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Shrub encroachment in semi-arid rangelands of southwestern Buenos Aires, Argentina does not affect plant diversity and composition

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ABSTRACT

Shrub encroachment in semi-arid rangelands is a phenomenon associated with changes in floristic composition, loss of diversity and ecosystem degradation, enhanced by inappropriate grazing practices. However, the outcome depends on the species' identity and the management carried out. The objective of this study was to evaluate shrub species dynamics and their effect on plant community composition in a Monte rangeland of Argentina, under conservative grazing management at two different working scales. During two years, ground-based vegetation and soil cover measurements were performed in patches with and without shrubs using Daubenmire and Canfield's methods. Herbaceous and woody species recorded were classified according to their functional traits and forage value. Specific richness, Shannon's diversity index and Pielou's evenness were calculated. At a larger-scale evaluation, Sentinel-2A satellite images from year 2016–2022 were classified into three cover classes to evaluate the shrub encroachment process. Although an increase in shrub presence was observed over the years at both scales no effect was found on the diversity and specific composition, nor on the occurrence of forage species. Shrub presence promotes the coexistence of species with different functional traits and creates favorable conditions for soil protection and the establishment of desirable species for livestock purposes.

1. Introduction

Shrub encroachment, increases in density and cover of native shrubs into grasslands, is a global phenomenon that occurs in different environments and affects several hundred million hectares worldwide (Eldridge et al., 2011). In some arid and semi-arid environments, landscape shifts from grasslands to shrublands have been associated with changes in the spatiotemporal distribution of soil and vegetation resources, thus creating a more heterogeneous environment (Reynolds et al., 2007). Encroachment has been observed along with a decrease in grass density and cover and an increase in bare soil patches, leading to a species composition shift, an intensification of water and wind erosion, loss of nutrient-rich soil particles and mobilization of sediments under shrub canopies creating "fertility islands" (D'Odorico et al., 2019). These disturbances in the structure and functioning of plant communities could finally lead to desertification processes and a decline in ecosystem functions (Schlesinger et al., 1990; Archer et al., 2017). This phenomenon aligns with a widely held belief among scientists and practitioners that shrub encroachment and desertification are often considered synonymous (Eldridge et al., 2011). However, in some environments, shrub advancement would contribute to reverse rather than increase desertification, depending on the functional traits of the species involved and the degree to which this process occurs (Maestre et al., 2009; Eldridge et al., 2011, Eldridge and Soliveres, 2015). Numerous studies highlight the positive effects of shrubs on their understory plant communities and soil conditions in semi-arid environments. A greater cover of woody species has been associated with increases in soil fertility (increased organic carbon, total nitrogen, exchangeable calcium, available phosphorus and potential nitrogen mineralization), and higher above- and below-ground biomass production, contributing to greater

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plant diversity and primary productivity (Eldridge et al., 2011; Soliveres and Eldridge 2014). Changes in woody species dynamics are attributed to different natural and anthropic factors, such as climatic variability, CO_2 and N deposition increases and altered disturbance regimes (e.g., grazing and fire) (Naito and Cairns, 2011; Archer et al., 2017). In central semi-arid Argentina, since the introduction of domestic livestock (mainly cattle) many decades ago, overgrazing of native grass species triggered an increase of woody vegetation cover (Peláez et al., 1994; Cabral et al., 2003). Cattle diets are mainly grass based, while woody species are rarely included (Boo et al., 1993). Grazing can reduce competition that favors the growth of woody species and non-palatable grasses at the expense of desirable perennial vegetation. The presence of woody species results in competition for water, light, nutrients, and space, and thus reduces herbaceous forage production for domestic livestock (Peláez et al., 2017). In addition, inadequate cattle management can decrease plant biomass, species diversity and richness, with direct effects on secondary productivity (Zarovali et al., 2007). These changes in plant communities composition are considered one of the most threatening forms of rangelands degradation and one of the main concerns for livestock producers (Archer et al., 2017).

When assessing an encroachment process, it is useful to complement field surveys of vegetation cover with a larger-scale evaluation. The remote sensing approach offers a cost-effective and time-efficient assessment (Bigi et al., 2021). Remote sensing systems are widely used tools to characterize the spatial configuration of land resources and to detect changes over time (Brendel et al., 2019). The temporal analysis of optical remote sensing and GIS data allows for accurately corroborating the information obtained from vegetation sampling and classifying plant community changes. Having reliable information on the inventory of plant resources, both herbaceous and woody, is a valuable tool for developing land use policies that contribute to the maintenance of livestock activities without compromising natural resource conservation.

Rangelands of Southwestern Buenos Aires are part of the semi-arid regions of Argentina. A combination of environmental factors (droughts, strong winds, irregular rainfall) and anthropic factors (excessive clearing and tillage, overgrazing) have led the region to a state of degradation coinciding with the appearance of desertification processes (Millennium Ecosystem Assessment, 2005). Rainfall averages are intermediate between arid and humid regions. However, these averages show a high inter-annual variability, increasing over the years (Stritzler et al., 2007). Both climatic and edaphic characteristics limit productive activities, with a wide predominance of extensive cattle raising, mainly bovine but also ovine, with different management of forage and soil resources and rotation schemes of varying intensity. When properly managed, this land use, allows for the integration of biodiversity conservation in grasslands biomes and the provision of invaluable ecosystem services and utilities (O'Connor et al., 2011). Several characteristics of rangelands reinforce this idea, such as the adaptation of native species to the local environment, the time of year in which they provide forage (autumn-winter-spring), and the diversity of species, which increases and stabilizes production and contributes to the system resilience (Hooper et al., 2005; Gaitán et al., 2014). Using native grass species as a forage resource depends on the condition and forage quality of the species that compose it. Maintenance of a desirable mixture of herbaceous and woody species is a key component of sustainable ecosystem management in semi-arid rangelands with a shrub component (Archer et al., 2017). Several studies have described the effects of different grazing intensities on the cover of herbaceous and shrub species in Patagonian Monte rangelands with varied outcomes (e.g. Cesa and Paruelo, 2011; Peláez et al., 2010; Zeberio et al., 2018), however, studies are required on the impact of shrub presence on plant diversity and floristic composition of species with different functional traits under a conservative grazing management.

The objectives of this study were to evaluate shrub species dynamics and their effects on plant community composition in a Monte rangeland in Southwestern Buenos Aires (Argentina), with two complementary approaches: ground-based measurements and remote sensing analysis. The working hypotheses were that: 1) shrub presence increases over the years and 2) shrub presence modifies the composition, diversity and specific richness of the vegetation, with direct implications on the availability and quality of forage for livestock.

2. Materials and methods

2.1. Study site

The study was conducted in the Chacra Experimental Patagones, Buenos Aires, Argentina (40°39′49.7″, 62°53′6.4″ W; 40 masl), within the Phytogeographical Province of the Monte (Cabrera 1976; known locally as "Monte"). Climate belongs to temperate semi-arid, with higher precipitations during summer and fall seasons (Peláez et al., 2010). Long term mean annual precipitation (1981–2020) is 432.8 mm with a maximum of 877 mm in 1984 and a minimum of 196 mm in 2009. Monthly precipitation data during the study period are shown in Fig. 1. Mean annual, minimum and maximum temperatures are 14.1 °C, 7.3 °C and 20.8 °C, respectively. According to the Aridity Index proposed by the UNESCO (UNESCO 1979), expressed as the ratio between mean annual precipitation (mm) and potential evapotranspiration (mm), the study site is classified as semi-arid, with a value of 0.36 (calculated over a 30-year period). Soil is a typical Haplocalcid. Average pH is 7 and the soil layer depth is not a constraint factor for root growth in the soil profile.

Plant community in the Monte is characterized by an open shrubby stratum, which includes herbaceous species of different grazing value (Giorgetti et al., 1997). Species dominance in the community depends, at least in part, on grazing history and frequency and intensity of fires (Peláez et al., 2017). Dominant woody species are *Condalia microphylla*, *Chuquiraga erinacea*, *Larrea divaricata, Schinus johnstonii, Geoffroea decorticans, Neltuma alpataco* and *Prosopidastrum angusticarpum* The herbaceous layer is dominated by perennial grasses as *Nassella longiglumis*, *N. tenuis*, *Piptochaetium napostaense* and *Poa ligularis*. Other common perennial grasses in the region include *Pappophorum vaginatum*, *Pappostipa speciosa*, *Jarava plumosa* and *Amelichloa brachychaeta*. During the study period, the experimental units were grazed with bovine cattle using rotational grazing and one herd. The stocking rate was approximately 7.8 ha/animal unit. The time the animals remained in each unit was calculated based on forage availability to avoid overgrazing. A previous study conducted at the same site in 2004, showed that the average cover of woody and herbaceous species was about 32% and 24%, respectively (Peláez et al., 2010).

2.2. Experimental design and measurements

2.2.1. Ground-based measurements

Research was conducted during 2017 and 2018 in a native Monte rangeland. Six blocks (replicates) of 10 ha each were defined. In each

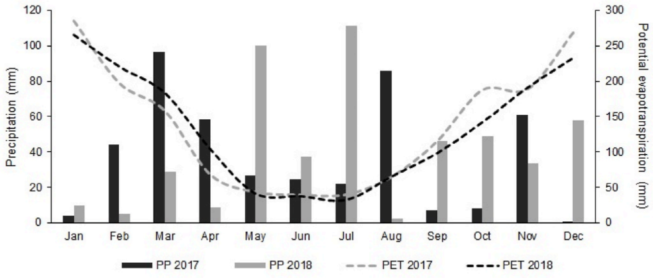

Fig. 1. 1Monthly precipitation (PP) and potential evapotranspiration (PET) during the study years at the Chacra Experimental Patagones.

block two 10 m linear transects were randomly placed, one in an area with shrubs (Sh; shrubs cover ≥50% of total plant cover, visually estimated) and another in an area without (WSh) shrubs (Fig. 2). The length and number of transects were determined considering patches size (with and without shrubs) and that plants species in the patches were similar between the different paddocks. On December 2017 (during the reproductive phase of most of the species), density and cover of herbaceous dicotyledonous and grass species (H) and cover of litter (L) and bare soil (B) were estimated, in each transect, using Daubenmire's method (10 plots/transect; Figs. 2 and 3) (Daubenmire, 1959). Renewals (R) of subshrub and shrub species found at WSh sites were also recorded to assess open space encroachment. Additionally, in Sh transects, woody species (W), litter (L) and bare soil (B) cover were estimated by the line intercept method (Figs. 2 and 3) (Canfield, 1941). Plant density was recorded using each line as the central axis of a quadrat (1 × 10 m).

All plant species found at each site were classified according to their origin, life cycle and forage value for livestock (Kröpfl et al., 2012; Teysseire et al., 2017) and grouped into different categories in order to contrast their relevance in the community (Fig. 3). In this way, at sites sampled with Daubenmire's method, the following categories were analyzed: (1) all herbaceous plant species (and some renewals; R); (2) desirable (D; mostly forage perennials) vs. undesirable (U; non-forage perennials and annuals) herbaceous species; (3) annual (A) vs. perennial (P) herbaceous species (without considering their forage value); (4) forage annual (F) vs. non-forage annual (NF) herbaceous species (Fig. 3). Additionally, at sites sampled with Canfield's method plants were classified as follows: (5) all woody species (W; subshrubs and shrubs) and (6) evergreen (E) vs. deciduous (De) woody species (Fig. 3). With all the data obtained, (7) specific richness (S), Shannon's diversity index (H'; Shannon and Weaver, 1963) and Pielou's evenness (J; Pielou, 1966) were determined. The study was repeated in December 2018, applying the same methodology as in 2017 but at 12 different transects.

2.2.2. *Remote sensing analysis*

For the land cover changes detection, seven Sentinel-2A images freely obtained from European Space Agency's website (https://browser.dataspace.copernicus.eu) for the 2016–2022 period were used (Table 1). The L1C-level data was applied to atmospheric correction with Sen2Cor processor (European Space Agency, 2021) using SNAP (Sentinel Application Platform). Afterward, these images were mosaicked, stacked, and resampled to get a continuous data set of 10 m spatial resolution. The image quality was generally good, with mean cloudiness of less than 10%.

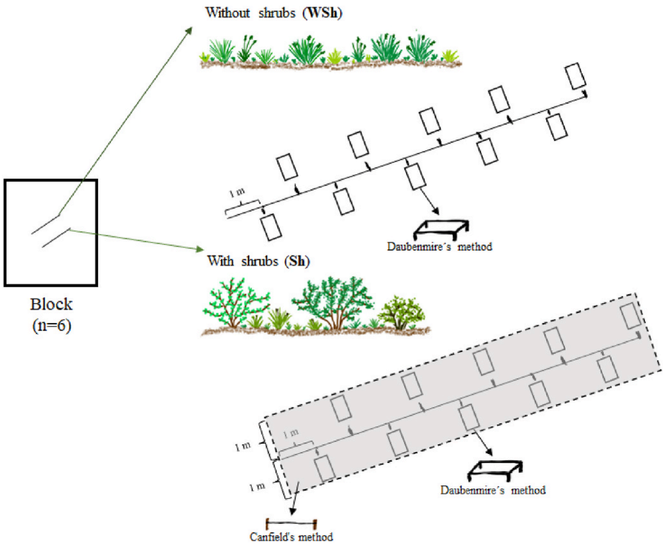

Fig. 2. Details of the experimental design and sampling methods used. In each block, one transect was located in a site without shrubs (WSh) and another one in a site with shrubs (Sh).

In the summer of 2019, the ground truth data were collected for the supervised classification through simple random sampling at the same study site. This randomness of ground truth data ensures that all parts of the study area have an equal chance of being sampled. Therefore, training sites were identified based on field-collected points data using the Global Positioning System (GPS). A total of 125 control points were selected at three sites of 20 ha. In each one the vegetation of the study area was classified into three classes: rangeland (R; vegetation area dominated by herbaceous species), open shrubland (vegetation area dominated by a shrub layer with woody species cover of less than 75%; OS), and closed shrubland (vegetation area dominated by a shrub layer with woody species cover of more than 75%; CS) (González-Roglich et al., 2012). Subsequently, geo-referenced samples or ROIs (Regions Of Interest) were created to perform the supervised classification. To do so, three spectral indices were considered: normalized difference vegetation index (NDVI), enhanced vegetation index (EVI) and soil-adjusted vegetation index (SAVI). This allowed to understand the spectral behavior of each land cover and increased the spatial samples to improve land cover discrimination (Brendel et al., 2019). Afterward, the Maximum Likelihood Classification method was applied because it is the most accurate method for monitoring the land covers (Brendel et al., 2019). Finally, the change confusion matrix was created to evaluate the accuracy of each classification process. This one comprises two metrics: the overall accuracy (OA) and the Kappa Coefficient (KC). The OA indicates the percentage of correctly classified pixels and the KC is a measure of precision calculated between the actual agreement data, an automated classifier, and the change agreement between the reference data and a random classifier (Congalton and Mead 1983). The KC oscillates between 0 and 1. Values from 0.7 to 0.85 are considered a very good performance and those above 0.85 an excellent classification agreement (Monserud and Leemans 1992).

2.3. *Statistical analyses*

Ground-based data were analyzed using a two-way ANOVA, in a split block design, with fixed factors being the categories at each site (combination between sites with and without shrubs and vegetation classification; Fig. 3) and the years (2017 and 2018). To comply with the assumptions of normality and homoscedasticity, S data were transformed with root (x) and H′ and J data with ln (x+1).

Data obtained from the remote sensing analysis were transformed with arcsine $\sqrt{\text{(cover proportion)}}$ and analyzed with a two-way ANOVA, without block splitting, considering as fixed factors the cover classes (open and closed shrubland and rangeland) and the years (2016–2022).

In all the analysis, in case of interaction between factors ($p \leq 0.05$), each one was analyzed separately. Mean separation was conducted using protected Fisher LSD test at a significance level of 5%. All statistical analyses were performed with Infostat version 2020 (Di Rienzo et al., 2020). Untransformed values are shown in all the illustrations.

3. Results

3.1. *Ground-based measurements*

The major characteristics of all plant species (herbaceous and woody) found in the study site in both years are summarized in Table 2. Species scientific names have been updated according to Instituto de Botánica Darwinion (http://www2.darwin.edu.ar/). The term subshrub refers to woody species less than 1 m tall, with a more prostrate disposition, while the term shrub refers to species also woody but more than 1 m tall (Zeberio et al., 2018).

3.1.1. *Herbaceous plant species (and some renewals)*

Renewals of subshrub (*Baccharis crispa, B. gilliesii, B. salicifolia and B.*

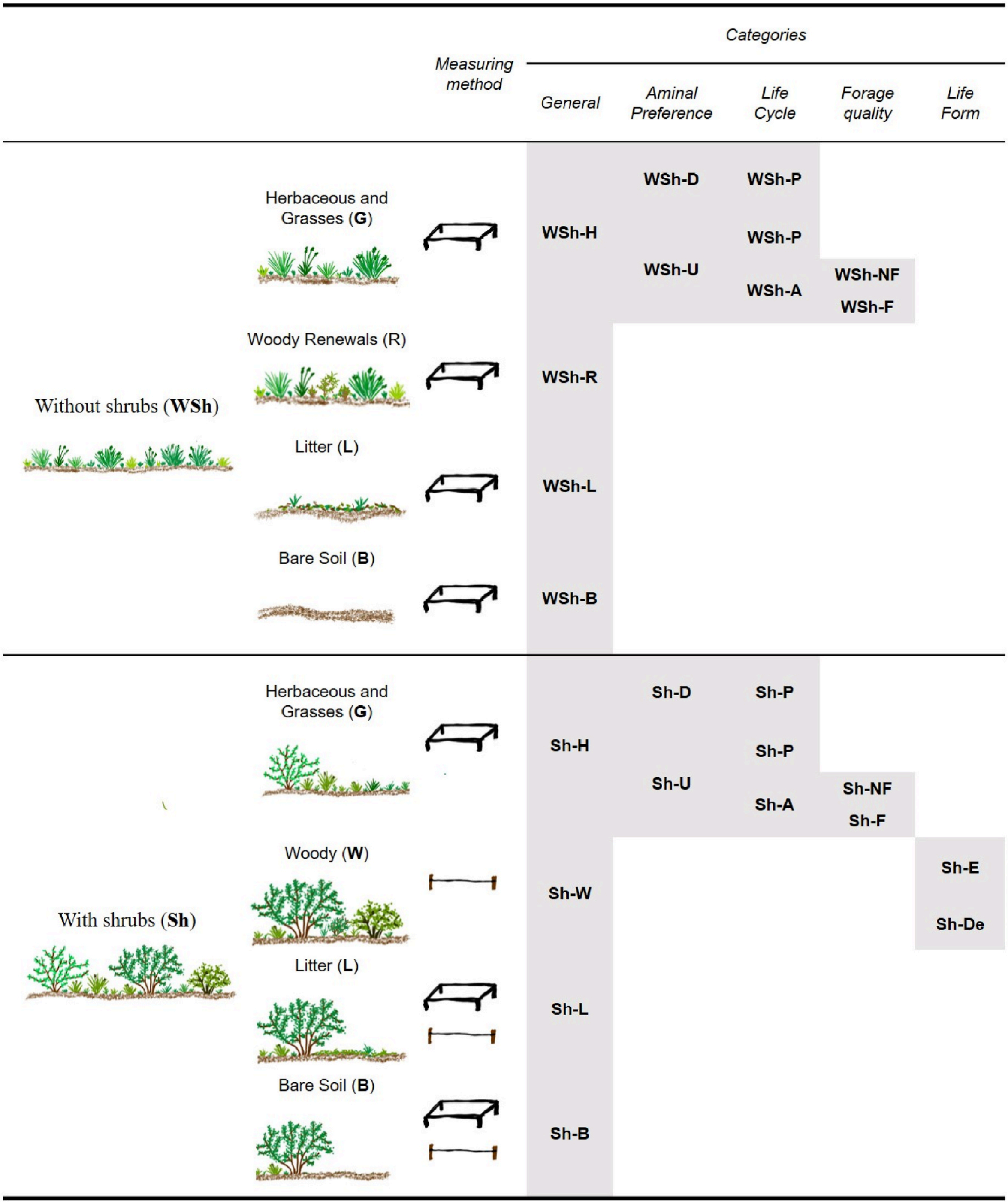

Fig. 3. 3Sampling areas, measuring methods, and categories used in the ground-based measurements study in a Monte rangeland: Daubenmire () vs. Canfield (); Desirable (D) vs. Undesirable (U); Perennial (P) vs. Annual (A); Forage annual (F) vs. Non-forage annual (NF) herbaceous species; Evergreen (E) vs. Deciduous (De) woody species.

Table 1
Remote sensing image data used for land cover classification.

Image ID	Acquisition Time
S2A_MSIL1C_20160113T135952_N0201_R067_T20GMA_20160113T140927	2016.1.13
S2A_MSIL1C_20170107T140041_N0204_R067_T20GMA_20170107T140456	2017.1.17
S2A_MSIL2A_20181218T140041_N0211_R067_T20GMA_20181218T175458	2018.12.18
S2A_MSIL2A_20190117T140051_N0211_R067_T20GMA_20190117T175217	2019.1.17
S2A_MSIL2A_20201008T140101_N0214_R067_T20GMA_20201008T180442	2020.1.8
S2A_MSIL2A_20211222T140051_N0301_R067_T20GMA_20211222T180725	2022.12.21
S2A_MSIL2A_20220101T140051_N0301_R067_T20GMA_20220101T181458	2022.1.1

Table 2
Major characteristics of the species found at the study site. Origin: N (native), E (exotic); Functional group: H: herbaceous, Ssh: subshrub, Sh: shrub; Life cycle: A: annual, BA: biannual, P: perennial; Animal preference: NP: not preferred, I: intermediate, P: preferred; ND: no data. Life form (only for shrub and subshrub species):^{E}: evergreen, ^{De}: deciduous.

Species	Origin	Functional group	Life cycle	Animal preference
Acantholippia seriphioides (A. Gray) Moldenke^{E}	N	S	P	I
Amelichloa brachychaeta (Godr.) Arriaga and Barkworth	N	H	P	NP
Avena barbata Pott ex Link	E	H	A	P
Baccharis crispa Spreng.^{E}	N	Ssh	P	I
Baccharis gilliesii A. Gray^{E}	N	Ssh	P	NP
Baccharis salicifolia (Ruiz and Pav.) Pers.^{E}	N	Ssh	P	I
Baccharis ulicina Hook. and Arn.^{E}	N	Ssh	P	I
Boopis anthemoides Juss.	N	H	P	NP
Brachyclados lycioides D. Don^{E}	N	Sh	P	I
Bromus brevis Nees ex Steud.	N	H	A	P
Bromus mollis L.	E	H	A	P
Capsella bursa-pastoris (L.) Medik.	E	H	A	I
Carduus nutans L.	E	H	BA	I
Cereus aethiops Haw.	N	Sh	P	I
Chuquiraga erinacea D. Don^{E}	N	Sh	P	NP
Condalia microphylla Cav.^{E}	N	Sh	P	I
Dichondra sericea Sw.	N	H	P	NP
Ephedra ochreata Miers^{E}	N	L	P	P
Ephedra triandra Tul. emend. J.H. Hunz.^{De}	N	L	P	P
Erodium cicutarium (L.) L'Hér. ex Aiton	E	H	A-BA	P
Festuca megalura Nutt.	E	H	A	P
Gamochaeta filaginea (DC.) Cabrera	N	H	A	ND
Geoffroea decorticans (Gillies ex Hook. and Arn.) Burkart ^{De}	N	Sh	P	I
Hoffmannseggia trifoliata Cav.	N	H	P	I
Hordeum murinum spp leporinum (Link) Arcang.	E	H	A	P
Jarava plumosa (Spreng.) S.W.L. Jacobs and J. Everett	N	H	P	P
Koeleria permollis Nees ex Steud.	N	H	P	P
Lactuca serriola L.	E	H	A-BA	NP
Larrea divaricata Cav.^{E}	N	Sh	P	NP
Lolium multiflorum Lam.	E	H	A	P
Lycium chilense Miers ex Bertero^{De}	N	Sh	P	I
Medicago minima (L.) Bartal.	E	H	A	P
Melica bonariensis Parodi	N	H	P	NP
Nassella longiglumis (Phil.) Barkworth	N	H	P	P
Nassella tenuis (Phil.) Barkworth	N	H	P	P
Nassella trichotoma (Nees) Hack. ex Arechav.	N	H	P	NP
Neltuma alpataco Phil.^{De}	N	Sh	P	I
Oxalis lasiopetala Zucc.	N	H	P	NP
Pappophorum vaginatum Buckley	N	H	P	P
Pappostipa speciosa (Trin. and Rupr.) Romasch.	N	H	P	I
Piptochaetium napostaense (Speg.) Hack.	N	H	P	P
Plantago patagonica Jacq.	N	H	A	I
Poa lanuginosa Poir.	N	H	P	P
Poa ligularis Nees ex Steud.	N	H	P	P
Prosopidastrum angusticarpum A. Palacios and Hoc^{De}	N	Sh	P	NP
Schinus johnstonii F.A. Barkley^{E}	N	Sh	P	I
Schismus barbatus (L.) Thell.	N	H	A	P
Sonchus oleraceus L.	E	H	A	I
Stellaria media (L.) Cirillo	E	H	A	P
Taraxacum officinale F.H. Wigg.	E	H	P	P
Trichocline sinuata (D. Don) Cabrera	N	H	P	ND

ulicina) and shrub species (*Chuquiraga erinacea*, *Lycium chilense* and *Ephedra triandra*) were found in some without shrubs sites (WSh-R). Herbaceous, renewals and woody species density increased from one year to the next, with higher values for WSh-H species, followed by Sh-H sites and finally for WSh-R and Sh-W species (Fig. 4a). The Sh-L category presented the highest cover percentages in both years. In contrast, in 2017 bare soil cover was higher in WSh than Sh sites (Fig. 4b). Plant species did not increase their cover.

3.1.2. Desirable vs. undesirable herbaceous species

In 2017 there were no differences between categories, while in 2018 an increased in undesirable species density was observed in both, WSh and Sh sites (Fig. 5a). Only WSh-U species cover increased from year to year (Fig. 5a). However, in 2017 plant cover was higher for desirable than for undesirable species, regardless of the presence of shrubs, a situation that was evened out in 2018 (Fig. 5b). Prevalent desirable species were *Nassella longiglumis* and *Poa ligularis*.

3.1.3. Annual vs. perennial herbaceous species

The only difference observed in plant density was for annual species, with a higher value in 2018, in both sites, in relation to perennial ones (Fig. 5c). However, in both years, perennial species cover was higher in both sites, registering a decrease in 2018 (Fig. 5d).

3.1.4. Forage annual vs. non-forage annual herbaceous species

There were no differences between years or categories, being the mean values ± 1 S.E. of density and cover, for both years, F: 26.6 ± 9.9 plants m^{-2}, NF: 38.2 ± 7.9 plants m^{-2} (n = 24) and, F: 3.6 ± 1.4% and NF: 4.9 ± 1.1% (n = 24), respectively.

3.1.5. Woody species

Although an increase of approximately 83% in woody plant density in Sh sites was observed between years (2017: 1.5 ± 0.2; 2018: 2.75 ± 0.9 plants m^{-2}; n = 6), the difference was not significant. Plant cover also did not differ between years, but did differ between different

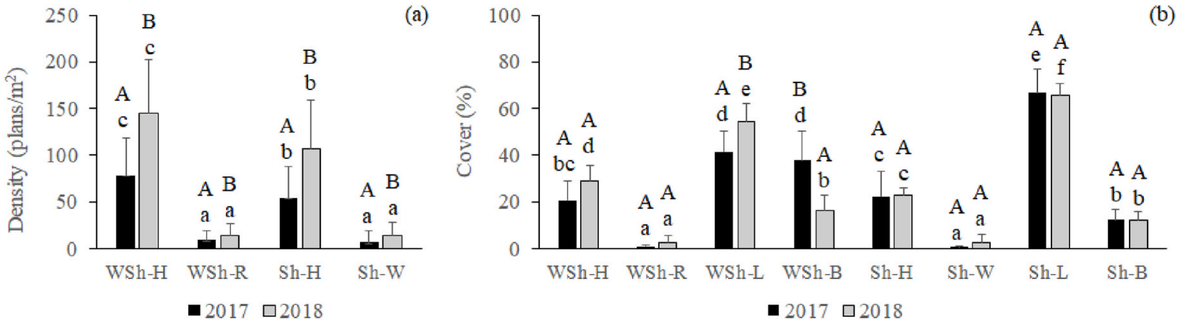

Fig. 4. 4(a) Density (plants m^{-2}) of herbaceous (H), renewals (R) and woody (W) species in sites without (WSh) and with (Sh) shrubs; (b) Plant cover (%) of H and W species, litter (L) and bare soil (B). Different letters indicate differences ($p \leq 0.05$) between years within each category (uppercase letter) or between categories within each year (lowercase letter). Each histogram is the mean ± S.E. ($n = 6$).

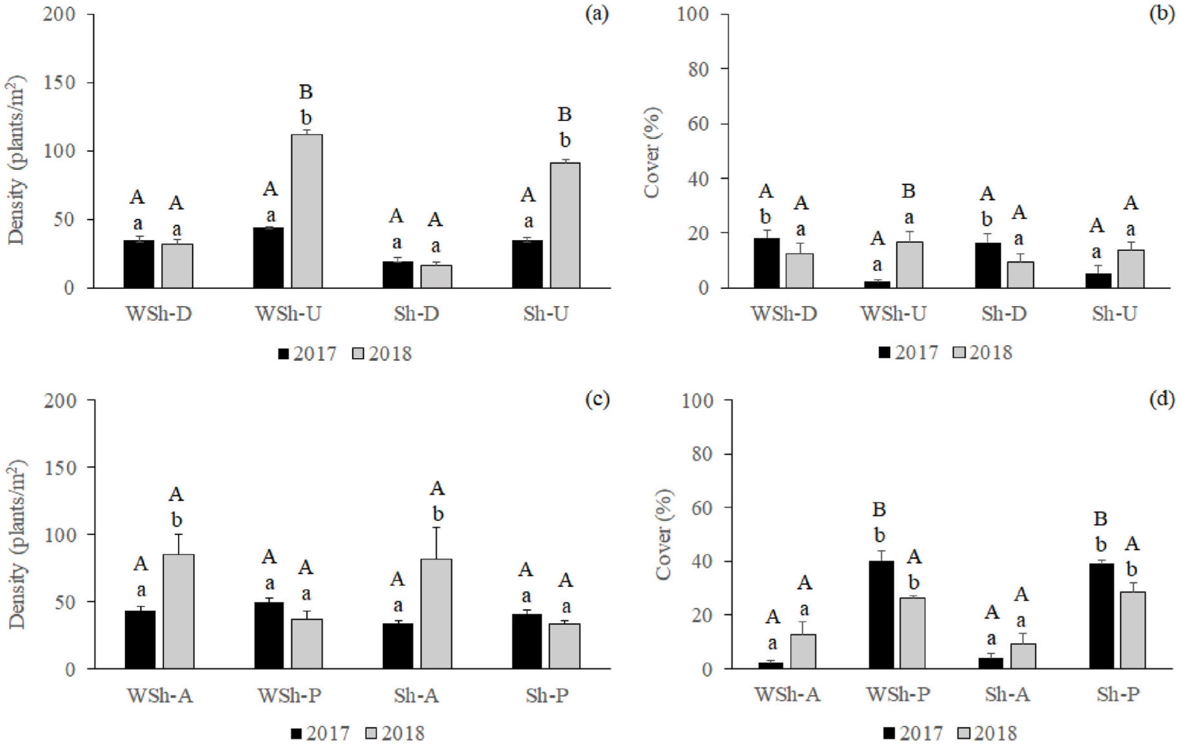

Fig. 5. 5Density (plants m^{-2}) and cover (%) of herbaceous species, in sites without (WSh) and with (Sh) shrubs, classified according to their degree of preference by livestock as (a and b) desirable versus undesirable and (c and d) annuals versus perennials. Different letters indicate differences ($p \leq 0.05$) between years within each category (uppercase letter) or between categories within each year (lowercase letter). Each value is the mean ± 1 S.E ($n = 6$).

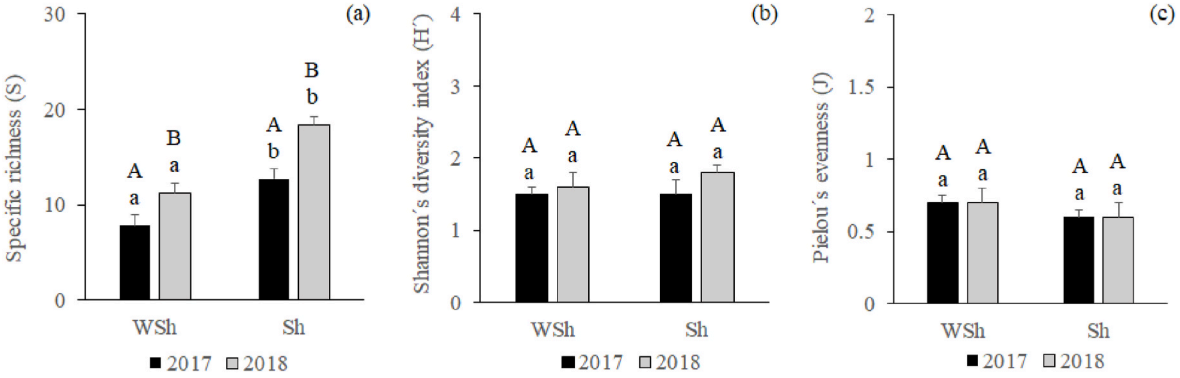

Fig. 6. (a) Specific richness (S), (b) Shannon's diversity index (H′) and (c) Pielou's evenness (J) in sites without (WSh) and with (Sh) shrubs. Different letters indicate significant differences ($p \leq 0.05$) between years within sites (uppercase letter) or between sites within each year (lowercase letter). Each value is the mean ± 1 S.E. ($n = 6$).

categories ($p \leq 0.05$), being higher for Sh-W: 78.6 ± 4.4%, followed by Sh-L: 19.2 ± 3.6% and thirdly Sh-B: 6.7 ± 1.3% (n = 12). *Chuquiraga erinacea* was the dominant species, both in density and cover and also registered an increase between years in both variables. The following most important species were *Baccharis ulicina* and *B. gilliesii*.

3.1.6. *Evergreen vs. deciduous woody species*

For both density and cover, no significant differences were found between years. Evergreen woody plant density was significantly higher (1.7 ± 0.04 plants m^{-2}) than that of deciduous ones (0.4 ± 0.01 plants m^{-2}; n = 12), while plant cover was similar in both categories (Sh-E: 45.5 ± 5.0% and Sh-De: 33.9 ± 6.6%; n = 12).

3.1.7. *Specific richness, Shannon's diversity index and Pielou's evenness*

The maximum S recorded, considering both years, was 51 species, with 74.5% of native origin. Within these species, 34 were herbaceous (16 annuals and 18 perennials) and 17 were shrubs or subshrubs. The S value was higher in Sh sites, which increased in 2018 (Fig. 6a). On the other hand, H′ an J did not vary between years or sites (Fig. 6 b y c).

3.2. *Remote sensing analysis*

No significant differences were detected in the cover of the different classes between years. Closed and open shrublands showed higher cover (44.5 ± 0.03% and 38.6 ± 0.02%, respectively; n = 21), than rangelands (16.7 ± 0.02%; n = 21). Fig. 7 shows the dynamics of the area occupied by the different vegetation classes during seven years of satellite image analysis.

4. Discussion

This is the first work that addresses the effect of shrubs on plant community composition in a semi-arid Monte rangeland, analyzed from two different working scales and complements another simultaneous study on soil quality parameters. According to the results, there is evidence of a beneficial effect of shrub presence on chemical and biochemical parameters associated with the efficient use of nutrients, functionality and activity of microbial communities (Ambrosino et al., 2023) as well as on plant community. It has been demonstrated that

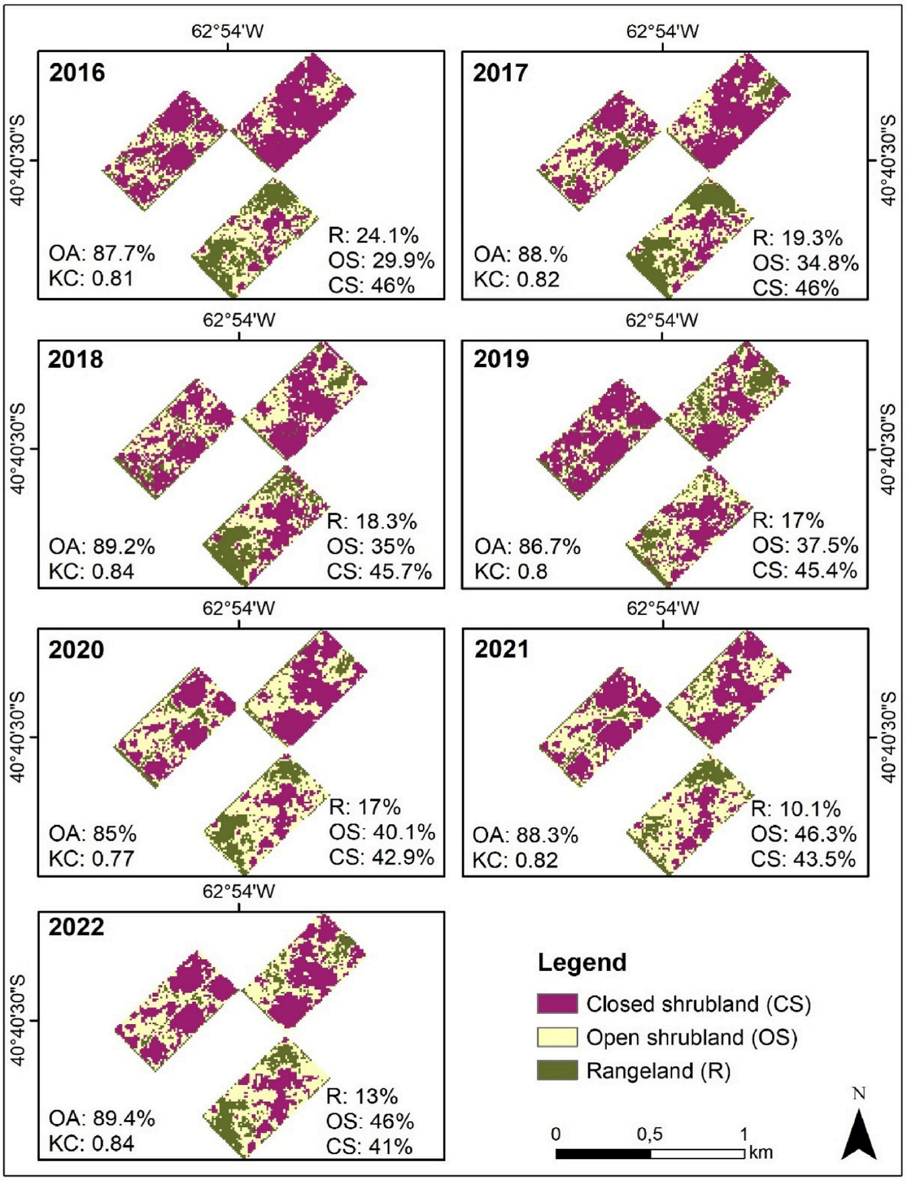

Fig. 7. Land cover classification during the 2016–2022 period. Cover classes (%): Closed shrubland (CS), Open shrubland (OS), Rangeland (R). For each year, the overall accuracy of the classification (OA) and Coefficient Kappa (KC) are indicated.

when shrub cover is kept at intermediate values (up to 50–60%), the positive effects on various ecosystem services, such as forage production, soil fertility, carbon sequestration and maintenance of diversity, are preserved (Soliveres and Eldridge 2014; Maestre et al., 2016; Ambrosino et al., 2023).

Considering all species sampled with Daubenmire's method, a general increase in plant density was observed between years. However, the same was not detected in plant cover, possible due to the small size of plant species (mostly annuals). Rainfall recorded during 2018 compared to 2017 was not only higher and over a longer period of time (64 days vs. 45 days), but also the amount registered during spring was twice as much (70 mm vs. 140 mm). This led to an increased germination and establishment of mostly annual species at both WSh and Sh sites. However, as there was a larger area of bare soil at WSh sites relative to Sh in 2017, this could have been exploited by opportunistic species largely present in the seed soil bank, which upon receiving a higher moisture input in 2018 increased their density and litter contribution at the time of sampling (December). Southwestern Buenos Aires is an area characterized by its high dependency on short-term climatic events (Ferrelli et al., 2019). Busso et al. (2004) reported that rainfall is the main factor responsible for most of the variation in biomass production between years in this site. It also has been observed that both herbaceous and woody species in semi-arid rangelands increase their leaf litterfall production after a rainfall peak, with different lag times depending on the species (Campanella and Bertiller 2010). In contrast, at Sh sites, in both years, the soil was covered mainly by litter, possibly due to a higher input of plant material per species (herbaceous and woody) and less decomposition recorded under the canopy of woody species (mostly evergreens) because of reduced solar radiation. In arid and semi-arid environments, photodegradation plays an essential role in litter decomposition while biological decomposition is lower and, therefore, may partly explain the persistence of litter observed under the shrubs (Brandt et al., 2010). In addition, evergreen shrubs, with long-lasting leaves, produce a recalcitrant litter with a high concentration of secondary compounds (such as lignin and soluble phenols) which may retard microbial decomposition (Carrera and Bertiller 2013).

The lower cover of bare soil in Sh sites relative to WSh in 2017 evidences a beneficial effect of shrub presence. The aridity index (AI) has proven to be a reliable predictor of the impact of woody species on herbaceous ones, indicating a facilitation effect for values between 0.1 and 1.5, as opposed to a competitive interaction between species for higher values (Mazía et al., 2016). An AI of 0.36, as found in the study site, reinforces the existence of positive interactions in these stressful environments. In drier years, shrubs could exert a protective effect, on plant species and the soil of bare interspaces, which is also reinforced due to the fact that 31.25% of the woody species found are deciduous, with 60% of representatives of the Fabaceae family, which generally increase total soil nitrogen through atmospheric fixation and also soil organic carbon increasing herbaceous biomass production (Soliveres and Eldridge 2014; Archer et al., 2017). Besides, on sites subjected to moderate disturbance nurse shrub effects are more evident (Leder et al., 2017).

The greater density of undesirable plant species observed in the second year is consistent with the greater record of annual species. From the point of view of forage production, these ephemeral and opportunistic species are considered undesirable, since they compete for resources with perennial species but make a low contribution to the cattle diet (Boo et al., 1993). However, considering plant cover, only in WSh sites, undesirable species increased between years, while desirable species maintained their cover in both situations. This is a positive result since desirable species (forage perennial grasses) are the ones that provide food for livestock throughout the year and the most important component in its diet (Boo et al., 1993). Despite the increase in the total density of annual species, a similar contribution of forage and non-forage species was observed, so the persistence of the former in the seed bank is an indicator of the conservation status of the site (Leder et al., 2017). On the other hand, a greater cover of perennial species (mostly desirable), regardless of the presence or absence of shrubs, guarantees greater soil protection and a continuous contribution of quality litter to the system (Ambrosino et al., 2019). It has been proposed that communities dominated by C_3 species, such as this case (Giorgetti et al., 1997), would be less affected by the presence of woody species, due to their greater tolerance to light reduction by shrub canopy in comparison to C_4 species (Mazía et al., 2016). Only one C_4 species was found in the study, *P. vaginatum*, growing equally well on sites with and without shrubs. This native forage grass is virtually the only palatable perennial herbaceous species available for livestock grazing during the warm season (Torres et al., 2020), and does not appear to be affected by the presence of shrubs. In fact, in stressful environments, the effect of woody plants on C_4 (as well as C_3) grass biomass could be positive, due to improved abiotic conditions, such as lower temperature, greater soil water and nutrient availability (Scholes and Archer 1997). Also, shade conditions can improve grass forage quality (N concentration, *in vitro* digestible dry matter), although this effect may be species-specific (Kephart and Buxton 1993).

In relation to the first hypothesis, a differential response was observed depending on the method and scale of work used. A considerable increase in woody plants density was observed, at both WSh and Sh sites, being significant with Daubenmire's method (in agreement with the hypothesis), but not with Canfield's (used only in Sh sites). Also, the cover showed no variation with either method. In many cases, the high variability among samples made it difficult to find significant differences, which is common in semi-arid regions with high environmental heterogeneity (Leder et al., 2017). However, the difference between both methods may be because, in the case of Canfield's method, established large shrubs have a greater preponderance in the sampling. At the same time, woody plants found in Daubenmire's plot are smaller. Nevertheless, the combined use of both methods made it possible to record shrub advancement. Woody species components of the Monte community are of medium to low size and have a slow growth rate (Peláez et al., 2017; Zeberio et al., 2018). The increased in density observed is mostly due to the presence of renewals of shrub species or individuals of subshrub species, such as *Chuquiraga erinacea*, *Baccharis ulicina* and *B. gilliesii*. Other studies have reported a high dominance and/or an increased presence of these native perennial species of the family Asteraceae in these shrubland communities (Tucat 2015; Álvarez Redondo et al., 2018). The presence of achenes with pappus gives these species a great dispersal capacity, so that, in some cases, they are consider weeds due to their ability to colonize open spaces and to compete with perennial grasses. *Chuquiraga erinacea* was the most abundant woody species found at both, WSh and Sh sites. Campanella and Bisigato (2019) reported in another species of the genus (*C. avellanedae*), the existence of negative effects of litter on the emergence of conspecific seedlings, due to the mechanical impediment that this would exert. This contributes to explain the over-dispersion observed in this species, i.e., a greater separation between individuals than that observed by chance. Both species, *C. erinacea* and *C. avellanedae*, produce large amounts of litter (Campanella and Bertiller 2010), so it is possible that the advance of *C. erinacea* into open spaces is the result of the need to find new environments away from the negative influence of adult plants to grow. This situation, together with its high dispersal capacity, would contribute to the advancement of this species into new spaces. Although plants of *C. erinacea* are small in size and, therefore, have little cover, it has been recorded that it has a high rainwater retention capacity, due to their dense canopy of persistent leaves, which prevents water from reaching the ground (Álvarez Redondo et al., 2018). In a semi-arid environment, where water is a limiting resource, it is necessary to control the advancement of this species, since it could modify the dynamics of water flow and its availability for other species. Regarding *B. ulicina*, in a study conducted in this same study site, a great adaptive capacity for germination was recorded, under different luminous and water stress conditions. Besides, the existence of allelopathic compounds in the aerial and belowground parts was also confirmed, with inhibitory effects on the germination and establishment of native grasses, such as *Nassella tenuis* and *N. longiglumis* (Tucat 2015). This contributes to explain their colonization success in these environments, regardless of the presence of shrubs. Although similar studies have not been conducted in *B. gilliesii*, its increase in these environments may be due to similar mechanisms. About the life form of woody species, the higher density of evergreen vs. deciduous plant species (without differences in cover), is coincident with the presence of the previously mentioned species, which have been gaining territory. In this sense, an increase over time in evergreen species could modify nutrient cycling in the long term, given the greater presence of recalcitrant compounds that prevail in their leaves compared to deciduous ones that can delay soil litter decomposition (Saraví Cisneros et al., 2013).

Specific richness showed higher values in Sh sites due to the inclusion of shrub species in the count, and increased between years mainly due to the occurrence of annual herbaceous species. On the other hand, specific diversity and evenness remained constant between sites and years, which would indicate that shrubs do not exert a dominant effect in this environment. Diversity and richness values are within those expected for shrubby Monte communities (Leder et al., 2017; Zeberio et al., 2018). Except for *T. officinale*, all exotic species found are annuals or biennials. The presence of these species in the seed soil bank may be an indicator of the degree of site disturbance, in this case caused by herbivory. However, as previously mentioned, a part of them correspond to forage species and most of the species found in the study are indeed perennials. A survey conducted in 1977, classified the community as an open shrubland of *C. erinacea* and *C. microphylla* with islands of *G. decorticans* within a continuous herbaceous layer of *N. tenuis* (Busso et al., 2004). The plant community composition has remained fairly similar since then, so the second hypothesis is rejected. The only exception is that *N. tenuis* (a mid-seral species) has been overtaken by *N. longiglumis* and *P. ligularis* (a late-seral species), whose presence indicates adequate grazing management. These findings are noteworthy as they validate that shrub presence does not alter plant composition. Instead, it enables ecological succession to progress, leading to the establishment of more desirable species for livestock production. Maintenance of diversity and specific composition is desirable for community resilience and sustainability (Loydi and Distel, 2010) since species with different functional traits can make more efficient use of limiting resources due to niche complementarity and synergistic interactions with each other (Gaitán et al., 2014).

The multitemporal analysis of satellite images of the study site, performed to complement the ground-based study, shows a clear dominance of shrub cover over rangelands. Although no significant differences were found, an increase over the years in the area occupied by the open shrubland is evident, in agreement with the first hypothesis. This is consistent with the results recorded during the two years of sampling, where there was an increase in renewals and small shrubs in open spaces, which were considered shrubless sites. This spread of a few isolated individuals, over time, may occupy a larger area until they form closed shrublands, which are difficult for cattle to access. Two previous long-term studies conducted at this same site using permanent transects and Daubenmire and Canfield's methods showed a 32% cover of woody species for 2009 (Peláez et al., 2010), with a density of 8 thousand plants/ha; while for 2016 these values increased to 45% and 10 thousand plants/ha, respectively (Peláez et al., 2017). Although in these studies the results between years were not statistically analyzed, there is also a trend towards an increase in cover and density of woody species, coinciding in 2016 with the cover value observed in the image analysis corresponding to the closed shrubland (46%). Considering the values recorded in density (2007: 15 and 2008: 27.5 thousand plants/ha) and cover (78%) from field sampling, and the results from the images analysis, it can be inferred that the site is under a process of shrub encroachment. Although poor grazing management would not be the cause of this encroachment process, herbivory-induced reduction in aboveground biomass could lead to a decrease in fine plant fuel, reducing or eliminating the occurrence of natural fires (Peláez et al., 2010). Otherwise, these fires would have played a role in controlling woody species density and preventing the invasion of new areas. Livestock and local fauna also contribute to the dispersal and germination of seeds, especially legumes, of certain woody species in the study site (Cabral et al., 2003). In recent decades, there have been changes in precipitation patterns and increases in temperature in the study area (Ferrelli et al., 2019), which may have altered soil water balance, favoring the proliferation of woody species resistant to water stress. However, plant species cover considered desirable has remained relatively constant over the years, with values varying between 10 and 18%, approximately, indicating that the increase of woody species would not be affecting the presence of desirable ones (Peláez et al., 2010, 2017). Grass species can reduce the emergence, growth and survival of woody seedlings through competition, as long as the cover of the woody layer is moderate and relatively open and grazing management allows the recruitment and persistence of the herbaceous stratum (Loydi and Distel 2010; Zeberio et al., 2018). These results confirm that with proper management of shrub vegetation it is possible to integrate livestock activity and the preservation of soil and native forest resources.

5. Conclusions

The results obtained in this study confirm that shrubs presence, in this Patagonian Monte rangeland, under proper grazing management, does not affect plant community composition and promotes the coexistence of species with different functional traits. In this environment, shrub cover plays an important role against soil degradation of bare areas and in ecological succession. Together with litter production, it provides a safe place and creates proper conditions for the establishment of herbaceous species, which favours the functioning and resilience of the ecosystem in a context of desertification and climate change. However, the presence (and increase) of shrubs renewals in open spaces indicates an imminent encroachment process that should be monitored annually, to keep it under control.

CRediT authorship contribution statement

Yanina A. Torres: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Project administration, Funding acquisition. **Leticia S. Ithurrart:** Methodology, Investigation, Writing – review & editing. **Mariela L. Ambrosino:** Investigation, Writing – review & editing, Funding acquisition. **Andrea S. Brendel:** Investigation, Visualization, Writing – review & editing. **Francisco R. Blázquez:** Investigation, Writing – review & editing. **Lorena V. Armando:** Investigation, Writing – review & editing. **Alejandro Pezzola:** Investigation, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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