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Research article

Traditional cattle vs. introduced deer management in Chaco Serrano woodlands (Argentina): Analysis of environmental sustainability at increasing densities

José Luis Charro [a], Aida López-Sánchez [a], Ramón Perea [a, b, *]

[a] Departamento de Sistemas y Recursos Naturales, Universidad Politécnica de Madrid, Ciudad Universitaria, s/n, 28040 Madrid, Spain
[b] Department of Biology, Stanford University, 371 Serra Mall, Stanford, CA 94305, USA

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ABSTRACT

Wild ungulate populations have increased and expanded considerably in many regions, including austral woodlands and forests where deer (*Cervus elaphus*) have been introduced as an alternative management to traditional cattle grazing. In this study, we compared traditional cattle with introduced deer management at increasing deer densities in the "Chaco Serrano" woodlands of Argentina to assess their ecological sustainability. We used three ecological indicators (abundance of tree regeneration, woody plant diversity and browsing damage) as proxies for environmental sustainability in woody systems.

Our results indicate that traditional cattle management, at stocking rates of ~10 ind km^{-2}, was the most ecologically sustainable management since it allowed greater tree regeneration abundance, higher richness of woody species and lower browsing damage. Importantly, cattle management and deer management at low densities (10 ind km^{-2}) showed no significant differences in species richness and abundance of seedlings, although deer caused greater browsing damage on saplings and juveniles. However, management regimes involving high deer densities (~35 deer km^{2}) was highly unsustainable in comparison to low (~10 deer km^{-2}) and medium (~20 deer km^{-2}) densities, with 40% probability of unsustainable browsing as opposed to less than 5% probability at low and medium densities. In addition, high deer densities caused a strong reduction in tree regeneration, with a 19–30% reduction in the abundance of seedlings and young trees when compared to low deer densities. These results showed that the effect of increasing deer densities on woody plant conservation was not linear, with high deer densities causing a disproportional deleterious effect on tree regeneration and sustainable browsing. Our results suggest that traditional management at low densities or the use of introduced ungulates (deer breeding areas) at low-medium densities (<20 deer km^{-2}) are compatible with woody vegetation conservation. However, further research is needed on plant palatability, animal habitat use (spatial heterogeneity) and species turnover and extinction (comparison to areas of low-null historical browsing) to better estimate environmental sustainability of Neotropical ungulate-dominated woodlands.

1. Introduction

Over the last four decades, there has been an increasing interest in incorporating wildlife into conservation and sustainable management practices (Font and Tribe, 2000; Bauer and Giles, 2002; Rodríguez-Piñeros and Mayett-Moreno, 2015). This trend has been influenced, in part, by the increasing wild ungulate populations in most temperate regions over the past few decades (Fuller and Gill, 2001; Gordon et al., 2004; San Miguel et al., 2010; Acevedo et al., 2011). In many areas, wild ungulate populations (e.g. deer) have also reached high densities due to intensive management (e.g., fencing and supplementary feeding), causing significant biodiversity damage (Perea et al., 2014), and affecting public safety, livestock health, and wildlife conservation (Gortázar et al. 2006; Bissonette et al., 2008; Berentsen et al., 2014). As a result, forest and woodland management in areas where wild ungulates (either native or introduced) are abundant or overabundant is currently receiving great attention (Schulze et al., 2014; Massei et al., 2015;

* Corresponding author. Departamento de Sistemas y Recursos Naturales, Universidad Politécnica de Madrid, Ciudad Universitaria, s/n, 28040 Madrid, Spain.
E-mail address: ramon.perea@upm.es (R. Perea).

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Perea et al., 2016; Pastur et al., 2016). In this sense, managers are interested in new ungulate-adapted practices that help minimize conflicts between wild ungulate populations and land users (Kuijper, 2011; Apollonio et al., 2010; Edenius et al., 2014). This change of paradigm deserves further attention since it brings important economic and environmental implications for sustainable land management.

Extensive livestock, with domestic ungulates, represents another typical use of ungulates in many ecosystems. Some research has shown that compatibility of wild and domestic ungulates might be possible due to their differential behavior and food preferences (Vavra et al., 1999; Pordomingo and Rucci, 2000; Stewart et al., 2003) although diseases that benefit from abundant wild ungulate populations have proved to increase disease transmission to livestock (Berentsen et al., 2014). Both wild and domestic ungulates represent strong ecological forces that can significantly affect ecosystem structure and composition, particularly by selectively foraging on some woody species (Veblen et al., 1989; Bugalho and Milne, 2003; Rooney and Waller, 2003; Stockton et al., 2005; Martin et al., 2010; Perea et al., 2015; Pastur et al., 2016). Numerous studies have shown that high ungulate densities, either domestic or wild, can cause severe problems on plant regeneration (Côté et al., 2004; Giorgis et al., 2010; Marcora et al., 2013; Perea and Gil, 2014; Bradshaw and Waller, 2016). Furthermore, prolonged ungulate browsing has been shown to limit tree recruitment (Putman and Moore, 1998; Teich et al., 2005; White, 2012) and reduce overall woody plant diversity, thereby hampering the ecological sustainability of forests and woodlands (Côté et al., 2004; Rooney, 2009; Perea et al., 2014). These detrimental effects of ungulate overpopulation are well known, and its remediation represents a complex and slow process (Klein, 1981; Brown et al., 2000). However, very few studies have compared the effect of domestic vs. wild ungulate management regimes on woody plant recruitment (Wisdom et al., 2006; López-Sánchez et al., 2014, 2016; Perea et al., 2016) and, particularly on woody plant diversity and overall environmental sustainability.

Animal density (i.e., stocking rate) has been recognized as an important factor determining herbivory pressure on woody plants (Bradshaw and Waller, 2016). Many studies have assessed the effect of different ungulate densities on tree recruitment, particularly for domestic ungulates (Fischer et al., 2009; Zimmermann et al., 2009). However, the impact of increasing densities of wild ungulates has traditionally received less attention (Tremblay et al., 2006; San Miguel et al., 2010; Bradshaw and Waller, 2016), probably as a result of their complex movement patterns and the challenges involved in estimating their population size and dynamics (Gaillard et al., 1998; Acevedo et al., 2008; Serrouya et al., 2017). Despite methodological difficulties, reliable comparisons among different wild ungulate densities are essential to assess the sustainability of ungulate populations (De Calesta and Stout, 1997; Tremblay et al., 2006). In fact, selection of adequate ungulate densities represents a crucial management decision that requires further scientific support. Therefore, there is a strong need to compare how different management approaches, including different grazing species at different densities, may affect tree regeneration and woody plant diversity in order to achieve sustainable management of woody systems. Previous studies have already shown that ecological sustainability of woody systems is mostly limited by the impact on woody vegetation (De Calesta and Stout, 1997; Morellet et al., 2007; San Miguel et al., 2010; Perea et al., 2015). Therefore, woody plant regeneration, browsing damage and woody plant diversity have been used as reliable indicators of ecological sustainability in systems dominated by woody plants (De Calesta and Stout, 1997; Perea et al., 2015; Velamazán et al., 2017) such as Chaco Serrano woodlands.

In this study, we analyzed the ecological sustainability of four different management regimes that involve domestic (cattle) and introduced red deer (*Cervus elaphus*) management (deer breeding areas) at increasing densities in Chaco Serrano woodlands of Argentina. Particularly, we used three ecological indicators (abundance of tree regeneration, woody plant diversity and browsing damage) to compare traditional cattle management with introduced deer management. We, specifically, address the following questions: (1) Is regeneration abundance (i.e., density of both seedlings and young trees) and woody plant diversity higher in areas with traditional cattle management than in any deer-managed areas?, (2) Will probability and intensity of herbivory over young trees increase linearly with higher deer densities?, (3) Will regeneration abundance and woody plant diversity be significantly reduced at increasing deer densities?, (4) Will unsustainable browsing damage (i.e. proportion of plant species with unsustainable damage) be greater in deer-managed areas than under traditional cattle management?. Overall, this study aims to improve our understanding of the long-term effects of traditional cattle management on woody systems as compared to new alternative management approaches that involve introduced deer populations at different densities.

2. Materials and methods

2.1. Study area

The study area is located in Catamarca province, in the Northwest-Region of Argentina. It covers four adjacent ranches in the east part of the “Sierra de Ancasti” mountain range (Fig. 1). The climate is highly seasonal, with hot summers (temperatures can reach 41 °C) and mild to cold winters (mean temperature 10 °C, with frequent frosts). During winter, rainfall is scarce or null, with sporadic dry “Zonda” winds (particularly active in August). The elevation range varies from 450 to 700 m. The average annual rainfall is 550–650 mm, concentrated in November–April. Soils are acidic, with abundance of gneisses, migmatites and schist stones and predominance of thin sand and slime.

The study area belongs to “Chaco Serrano” ecoregion. Vegetation is dominated by woody plants, with some large tree species such as *Schinopsis haenkeana* Engl., *Anadenanthera colubria* Vell., *Prosopis nigra* Griseb., *Prosopis alba* Griseb., and medium-size species such as *Geoffroea decorticans* Gill., *Ziziphus mistol* Griseb., *Acacia aroma* Hook., *Celtis tala* Gillies, *Ruprechtia appetala* Wedd. and *Parkinsonia praecox* Hawkins. Typical shrub species include *Larrea divaricata* Cav., *Condalia microphylla* Cav., *Lithraea molleoides* Vell., and *Mimosa farinosa* Griseb.

Red deer (*Cervus elaphus* L.) have been introduced from Europe and are actually spread over different parts of Argentina (Veblen et al., 1989; Flueck, 2010).

2.2. Study sites and species

The four ranches (hereafter sites) have similar ecological characteristics (elevation range, aspect, soil, climate and vegetation composition). Sites mostly differ in the type of management and the animal density (Table 1). One of them has maintained cattle grazing over the last two centuries (hereafter CT), representing the traditional livestock management in the area. The stocking rate in CT is known thanks to the information provided by the owners (Table 1). Cattle browsed all year round and no supplementary feeding was provided. The other three sites are red deer breeding areas, and have had red deer (*Cervus elaphus* L.) populations since 1998, when the ranches abandoned the traditional cattle management. No other browsers are present in the study sites. All study