate elimination of grazing and cattle trampling.

In the second phase, we called gradual decline (2011-2014), the portion of bare soil continued to decrease to 31.7%, due to the expansion of basal cover and leaf litter cover. At the third phase, called absolute minimum (2015-2018), bare soil reached the lowest value (14.5%) in the evaluation; that is, a reduction of 80.2% compared to the initial value. This minimum coincided with the second highest value of vegetation cover and with the most extensive leaf litter cover, which decreased soil exposure. In the fourth phase, called partial rebound (2019-2022), the area with bare soil showed an increase to 33.1%. That is, it remained at less than half of the baseline, but indicated the partial loss of the protection achieved. This uptick was related to the simultaneous decrease in basal cover and leaf litter cover.

When considering the entire period, grazing exclusion substantially reduced the area of bare soil during the first decade; however, in the following four years this trend was reversed and the exposed soil increased again. This represents an aggravating factor, since a higher proportion of bare soil increases the vulnerability of the grassland to erosion, both by water runoff and by wind (Pellant *et al.*, 2020).

Temporal dynamics of plant functional groups during the 14-year grazing exclusion

The temporal dynamics of the plant functional groups in the SONP grassland during the period excluded from grazing (2008-2022) was expressed as the relative frequency (%) of grasses, herbaceous plants, shrubs, and trees within the plant community (Figure 3).

Grasses, which constituted the dominant group at the beginning of GE, retained a proportion of more than 92% in the plant community during the first ten years. This confirms historical dominance as a stratum of grassland perennial plants. However, after 2018, the proportion of grasses decreased significantly, lowering to 83.1% in 2022, which coincided with a simultaneous increase in herbaceous plants and shrubs. This pattern could be due to the low incorporation of new plants and the progressive mortality of grass tillers. The latter is mainly induced by the natural aging of plants and the accumulation of leaf litter caused by prolonged grazing exclusion.

Herbaceous plants showed fluctuating dynamics in the period, with intermittent increases and decreases that reached their maximum value in 2022 (9.0%), with a

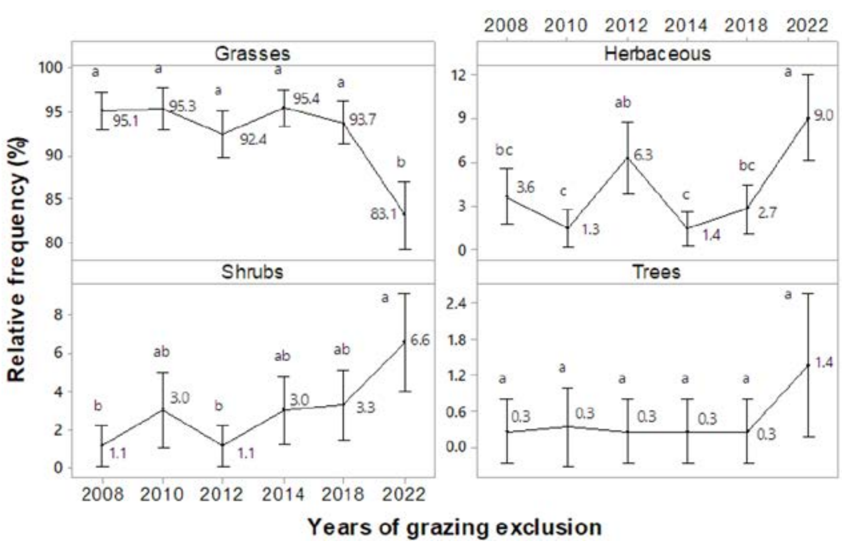

Figure 3. Dynamics of the relative frequency (%) of plant functional groups (grasses, herbaceous, shrubs, and trees) in the grassland vegetation of the Sierra de Órganos National Park during a 14-year grazing exclusion (2008-2022). Means with different letters indicate statistical difference (Tukey; p≤0.01). Lines represent means ± SE (1 unit of standard error).

statistically significant increase compared to most previous years. This trend indicates that these species have managed to establish themselves successfully, probably favored by prolonged grazing exclusion, and the consequent accumulation of leaf litter (Figure 3). Our results are consistent with those of Song *et al.* (2020), who observed that grazing exclusion in different periods favored the increase in the relative cover of herbaceous plants.

Shrubs showed a pattern of gradual increase, going from a relative frequency of 1.1% in 2008 to 6.6% in 2022. This statistically significant ($p \leq 0.01$) increase reflects a progressive colonization of the grassland by low-growing woody species, facilitated by the lack of grazing. Our results are consistent with those reported by Zhang *et al.* (2024), who also observed an increase in shrub abundance during a livestock exclusion period.

Similarly, Shi *et al.* (2023) documented this increase and noted that it is linked to both grazing exclusion and the competitive advantage that shrubs develop through interspecific interactions during that period. Those authors reported that the increase in shrubs would significantly decrease the quality of grasslands and suggested that livestock exclusion strategies should be implemented with caution, and with careful consideration of their possible long-term effects on the structure and functionality of ecosystems.

Therefore, one recommendation is to return grazing to the SONP through the adaptive grazing modality (Derner et al., 2022). Trees maintained a low and stable proportion (0.3%) during the first decade, but showed a significant increase in 2022 (1.4%). This increase may indicate the beginning of a transition to vegetation of greater height and structural complexity, which could be consolidated in later stages if grazing exclusion continues.

In general terms, the persistent dominance of grasses during the first ten years of GE confirms the initial success of this practice in conserving the grass layer. However, the significant changes observed in 2022 in the structure of plant functional groups, particularly the decline of grasses and the simultaneous increase of herbaceous plants and shrubs, suggest a turning point in the successional process. This is a shift towards more diverse plant communities, although potentially less productive from a grazing point of view.

The increase in shrubs and the expansion of herbaceous plants in the grassland highlighted the importance of reintroducing controlled disturbances, such as livestock grazing, through rational or adaptive systems that allow maintaining the dominance of grasses and counteracting the proliferation of other species. Porensky *et al.* (2020) supported this strategy, suggesting that maintaining light to moderate levels of grazing by large herbivores is key to preventing the invasion of undesirable species and preserving the ecological integrity of rangelands. In addition, the ecological feedback mechanisms generated by herbivores favor plant growth and regulate systemic ecological processes in grasslands, confirming the fundamental role of grazing in grassland dynamics and resilience (Frank *et al.*, 1998).

CONCLUSIONS

Grazing exclusion increased basal cover, soil cover, and leaf litter accumulation during the first decade, and reduced the proportion of bare soil. After that period, basal cover, leaf litter cover, and soil cover decreased, while bare soil increased. This is evidence that the initial benefits of grazing exclusion were reversed. In the first ten years, grasses retained their dominance, but afterwards, herbaceous plants and shrubs increased towards a significant change in the structure and composition of the grassland.

Therefore, it is not recommended that grazing exclusion extends beyond six to ten years. But to reintroduce livestock through adaptive management schemes that adjust the animal load according to climate variability. This strategy helps to maintain basal cover, avoiding excessive accumulation of leaf litter and preventing the increase of bare soil. Also, it allows to conserve the levels of soil cover achieved during the first decade, maintaining the dominance of grasses, and limiting the expansion of herbaceous plants and shrubs. In the long term, it would be expected to favor both forage productivity and the ecological integrity of the SONP grassland.

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