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REGULAR PAPER

Combined fire and grazing of surrounding grassland does not prevent saxicolous lichens growth

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Background and aims – The use of fire as a managing tool influences and maintains many types of vegetation and may determine landscape physiognomy and species composition. Fire has a strong effect on lichens but studies about their recolonization or resistance are rare. Considering this, the objectives of this study are to investigate how fire impacts the structure of saxicolous lichen communities on rocks in grassland, considering richness, cover and lichen taxa composition and to verify if there are changes on functional diversity and redundancy among sites with different fire events.
Methods – The study was undertaken in an area composed of mosaics of native Araucaria forests and grasslands, in southern Brazil, where two sites were sampled. One of them experienced a recent intense fire episode, after being fifteen years without fire or grazing influence, and the other was regularly subjected to grazing and annual fire episodes.
Key results – The sites differed in lichen cover, lichen taxa richness and composition. Regarding the environmental and structural variables of the surrounding vegetation, significant influence on saxicolous lichen communities was also observed, with taller vegetation and greater vegetation cover on the rocky outcrops from the site with only one and intense recent fire event. Functional diversity and functional redundancy was also significantly different between both sites.
Conclusion – Based on these results it is possible to affirm that managing southern Brazilian natural grasslands with annual fire and grazing, unless it is not too intense, does not prevent the development of saxicolous lichen communities. The effect of fire on abandoned grasslands, with a high quantity of organic matter and taller vegetation, is importantly negative to saxicolous lichen community. Lichens take more time to grow and occupy the rock than the surrounding vegetation recovers, which can cause microclimate changes. The recolonization of these rocky outcrops can therefore take a long time and the new lichen community will probably never be the same as the former one.

Key words – Community ecology, fire recovery, lichenized fungi, Brazilian grasslands.

INTRODUCTION

Besides the natural occurrence of fire in many ecosystems around the world, mainly in grassy formations (Vogl 1974), the use of fire as a management tool is also important, influencing and maintaining many vegetation types (Mistry 1998a). In some grassland areas in southern Brazil, fire is probably the most important limiting factor of physiognomy and species composition (Pillar & Quadros 1997), especially on grassland-forest ecotone zones (Müller et al. 2012a). However, the effects of fire on species and functional diversity remain unclear yet, since experimental and observational studies on this subject are scarce (Overbeck et al. 2007, Müller et al. 2007).

It is already known that there are differences on fire behaviour depending on the type, structure and flammability of the grassland ecosystem (Bond & van Wilgen 1996). Fire intensity may also strongly vary in similar types of grasslands (Gibson et al. 1990, Fidelis et al. 2010), being then important to comprehend the nature and the consequences of such variation in community patterns after fire episodes (Johansson & Reich 2005). Spatial heterogeneity within the grasslands, such as the presence of rocky outcrops, also influences fire intensity and may allow the occurrence of distinct assemblies above or adjacent to rocks (Carlucci et al. 2011, Clarke 2002).

Rocky outcrops are relatively frequent in southern Brazilian grasslands (Carlucci et al. 2011, Müller et al. 2012b) and the presence of lichens over them is very common. Such lichens are pioneer organisms playing an important role in ecosystems since they initiate the slow erosion of the rocks through some lichen acids (Valencia & Ceballos 2002). This change on rock's surface may then allow other organisms to establish, such as mosses and subsequently vascular plants (Nash III 2008). Lichens have a wide geographic distribution (Valencia & Ceballos 2002), which is mainly influenced by light and humidity (Marcelli 1992), besides physical and chemical substrate characteristics (Brodo 1973, Marcelli 1996, Nash III 2008).

Fire disturbances have strong impacts on lichens and, in general, most species are drastically reduced in burned sites (Holt & Severns 2005). Their vulnerability to fire may be explained due to the low rate of thallus growth and the slow colonization rate of most species (Schulten 1985). Besides, lichens must be hydrated to be photosynthetically active, and after being partially burned they are probably dry and metabolically inactive, which may hugely affect their ability to regenerate from small fragments (Romagni & Gries 2000).

Lichen recolonization after fire disturbance has been ignored, although these organisms are important ecosystem compounds and contribute to nutrient cycling (Knops et al. 1996). So far, few studies were carried out about the effects of fire on lichen communities (Mistry 1998a, Johansson & Reich 2005, Dunford et al. 2006) and none of them with a functional approach. Considering that such effects may also be dependent on fire magnitude and frequency, which are both related to surrounding vegetation features and to the lichen substrate, the patterns of lichen communities might be variable and context-dependent. Based on these assumptions, this paper aims to (1) investigate how the structure of saxicolous lichen communities, considering richness, cover and lichen taxa composition varies in relation to differences in fire disturbance on surrounding grasslands, and also to (2) verify if there are changes on lichen functional diversity and redundancy among these grasslands. We expect differences regarding lichen taxa composition in the site with different fire regimes (sporadic but very intense fire events *versus* highly frequent but milder fire events). Besides, we also hypothesize that the lichen community inside the grassland that suffered a more intense fire will show lower richness, cover, and functional diversity and redundancy, due to lichen sensitiveness to this kind of impact.

MATERIAL AND METHODS

Study area

This study was carried out on rocky outcrops inside grasslands at Pró-Mata Research and Nature Conservation Center (CPCN Pro-Mata, 29°28′S 50°13′W) (site F) and in a nearby farm (site G), both in the city of São Francisco de Paula, Rio Grande do Sul state, southern Brazil. This is a highland region, and the sites are at an altitude of around 900 meters. Current climate is defined as warm temperate (subtropical) and humid without marked dry periods, with a mean annual rainfall of over 2,000 mm (Nimer 1989). The vegetation cover is characterized by mosaics of grasslands ("Campos de Altitude") and mixed rainforests named Araucaria forest, where *Araucaria angustifolia* (Bertol.) Kuntze (Araucariaceae) is the most characteristic tree species (Marchiori 2002).

There is paleoecological evidence that since the early Holocene fire occurs in this region of mosaics of grasslands and Araucaria forests in southern Brazil (Behling et al. 2004) and this practice may be related to native Brazilians arrival in this region (Overbeck et al. 2007). From this time on, these grasslands have been burned and after cattle introduction this burning occurs around every two years, usually at the end of winter (Pillar & Quadros 1997). Without fire and grazing, the grasslands of this region are subjected to shrub invasion and, when located next to forest patches, they are also subjected to forest expansion (Oliveira & Pillar 2004, Müller et al. 2007, 2012a).

Data collection

Two grassland sites were chosen to verify the fire disturbance impact on saxicolous lichens (fig.1): one of them located at CPCN Pró-Mata, where there was a fire episode two years before the sampling was carried out, after fifteen years without being burned or grazed (Oliveira & Pillar 2004). This site had taller grassland vegetation compared to the other site,

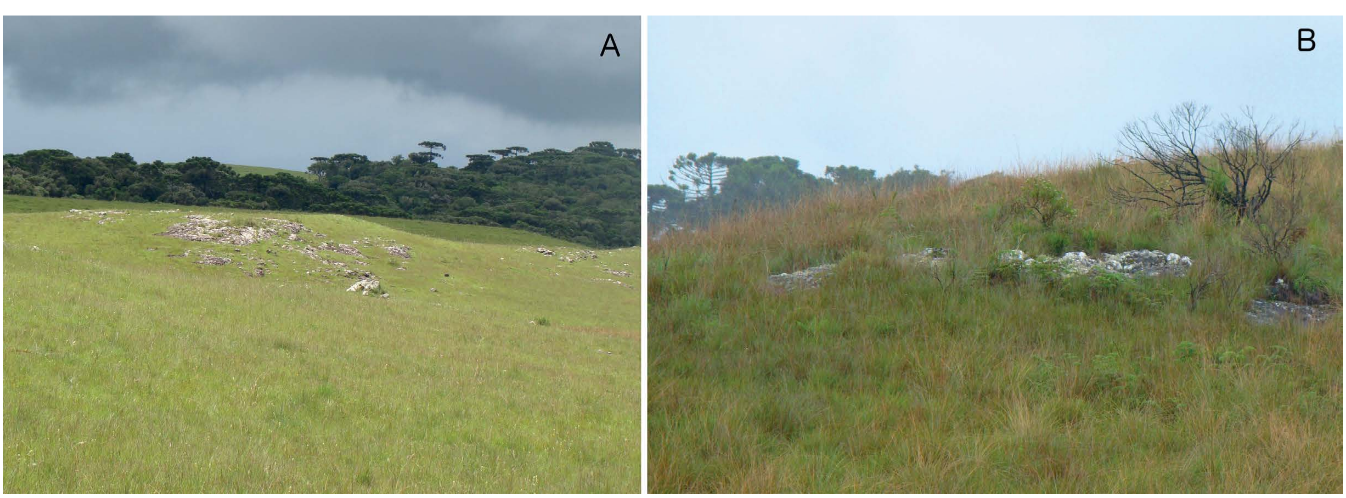

Figure 1 – A, site with annual fire and grazing (G); B, site with one recent and intense fire episode (F) after 15 years of vegetation recovery.

which was located in a farm close to CPCN Pró-Mata, and considering the accumulated dead biomass of tussock grasses and its influence on fire (Fidelis et al. 2010), the intensity of that event was surely much higher in comparison to events that occur on nearby managed grasslands. The grassland in the second site is traditionally managed with cattle grazing and annual (or every two years) fire events at the end of the winter season (Overbeck et al. 2007) and so the grassland vegetation is shorter and different in terms of species composition and richness (Baldissera et al. 2010). Twenty rocks (sampling units) were sampled in the grassland with sporadic but intense fire episode and sixteen rocks were sampled in the grassland managed with high frequent but milder fire events and grazing.

Lichens were sampled by placing a measuring tape along the widest length of the rock. Each lichen that touched this tape was considered and its thallus size was measured. Lichen percentage cover was estimated for each lichen specimen and calculated by dividing thallus size by the roughness of the rock (measure of the widest length including its projections and cavities). This sampling method aims to estimate lichen community patterns in a fast and simple way, considering the edges and the centre of the rocks, and can be replicated for different rocky outcrops from different environments. Environmental variables and structural variables of the vegetation that might influence lichen community were assessed, such as: rock area, rock roughness (measure of the rock projections and cavities by placing a measure tape along the biggest extension), height of the surrounding vegetation (average of four measures taken in each cardinal direction) and the estimated value for the plant species cover (not including mosses) on the rock. The average size of the sampled rocks was 1.2 m^2 (± 0.7).

For the functional diversity analysis, some lichen attributes were described from literature information, considering two categories: lichen growing form (attribute states: crustose, foliose or fruticose/dimorphic) and reproduction form (direct, indirect or non-defined). These traits were selected based on previous studies that showed their functional importance for lichen dispersion and establishment (Johansson et al. 2007, Ellis & Coppins 2006, 2007, Koch et al. 2013).

Data analysis

First, a Multivariate Analysis of Variance (MANOVA) was made through the software MULTIV (Pillar 2008a) with randomization and using Euclidean distance as the distance measure. This analysis aimed to verify whether the composition of the saxicolous lichen community varied significantly among sites, through a matrix of species described by their cover in each sampling unit (SU). Next, aiming to verify the community structure and to investigate the influence of the environmental and the structural variables on saxicolous lichen communities of both sites we carried out a Canonical Correspondence Analysis (CCA) with a Monte Carlo test for axis significance, through the software CANOCO 4.5 (ter Braak & Šmilauer 2002). A one-way Analysis of Variance (one-way ANOVA) was also made to verify whether the total lichen cover at the SUs varied between sites and to assess the differences on richness between them.

Table 1 – Lichen taxa sampled in each site.
All lichen taxa found in each site (intense fire event – F, annual fire and grazing – G) are presented.

Taxa	**Sites** Intense fire (F)	Fire and grazing (G)
TELOSCHISTACEAE		
Caloplaca sp. 1	x	x
Caloplaca sp. 2	x	x
Caloplaca sp. 3	x	x
CANDELARIACEAE		
Candelaria sp. 1	x	x
CLADONIACEAE		
Cladia aggregata (Swartz) Nyl.	x	x
Cladonia sp. 1		x
Cladonia sp. 2		x
ROCCELLACEAE		
Cryptothecia sp. 1	x	
PARMELIACEAE		
Flavoparmelia papillosa (Lynge ex Gyeln.) Hale		x
Hypotrachyna sp. 1		x
Hypotrachyna sp. 2	x	x
Hypotrachyna sp. 3		x
Hypotrachyna sp. 4		x
Hypotrachyna sp. 5		x
Hypotrachyna sp. 6	x	x
Hypotrachyna sp. 7	x	x
Parmotrema sp. 1		x
Parmotrema sp. 2		x
Punctelia sp. 1		x
Usnea sp. 1		x
Xanthoparmelia sp. 1	x	x
COLLEMATACEAE		
Leptogium sp. 1	x	x
NON IDENTIFIED		
Crustose lichen 1	x	x
Crustose lichen 2		x
Crustose lichen 3		x
Crustose lichen 4	x	
Total	13	24

Taxa and functional diversity indexes were calculated by using the software SYNCSA (Pillar 2008b), respectively considering the Gini-Simpson and the Rao quadratic entropy indices (Pillar et al. 2013). Furthermore, we also evaluated the functional redundancy as the difference between species diversity and functional diversity (de Bello et al. 2007). These values were then compared with a one-way ANOVA to assess the differences on functional diversity and redundancy between sites. All the ANOVAs were made through the software PAST v. 3.0 (Hammer et al. 2001).

RESULTS

A total of 26 lichen taxa, from twelve genera and six families, were identified in both sampled sites together (table 1).

Most of specimens were identified only until genus, since this was a rapid assessment and the identification had to be made in the field, without sample collections. From the total of taxa, 35% were crustose lichens, 50% foliose and 15% fruticose. Regarding the reproduction form, 39% of the taxa had direct reproduction, 46% indirect reproduction and 15% non-defined reproduction. This last type included the young thalli where it was not possible to find reproductive structures.

The main hypothesis, that both sites would differ in richness, cover percentage and taxa composition, was corroborated. Composition among sites, tested through the MANOVA, was significantly different (SS = 0.25; P < 0.007). This difference could be also noticed in the canonical ordination diagram (R = 0.8; F = 1.7; P < 0.002) (fig. 2). The rocky outcrops of sporadic fire (F) are most in the right side of Axis 1 (43.3% of explanation), while the rocks from the grassland with high frequent fire and grazing (G) are most in the left side of this axis. The diagram also shows that vegetation height (VH) and cover (VC) of surrounding grassland were more related to sites with sporadic fire, while rock roughness (RR) and area (RA) are related to the variation along Axis 2 (25.2% of explanation), comprising sampling units from both disturbance types.

Lichen cover percentage among sites compared through ANOVA was significantly different (F = 60.2; P < 0.0001) (fig. 3A) and the same was noted when comparing taxa richness (F = 46.3; P < 0.0001) among sites (fig. 3B). Both lichen

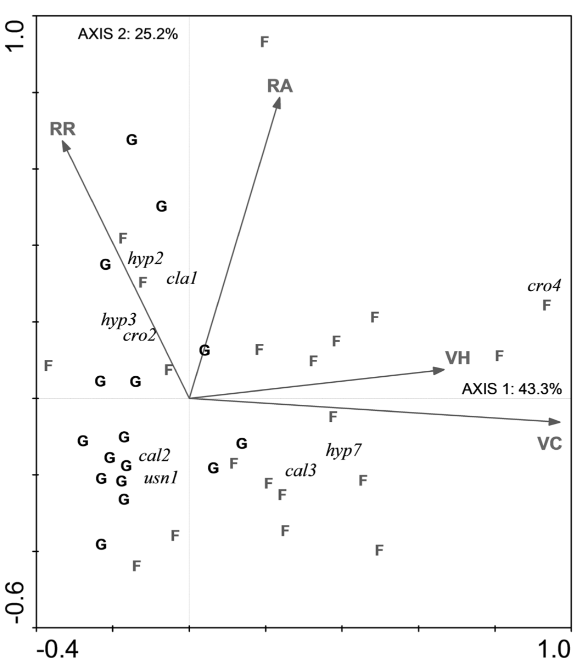

Figure 2 – Canonical ordination diagram of sites, environmental and structural variables and some of the taxa sampled. Abbreviations: F = site with only one and intense fire episode; G = site with annual fire and grazing; VH = vegetation height, VC = vegetation cover, RR = rock roughness, RA = rock area; *hyp2 = Hypotrachyna* sp. 2, *hyp3 = Hypotrachyna* sp. 3, *cla1 = Cladonia* sp. 1, *cro2* = Crustose lichen 2, *cal2 = Caloplaca* sp. 2, *usn1 = Usnea* sp. 1, *cal3 = Caloplaca* sp. 3, *hyp7 = Hypotrachyna* sp. 7, *cro4* = Crustose lichen 4.

cover and richness were greater in the grassland with high frequent fire (G), and varied, respectively, from 58 to 86% and from 3 to 9 taxa per rocky outcrop. In the sites of sporadic fire (F) lichen cover varied from 7 to 52% per rocky outcrop and species richness varied from 1 to 4 taxa. Species diversity, functional diversity and functional redundancy were all significantly different between both sites (respectively: F = 23.54; P < 0.001; F = 23.45; P < 0.001; F = 7.22; P = 0.011) (fig. 4A–C). Lower values were observed for the rocky outcrops with sporadic but more intense fire event (F).

DISCUSSION

The difference found in composition and taxa richness between both sites clearly shows the negative influence of sporadic and intense fire on saxicolous lichen communities, which can even be noticed by a rapid assessment as made in this study. While in the rocks from the grassland with sporadic fire a few lichen taxa were found, with cattle grazing and frequent fire almost twice the number of taxa were found. According to several authors, lichens are drastically reduced after fire events (Mistry 1998b, Johansson & Reich 2005, Dunford et al. 2006) and this reduction is softened by the amount of surrounding dead biomass (fuel) and by available shelters, which may prevent some species from burnt (Johansson & Reich 2005).

Significant difference in lichen cover among sites may be reflecting physical removal caused by fire. In the rocky outcrops where fire intensity was higher, more lichens were removed, while frequent rapid fire and grazing were not enough for the removal of many individuals. Grazing reduces fuel material (stand dead biomass) and so reduces fire intensity and extension due to natural spatial heterogeneity in grasslands (Harrison et al. 2003), minimizing the effect of this disturbance on saxicolous lichen communities within such areas.

Some environmental and structural characteristics (vegetation high and cover) were clearly related to the main features of both grassland types, which are also related to the disturbance regime, i.e. fire frequency and magnitude and presence/absence of cattle grazing. We hypothesize that these differences on the surrounding vegetation may also be related to the lowest lichen richness and cover in the sporadic fire grassland, once the shade in the rocks can be preventing that some pioneer and light-demanding lichen species could colonize these bared rocky outcrops.

Rock roughness and area varied independently of the grassland type, showing that both studied areas do not vary in substrate availability for lichens to establish and grow. Some authors have found that rock surface structure can determine saxicolous lichen community structure (Rajakaruna et al. 2012). Since the studied sites had both smaller and structurally less complex rocks and also bigger rocks with more heterogeneous surface, we did not note this influence.

Saxicolous lichens are sensitive to factors that determine humidity and light intensity, and also the surface temperature of the rock (John & Dale 1990). However, there are some species that are able to resist to higher light intensity, such as Parmeliaceae species (Marcelli 1998). These species benefit with the type of management currently used in South Brazilian highland grasslands (frequent fire + cattle grazing). Yet, there are other species more sensitive to the lack of humidity, and they may be disappearing in this region, as found by Johansson & Reich (2005) for terricolous lichens in the United States. Fire causes the destruction of very specific habitats, causing the loss of species with restricted ecology (Longán et al. 1999).

The results found for the functional structure corroborated our hypothesis that the site with lower fire intensity would show higher functional diversity, as well as higher taxa diversity. The studied grassland with sporadic intense fire also showed lower functional redundancy, demonstrating its high instability to face a new stress event, with few individuals playing the same role in the ecosystem (Yachi & Loreau 1999).

Based on all this, it is possible to assume that there was not enough time for lichens to recover after the intense burning, and that more than two years will be necessary for signals of lichen recolonization to be noted in the rocks from this grassland. Also, considering the rapid recovery of the grassland vegetation after the intense fire, pioneer and light-demanding lichens can find it difficult to establish, since the former condition of high light exposure was not maintained. The rapid recovery of the grassland vegetation biomass can also be a fuel for a new fire event on this site, what may completely extinguish the remaining lichens. By field observation, we could not find that new species have established in

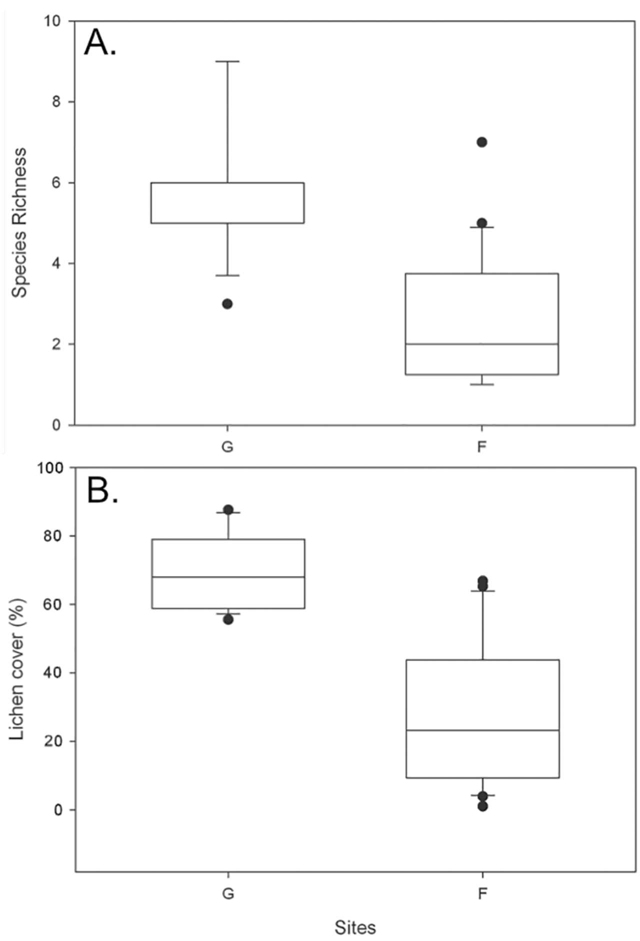

Figure 3 – A, differences on lichen cover (F = 60.19; P < 0.0001); B, richness between the two sites (F = 46.26; P < 0.0001). F = site with only one recent and intense fire episode; G = site with annual fire and grazing. Boxplot boxes represent the first and the third quartile and the line inside the boxes, the averages. The bars represent the standard deviations.

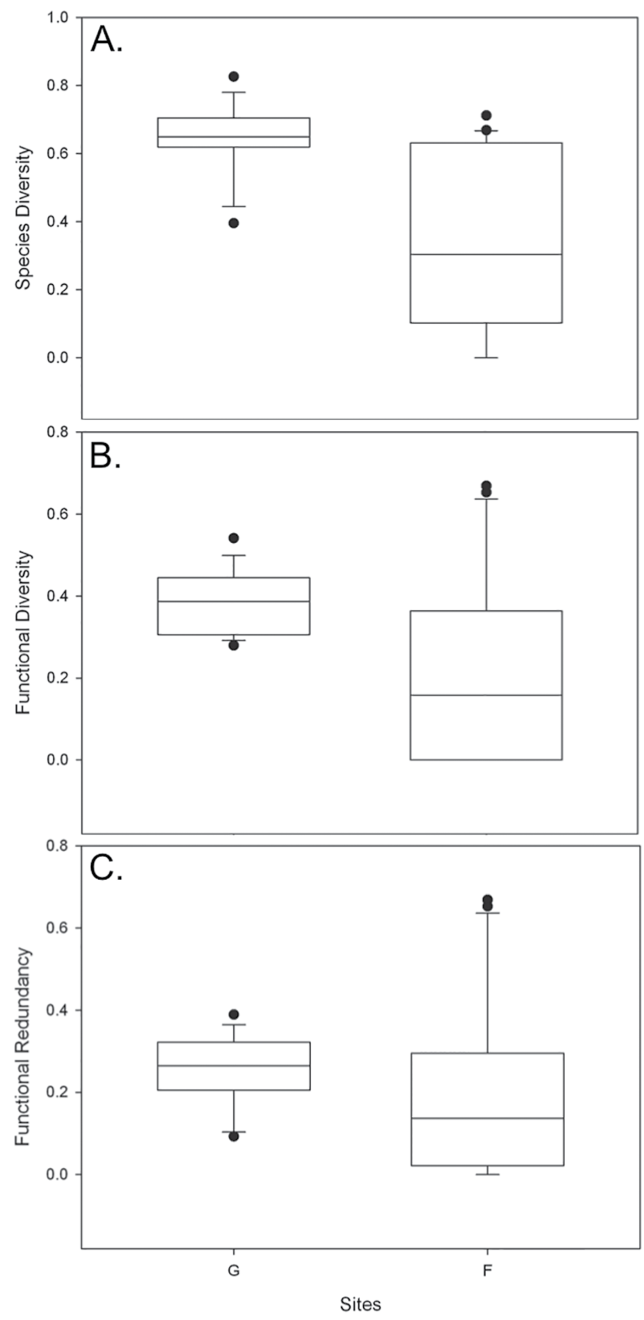

Figure 4 – A, differences on species diversity (F = 23.54; P < 0.001); B, functional diversity (F = 23.45; P < 0.001); C, functional redundancy (F = 7.22; P = 0.011) between the two sites. F = site with one recent and intense fire episode; G = site with annual fire and grazing. Boxplot boxes represent the first and the third quartile and the line inside the boxes, the averages. The bars represent the standard deviations.

the rocks where they were totally burnt. According to some authors, the necessary time for lichen community to recover after fire can greatly vary, depending on available propagules around the burnt site, on the type of substrate, and whether the species are used to surpass intense stress events (Rogmani & Gries 2000). It could take from one year (Rogmani & Gries 2000) to four years to start appearing visible signs of saxicolous lichen recolonization (Garty 1990, 1992).

CONCLUSIONS

Managing southern Brazilian natural grasslands with annual fire and grazing, unless it is not too intense, which then could cause species kneading, does not prevent saxicolous lichen community development. Some species that are more sensitive to fire may be disappearing, but to evaluate it, new studies would be necessary comparing managed with unmanaged areas. Furthermore, the effect of fire on abandoned grasslands, with a high quantity of standing dead biomass (fuel material) and higher vegetation, is highly negative to saxicolous lichen communities. Finally, it is important to highlight that the saxicolous lichen communities of these rocky outcrops may never return to their former state. Lichens take a long time to grow and occupy the rock, but the surrounding vegetation recovers fast and soon creates different conditions of light and humidity. This recolonization will depend on when each species will be able to arrive, since they will have to tolerate the new microclimate conditions.

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