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Original Research

# Paddock Size Mediates the Heterogeneity of Grazing Impacts on Vegetation ☆

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ABSTRACT

Domestic herbivores' effect on vegetation is spatially heterogeneous, being one of the major causes of forage resources degradation. It has been proposed that paddock size controls grazing impact's heterogeneity because as size decreases, herbivores' utilization is spatially more even. However, this has not been critically evaluated in commercial-scale paddocks isolating paddock size effects from other factors influencing the interaction between herbivores and vegetation. Here we assessed how paddock size mediates the heterogeneity of continuous sheep grazing effects on vegetation, at constant stocking rate in Patagonian steppes. We selected three small (ca. 110 ha) and three large (ca. 1 100 ha) paddocks dominated by the same plant community. All paddocks contained a single watering point and presented similar shape. Total and specific plant cover, vegetation patchiness, population size distribution of dominant grass species, plant morphology, and sheep feces density were estimated at increasing distances from watering points. Relationships between vegetation variables and distance from the watering point were in most cases asymptotic exponential, although responses generally differed between small and large paddocks. In small paddocks, vegetation variables mostly reached a plateau at a short distance from the watering point (~200 m). Instead, in large paddocks, the changes in vegetation variables were larger and more gradual, and reached a plateau at much greater distances (~2 000 m). Vegetation heterogeneity throughout the paddock was lower in small than large paddocks. Our findings suggest that paddock size mediates the spatial pattern of grazing effects on vegetation. Reducing paddock size decreases grazing impacts spatial heterogeneity, which makes plant-animal interactions more predictable and might improve forage utilization efficiency.



## Introduction

Herbivores' selectivity controls forage resources use heterogeneity (Prache et al., 1998). Thus, animal distribution is heterogeneous at different spatial scales, being grazing pressure heavy in some localized areas while other areas receive light or no utilization (Senft et al., 1987; Coughenour, 1991; Bailey et al., 1996; Bailey, 2004; Teague et al., 2004). In arid and semiarid rangeland ecosystems, this heterogeneous impact of selective grazing is exacerbated and has been identified as one of the major causes of forage resources degradation (Senft et al., 1985; Schlesinger et al., 1990; Golluscio et al., 2005; Teague et al., 2013; Norton et al., 2013). However, research experiments often assume a homogeneous forage distribution and utilization, ignoring uneven grazing impacts (Norton, 1998; Laca, 2009).

The spatial distribution of herbivores is mainly controlled by distance to water, spatial variation in vegetation structure (i.e., vegetation types, cover, floristic composition, forage quantity and quality), topography, and animal interactions (Coughenour, 1991; Bailey et al., 1996; Adler et al., 2001; Provenza, 2003; Briske et al., 2008). Many management actions focus on reducing the heterogeneous grazing impacts by promoting uniform animal distribution. The most common are manipulations of livestock type, stocking rate, grazing and rest periods, paddock structure (i.e., size and shape), herding and supply sites of water and supplements (Briske and Heitschmidt, 1991; Adler et al., 2001; Adler and Hall, 2005; Laca, 2009; Bailey and Brown, 2011). However, the impacts of some of these actions, such as the nonlinear effects of herd size or paddock size (potential grazing area), are still misunderstood (Laca, 2009). Paddock size is one of the leading factors that must be empirically evaluated because of its ecological importance (Laca, 2009) and economic cost of paddock size changes (Aguiar and Román, 2007). Decreasing paddock size has been proposed to counteract the undesired effects of uneven grazing (Bailey and Brown, 2011). In

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smaller paddocks, animals would be evenly distributed and grazing impacts would be more homogeneous (Hart et al., 1993; Norton, 1998; Barnes et al., 2008; Laca, 2009; Brown and Kothmann, 2009). Nonetheless, this assertion has not been critically studied by isolating paddock size effects from other factors influencing the interaction between herbivores and vegetation in commercial scale paddocks.

Few studies have evaluated how paddock size affects vegetation utilization (Norton et al., 2013), although they have generally studied different grazing systems (Norton, 1998; Barnes et al., 2008). This approach makes it difficult to separate paddock size effect from impacts associated with grazing pressure, rest periods, or animal behavior under different systems. One study separately evaluated different paddock sizes (24 vs. 207 ha) and showed that spatial utilization was more homogeneous in the small paddock than the large one (Hart et al., 1993). However, this work did not have replicates for paddock size treatments. Even the large paddock was smaller than those commonly found on farms (Barnes et al., 2008) and presented an unusual shape. Single-paddock treatment reduces the robustness of inferences. In another study, increasing paddock size reduced the proportion of the area that animals effectively explored (Hunt et al., 2007). Nevertheless, spatial grazing impact on vegetation is not necessarily linear with explored areas, due to the existence of other hierarchical controls of herbivore diet selection (Laca, 2009).

In most rangeland ecosystems, water is one of the major limiting factors for animals. Thus, watering points exert significant control over spatial distribution and impacts of grazing (Andrew, 1988). In general, domestic grazing causes great effects on vegetation and soil in areas close to watering points, which are defined as piospheres (Andrew, 1988). Numerous studies have evaluated domestic grazing impacts around piospheres and different vegetation response patterns as functions of increasing distance from watering points have been described (e.g., Bisigato and Bertiller, 1997; James et al., 1999; Heshmatti et al., 2002; Adler and Hall, 2005; Todd, 2006; Fensham et al., 2010). It has been stressed that these different response patterns may be mediated by the size of management units (Heshmatti et al., 2002), highlighting the importance of empirically studying the isolated effects of paddock size on piospheres (Heshmatti et al., 2002; Barnes et al., 2008).

The objective of this study was to evaluate how paddock size mediates the heterogeneity of domestic livestock effects on vegetation at constant stocking rate and grazing periods. Specifically, we estimated vegetation heterogeneity within paddocks of different sizes, among areas located at increasing distance from watering points. Vegetation response variables were total plant cover, vegetation patchiness, species abundance, and population plant-size distribution of dominant grass species (forage and nonforage species) and their plant morphology. The study was carried out in continuously grazed commercial paddocks, containing a single watering point. The hypothesis states that as the paddock size increases, forage utilization and grazing impact on vegetation within a paddock are more heterogeneous. This occurs because the highly selected patches near watering points receive higher grazing pressure in large paddocks, resulting from a greater animal concentration (as they tend to move in herds). On the contrary, distant patches are avoided because of the difficulty for herbivores to explore the entire area. Contrastingly, in smaller paddocks, herbivores explore the whole area and, therefore, use the available forage more evenly. In rangelands where intensive grazing promotes species replacement and nonpreferred species dominance, it is predicted that the boundary of heavy use around watering points (piosphere size) increases as the abundance of preferred plants decreases. This effect would be higher in large paddocks, where local grazing pressure in the piosphere is more significant than in small paddocks. It is also predicted that population size distribution of dominant grass species and vegetation patch structure are more uniform throughout the whole paddock (i.e., as distance to watering points increases) in small management units than larger ones.

## Materials and Methods

### Study Site Description

The study site corresponds to a grass-shrub steppe located in South Central Patagonia, Chubut province, Argentina. Studied paddocks were inside the Río Mayo INTA Experimental Station (lat 45°24'S, long 70°18"W, see Appendix A). This area has been grazed by sheep for > 100 yr. Grazing management is extensive, in continuously grazed paddocks (Golluscio et al., 1998). Mean monthly temperature varies between 2°C in July and 14°C in January. Average annual precipitation is 154 ± 44 mm, and most rainfall occurs between May and September (Jobbágy et al., 1995). Soils are Calciorthids and present a coarse texture (sandy), with a high content of pebbles of varying diameter (Paruelo et al., 1988). Few dominant perennial grass and shrub species contribute to 96% of total biomass (Oñatibia and Aguiar, 2016), and mean aboveground net primary production is 56 g $m^{-2}$ $yr^{-1}$, half of which corresponds to grasses and half to shrubs (Jobbágy and Sala, 2000). The dominant grass species are *Pappostipa speciosa* Trin. et Rupr., *Pappostipa humilis* Cav., *Pappostipa major* Speg., *Poa ligularis* Nees ap. Steud, and *Bromus pictus* Hook. The dominant shrub species are *Mulinum spinosum* Cav. Pers, *Adesmia volckmannii* Philippi, and *Senecio filaginoides* De Candolle. Among grasses, *Poa ligularis* and *Bromus pictus* are the most preferred species for sheep. *Pappostipa speciosa* is a species of intermediate preference, and *Pappostipa humilis* and *Pappostipa major* are unpreferred species (Bonvissuto et al., 1983; Oñatibia and Aguiar, 2016).

### Data Collection

We selected three small paddocks (between 100 and 120 ha) and three large paddocks (between 1 000 and 1 200 ha) ($n = 3$), located in a 150 $km^2$ homogeneous plateau dominated by the same grass-shrub community (see Appendix A). All paddocks presented the same soil type and topographic position (Cipriotti and Aguiar, 2005; Golluscio et al., 2009; Oñatibia and Aguiar, 2016). Paddock fences were installed more than 3 decades ago. Thus, we assumed that the community has been receiving the footprint of domestic herbivores grazing inside them. All paddocks have been continuously (yr-round) grazed by sheep at the same moderate stocking rate (~0.2 sheep $ha^{-1}$ $yr^{-1}$) for several decades (Oñatibia and Aguiar, 2016). The shape of evaluated paddocks was similar to an aureus rectangle. In all cases, paddocks had a single watering point (see paddocks' shape and configuration in Appendix A). Inside each paddock, 50 m − long transects were outlined at 50, 100, 200, 500, and 1 000 m distance from the watering point in small paddocks and 50, 100, 200, 500, 1 000, and 2 000 m in large ones (Fig. 1). The different distances to watering points were selected to detect piosphere patterns (Andrew, 1988).

Along each transect, we estimated total perennial plant cover (foliar), size and number of vegetation patches, interpatch distance, and specific cover of dominant species. These variables reflect medium- and long-term use heterogeneity impacts, and they are useful to study desertification processes in arid and semiarid ecosystems (Rietkerk et al., 2004; Kéfi et al., 2007; Maestre and Escudero, 2009; Oñatibia et al., 2018). We recorded perennial plant cover (the identity of the species or litter) or bare soil every 0.1 m, in 500 consecutive segments. A vegetation patch was defined as every discrete section of at least 0.1 m along each transect covered with perennial vegetation and/or standing dead biomass, separated by at least 0.1 m of bare soil. Along each transect, we also located a plot of 6 $m^2$ (30 × 0.2 m), where individual plant morphology and the population size distribution of dominant grass species were estimated. We measured specific density, the height of the top green leaves, and the basal diameter (average between the longest and its perpendicular) of each individual, while we visually estimated the standing dead biomass proportion (with an interval scale of 5%). Population size distribution of each species was characterized by

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