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The effect of altitude and grazing on seedling establishment of woody species in central Argentina

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ABSTRACT

Understanding the factors that determine altitudinal distribution of species is very important to evaluate the influence of global change. Although climate is the major driver of vegetation distribution, other factors, such as herbivory by livestock, can be more important locally and regionally. Despite its importance, the altitudinal range distribution of species and how it is influenced by climate and livestock are generally unknown. In the Sierras Grandes Mountains of central Argentina, woodlands of lower and upper altitudes are interrupted by an intermediate vegetation belt devoid of forest. Traditionally, this pattern was assumed to be determined by climate, although recent studies suggest that forest distribution would be driven by livestock grazing. However, the potential altitudinal range distribution of the principal woody species of these forests and how it is affected by livestock are still poorly known. In this study, we used an experimental approach to evaluate seedling survival and growth – with and without livestock presence – of the three principal woody species of the mountain woodlands along the entire altitudinal gradient of Sierras Grandes. In January 2009, we planted seedlings of *Polylepis australis*, *Maytenus boaria* and *Escallonia cordobensis* inside and outside livestock exclosures at seven altitudinal sites established every 200–400 m asl, from 940 m asl to 2700 m asl (i.e., maximum altitude of Sierras Grandes). During the three following winters, we evaluated seedling survival and height and measured stocking rates. Although the three species were able to sprout after browsing, livestock markedly reduced seedling survival and height. Inside the exclosure, the three species successfully survived and grew along the entire gradient, including the altitudinal belt devoid of forest. Furthermore, after three growing seasons *P. australis* and *E. cordobensis* flowered inside the exclosure at the altitudes where seedlings reach greater heights (2200 m asl and 1200 and 1600 m asl, respectively). We suggest that under the current high stocking rates, livestock would strongly hinder seedling establishment of the three principal woody species at most altitudes of Sierras Grandes. Our findings are in agreement with the assumption that the present altitudinal belt devoid of forest is not climatically driven; rather, livestock is the major factor of current forest distribution.

1. Introduction

Vegetation patterns along altitudinal gradients are primarily driven by a decrease in temperature with increasing elevation (Crawford, 1989; Körner, 1999; Tranquilini, 1979). Far less attention has been paid to the influence of anthropogenic disturbances such as livestock grazing (Cairns and Moen, 2004; Ellemberg, 1979), despite the importance of livestock rearing in many mountain areas of the world (Hofgaard et al., 2010). Both altitude and livestock can markedly affect several stages of forest development. However, since seedling establishment is foremost sensitive to environmental conditions, this stage can become a bottleneck due to the increasing unfavorable conditions towards the altitudinal limits of distribution (Hofgaard et al., 2009; Cierjacks et al., 2007; Cuevas, 2000; Jump et al., 2009). Additionally, livestock grazing might well prevent tree seedling growth, maintaining grasslands in sites with potential for forest development (Anderson, 1981; Bond, 2005; Vera, 2000). In fact, differences between current and potential climatically determined vegetation show that ecosystems dominated by woody plants would be more extended if climatic conditions were the major constraint and no

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other factors such as fire and livestock were also at play (Bond et al., 2005). However, the influence of livestock grazing on vegetation structure depends on a number of factors. Chief among them are the resistance of woody species to browsing, the ability of recruiting woody seedlings to succeed in the face of the disturbance and competition limitation imposed by herbivores, and the preference of herbivores for tree species over surrounding vegetation (Cairns and Moen, 2004).

The Sierras Grandes Mountains in central Argentina provide a suitable scenario to address the combined effect of both factors, altitude and livestock grazing, on the distribution pattern of tree species. In this system, the distribution of lower (400–1300 m asl) and higher (1700–2800 m asl) mountain forest belts is currently interrupted by an intermediate altitudinal belt devoid of forests, occupied by a mosaic of mountain grasslands and shrublands (1300–1700 m asl) (Giorgis, 2011; Luti et al., 1979). Continuous forests along the altitudinal gradient are only present in large ravines; outside ravines, the forests of the higher zone, dominated by *Polylepis australis*, are often restricted to rocky outcrops (Cingolani et al., 2004; Renison et al., 2002). This vegetation pattern has been traditionally assumed to be the consequence of more favorable climatic conditions in ravines and outcrops and, secondly, to a lower human disturbance in the rough relief of the ravines and in rocky outcrops (Cabido, 1985; Cingolani et al., 2003; Luti et al., 1979). However, recent studies challenge that assumption. Increasing evidence suggests that human activities, such as logging, fire management and livestock grazing, are the major drivers of the present forest distribution. These anthropogenic activities reduce *P. australis* growth and survival (Giorgis et al., 2010; Renison et al., 2002; Teich et al., 2005); forest remnants are far from the influence of humans, and topography *per se* cannot fully explain the present distribution of mountain forests (Cingolani et al., 2008). On the other hand, according to global patterns defined by Körner and Paulsen (2004) there should not be a climatic treeline explaining the lack of forests at certain altitudes in the Sierras Grandes. Treelines in mountains all throughout the world are expected to be determined by the isotherm of 6–7 °C of mean ground temperature during the growing season (Körner and Paulsen, 2004). Considering that at 6–7 °C, air and soil temperature are similar (Körner and Paulsen, 2004), the Sierras Grandes would not surpass this isotherm since the annual average air temperature at the maximum altitude (i.e., 2800 m asl) is 7.4 °C (Marcora et al., 2008). Accordingly, individuals of *P. australis* growing at these maximum altitudes can exhibit tree habit (Marcora et al., 2008).

Despite this sound evidence of the effects of both livestock grazing and climate on *P. australis* forests, no studies have still addressed the combined influence of both factors to explore the relative influence of each driver on forest distribution in Sierras Grandes. Furthermore, the potential altitudinal distribution of tree species still remains unknown, particularly for *Maytenus boaria* and *Escalonia cordobensis*, other representative trees frequently associated with *Polylepis* woodlands. Whether tree species present inside ravines can be established on more unfavorable high topographic positions, particularly between 1300 and 1700 m asl, also remains to be elucidated.

In this study we evaluate the combined effect of livestock grazing and altitude on the survival and growth of seedlings of three tree species occurring in the Sierras Grandes using a manipulative experimental approach. Unlike most previous studies that have focused only on *P. australis*, our study also provides basic information of *M. boaria* and the endemic species *E. cordobensis*. We hypothesize that the combined effects of livestock grazing and harsh weather conditions prevailing at the altitudinal limits of distribution could greatly retard or completely inhibit forest establishment.

2. Materials and methods

2.1. Study area

The study was conducted in the Sierras Grandes Mountains, Córdoba, central Argentina. The experimental plots were placed on the eastern slope which is more accessible than the western slope, and along an altitudinal gradient that ranging from 900 m asl up to the highest altitude of the mountain range, at 2700 m asl (Linderos road, 32°5′S, 64°9′W). The whole gradient comprises the following vegetation belts described by Cabrera (1976) for the Mountain Chaco District: (1) the upper portion of Chaco mountain forest, which is distributed between 400 and 1300 m asl; (2) an intermediate belt devoid of forest currently occupied by mountain grasslands and shrublands (1300–1700 m asl; Giorgis, 2011); and (3) a mosaic of high mountain grasslands and *P. australis* woodlands (above 1700 m asl). Along the gradient, mean annual temperature varies between 15.7 °C at 900 m asl and 7.4 °C at 2700 m asl (Marcora et al., 2008) and annual precipitation at 2100 m asl is about 840 mm (Cabido, 1985). The main economic activity is livestock rearing that began in the early 17th century and had completely replaced the native herbivores (*Lama guanicoe*) by the beginning of the 20th century (Díaz et al., 1994).

2.2. Study species

We selected three native woody species that grow along the altitudinal range. *E. cordobensis* (KUNTZE) HOSSEUS (Escalloniaceae) is an endemic shrub of mountains of central Argentina that grows in both low and highland mountain forest and can reach up to 5 m in height, whereas *M. boaria* MOLINA (Celastraceae) and *P. australis* BITT. (Rosaceae) are tree species that form forests at higher altitudes, but may be found as isolated individuals at lower levels, where other woody species dominate the forests. The best performance of *P. australis* (i.e. vitality of adults individuals, tree-ring growth, seed mass, seed productivity and seed germination) in the Sierras Grandes is observed at about 1900 m asl, where the largest forest areas currently occur (Cingolani et al., 2008; Marcora et al., 2008). To the best of our knowledge, no studies regarding the effect of altitude on distribution patterns of *E. cordobensis* and *M. boaria* have been conducted. Cattle browse a high proportion of *P. australis* stems, even under low stocking rates (Giorgis et al., 2010; Teich et al., 2005). *M. boaria* is also browsed by livestock (Donoso and Wendler, 1985). There are no reports about the response of *E. cordobensis* to livestock; however, browsed individuals have been observed (pers. obs.).

2.3. Experimental design

Seven sites were selected along the altitudinal gradient, placed at intervals of about 200–400 m asl (963, 1243, 1600, 1803, 2248, 2458 and 2685 m asl). All sites were established on ridges with similar gentle slopes and high solar insolation (Table 1). Soil characteristics of each site are summarized in Table 1 (Tecco P.A., unpublished data). At each altitudinal site, a 20×20 m exclosure was built to exclude domestic livestock. In January 2009, at each site we planted 50, 34 and 36 seedlings of *E. cordobensis*, *M. boaria* and *P. australis*, respectively. Half of the seedlings were planted inside the exclosure, whereas the other half were planted outside, in a plot adjacent to the exclosure, i.e., exposed to livestock grazing. Seedlings had been grown in a greenhouse using seeds from over 30 parent trees per species collected from the study area at altitudes from 1400 to 1900 m asl. At the moment of transplanting in the field, average seedling height was 14.80(±5.69) cm for *P.*