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Fire and grazing differentially affect aerial biomass and species composition in Andean grasslands

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ABSTRACT

Grazing and fire have been the most common disturbances in many grasslands ecosystems for many centuries. However, some mountain regions are currently experiencing a decrease in land use, and therefore in frequency or intensity of these disturbances. In this study, we evaluated how fire and grazing affect vegetation structure in mountain grasslands of NW Argentina. We hypothesized that they would have differential effects on plant species richness, vegetation composition and aerial biomass dynamics, predicting that fire would have a stronger effect on these variables than grazing. We tested this hypothesis by performing a controlled field experiment in which we manipulated fire and compared grazed plots with ungrazed exclosures, simulating current (high frequent fires and low livestock load) and future (fire suppression and grazing exclosure) scenarios. We recorded total of 90 species with 40 shared among all treatments. Tussock grasses (*Elionurus muticus*), followed by three shrubs represented the main contribution to live biomass in all treatments. Species richness, equitativity and diversity were higher in burned plots. Multivariate ordination indicated that burning is more important than grazing in determining plot to plot similarity in species composition. Burning reduced total aerial biomass, standing dead biomass and litter, as well as live biomass, that was also reduced by grazing. Burning also reduced standing dead biomass and litter proportions, but increased live biomass contribution, showing a more evident effect within the grazed plots. Burning, seasonality and growing season had significant effects on the relative contribution of all biomass categories. Biomass consumption showed a strong seasonality, being significantly higher in January of both growing seasons, and it was not affected by burning. We conclude that under the current fire and grazing scenario, fire plays a more important role than grazing in shaping these grasslands dynamics.

1. Introduction

Grazing and fire are the most common disturbances in many grassland ecosystems around the world and they play a key role in shaping grassland structure and dynamics (McNaughton et al., 1993; De Baro et al., 1998; Oesterheld et al., 1999; Geist and Lambin, 2002; Bond, 2005). Together with climate, they are the main factors involved in grasslands development and maintenance (Oesterheld et al., 1999).

Livestock raising represents one of the major causes of tropical forest deforestation (Geist and Lambin, 2002) and is one of the most important land uses in montane grasslands and forest ecotones (Eckholm, 1975). Grazing has been found to selectively affect grassland structure, increasing spatio – temporal heterogeneity, decreasing species dominance, and promoting forbs and unpalatable vegetation (Collins, 1990; Collins and Smith, 2006). This increase in diversity is often associated to the colonization by exotic species (Sala et al., 1986; Chaneton and Facelli, 1991; D'Antonio and Vitousek, 1992; Milchunas and Lauenroth, 1993).

Importantly, in mountain grasslands many management practices associated to grazing involve intentional burning during the dry season (Scott, 1977; Schmidt and Verweij, 1992; Hofstede et al., 1995; Grau and Brown, 2000). Fire has shown to promote resprouting and to encourage the development of more palatable life forms, however, in some cases, it can increase non palatable shrubs density and remarkably alter grassland structure (Liedloff et al., 2001). Fire is controlled by ignition sources (Flannigan and Wotton, 1991; Pyne, 1993) and by biomass fuel availability, which

Abbreviations: B–G, burned–grazed; B–UG, burned–ungrazed; UB–G, unburned–grazed; UB–UG, "control": unburned–ungrazed.

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in turn is affected by livestock biomass removal (Scott, 1977; Savage and Swetnam, 1990; Cochrane and Laurance, 2002) and by climate that regulates fuel production and desiccation (Swetnam, 1993; Kitzberger et al., 1997; Grau and Veblen, 2000).

In Andean montane ecosystems grasslands cover extensive areas, and they include both natural grasslands and those that have an anthropogenic origin (Ellenberg, 1979; Sarmiento and Frolich, 2002; Aragón et al., 2006; Carilla and Grau, 2010). Certain climatic and topographic conditions (e.g. abrupt forest – grassland ecotones, coexistence of both ecosystems at the same elevation and slope, no differences in geological formation or soil humidity with the surrounded forest) can be used as an indication of human influence. Importantly, grasslands are often associated to a long and intense land use history, which led to the degradation of their soils (Lægard, 1992; Cavelier et al., 1998). However, in the last 50 years subtropical mountains of NW Argentina as other Andean landscapes, had experienced a decrease in grazing intensity associated to human migration from rural to semi-urban and urban areas (Preston et al., 1997; Aide and Grau, 2004; Grau and Aide, 2007). Contrary to expectations, fire regime did not show the same trend. Anthropogenic fires became a cultural behaviour, independent of livestock load (Carilla and Grau, 2010). Interestingly, there is an active politics of fire suppression implemented mainly by the protected areas managers. These opposite trends are expected to produce changes in disturbance regimes that can, in turn, affect plant communities in different ways.

Fire and grazing can have similar as well as differential effects on grassland composition and structure. On the one side, they are both defoliating agents (Bond and Keeley, 2005), and therefore they reduce standing biomass, which modifies environmental variables (e.g. light and water availability), and plant productivity (Pucheta et al., 1998; Hubbard, 2003). Both disturbances may affect species richness in a similar way and force the selection for similar general traits, such as reduced plant height (Noy-Meir and Kaplan, 2002), serotony/thorns (Bond and Van Wilgen, 1996; Young et al., 2003), promotion of C4 species (Collins et al., 1998; Spajosevic et al., 2010) and exotic plants (Sala et al., 1986; D'Antonio and Vitousek, 1992). On the other side, fire and grazing can have differential effects on vegetation since fire acts as a not selective grazer (Bond and Keeley, 2005). The effect of grazing is usually differential among different biomass compartments, life forms or species (Díaz et al., 1994, 2001; Collins et al., 1998; Pucheta et al., 1998)

The effect of fire and grazing simultaneously has been scarcely assessed despite of their importance for shaping grassland structure, and affecting functioning and plant productivity (Fuhlendorf and Engle, 2004). The combined effect of fire and grazing depends on diverse factors such as previous history of grazing, plant productivity, and environmental moisture, which together influence the fire regime (Milchunas and Lauenroth, 1993; Valone and Kelt, 1999). Controlled field studies are needed to isolate fire and grazing effects and make specific predictions about their interaction in particular systems. Manipulative experiments become particularly useful to answer this kind of questions. Few studies have examined the effect of fire and grazing simultaneously and in an experimental set up (e.g. Noy-Meir, 1995; Valone and Kelt, 1999), and this approach so far was not used to explore the role of these disturbances in subtropical montane grasslands. Studying fire and grazing in combination reflects more accurately how they interact in most grasslands, and contributes to the overall understanding of this ecosystem functioning.

The aim of this study was to analyze how fire and grazing affect vegetation structure in mountain grasslands of NW Argentina, specifically using two possible scenarios of current levels and future trends. We hypothesized that fire and grazing interaction affect plant species richness, vegetation composition and aerial biomass dynamics differentially, than if they act separately, mainly because the fire effect may be damped by grazing consumption of fuel biomass. More specifically, we expect that fire, as a non selective herbivore (Bond and Keeley, 2005), may reduce aerial biomass in a larger degree than grazing, but in a more generalized manner, while the effect of grazing would be limited to certain biomass categories or life forms. We tested these hypotheses by performing a controlled field experiment in which we manipulated fire in extreme situations (i.e., high frequent fires as in present times and fire suppression as in future trends), and compared grazed plots with low livestock load (current situation) and ungrazed enclosures fenced at the beginning of the experiment (extreme future trends).

2. Materials and methods

2.1. Study area

This study was carried out in the valley of Los Toldos (22° 30′ S, 64° 50′ W), department of Santa Victoria, Salta, Argentina, located at 1600 m.a.s.l. (Fig. 1). This altitudinal level is classified as *Upper Mountain forest* within the phytogeographic province of the Argentinean Yungas (Cabrera, 1976). The study area is a mosaic of mountain grasslands, shrublands and secondary forest patches dominated by *Alnus acuminata* and *Podocarpus parlatorei*, encompassing an area of approximately 6000 ha. The mean annual temperature is 11.7 °C (Easdale et al., 2007), with an average precipitation of approximately 1300 mm (average value from 1972 to 1989) that is concentrated during summer months (November–March) (Bianchi and Yañez, 1992). As meteorological data from Los Toldos is relatively short (1972–1989), we used other meteorological stations close to the study area, such as Aguas Blancas (22° 43′ S 64°22′ N, 405 msnm, 80 km South from Los Toldos; Red Hidrológica Nacional, 2006) to compare rainfall temporal patterns, especially during the two years of the experiment.

Extensive cattle raising, with no fences limiting individual properties is the most common land use. Signs of soil erosion are frequent elements in the landscape may be as the result of the combination of grazing, frequent burning, high rainfall and steep slopes (Easdale et al., 2007). Data for the whole department, together with information provided by locals, suggest that grazing load at Los Toldos is currently low (0.3–0.4 livestock ha^{-1}), c. 35% less than at the beginning of the century (Gil Montero, 2005). The pastoral system involves transhumance, a seasonal movement of cattle between altitudinal sites. Cattle are driven up to highland grasslands like the valley of Los Toldos at the beginning of the warm period (October), and they are brought back to mid-altitude and piedmont forests in March (Grau and Brown, 2000). With these movements they avoid the period of shortage of forage in highland grasslands (April–August approximately). Summer grazing is usually preceded by spring intentional burnings. The extension and frequency of burning depends on the proximity of settlements, on weather conditions when fire starts (i.e., wind, temperature, soil humidity), and on fuel biomass availability (Carilla and Grau, 2010). Fire events, spread throughout the landscape, occur every year, but a given spot is seldom burned two years in a row (Carilla and Grau, 2010). As a result of this management practice, the landscape in this area is currently a mosaic of vegetation patches differing in the time since the last burning.

Soils are predominantly clayey and silty franc varying from haplic phaeozems (young and dark soils, rich in organic matter) to eutric regosols (Nadir and Chafatinos, 1990). We did preliminary measurements of soil surface temperature and humidity in the study area, and they showed a strong seasonality, but apparently no difference between areas that were or not burned. Soil surface