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Research article

Effectiveness of fencing and hunting to control *Lama guanicoe* browsing damage: Implications for *Nothofagus pumilio* regeneration in harvested forests

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ABSTRACT

Browsing damage by native ungulates is often to be considered one of the reasons of regeneration failure in *Nothofagus pumilio* silvicultural systems. Fencing and hunting in forests at regeneration phase have been proposed to mitigate browsing effects. This study aims to determine effectiveness of these control methods in harvested forests, evaluating browsing damage over regeneration, as well as climate-related constraints (freezing or desiccation). Forest structure and regeneration plots were established in two exclosures against native ungulates (*Lama guanicoe*) by wire fences in the Chilean portion of Tierra del Fuego island, where tree regeneration density, growth, abiotic damage and quality (multi-stems and base/stem deformation) were assessed. Exclosures did not influence regeneration density (at the initial stage with < 1.3 m high, and at the advanced stage with >1.3 m high). However, sapling height at 10-years old was significantly lower outside (40–50 cm high) than inside exclosures (80–100 cm), and also increased their annual height growth, probably as a hunting effect. Likewise, quality was better inside exclosures. Alongside browsing, abiotic conditions negatively influenced sapling quality in the regeneration phase (20%–28% of all seedlings), but greatly to taller plants (as those from inside exclosure). This highlights the importance of considering climatic factors when analysing browsing effects. For best results, control of guanaco in recently harvested areas by fencing should be applied in combination with a reduction of guanaco density through continuous hunting. The benefits of mitigation actions (fencing and hunting) on regeneration growth may shorten the regeneration phase period in shelterwood cutting forests (30–50% less time), but incremental costs must be analysed in the framework of management planning by means of long-term studies.

1. Introduction

Guanacos (*Lama guanicoe*) are the only large native herbivores on Tierra del Fuego island (Bonino and Fernández, 1994; Cavieres and Fajardo, 2005; Baldi et al., 2010). They are generalist species, which inhabits a large variety of environments, from arid steppe to subalpine grasslands, deciduous and evergreen forests (Bahamonde et al., 1986; Puig et al., 1997; Rebertus et al., 1997; Baldi et al., 2010), and they includes many plants in its diet, from young trees to epiphytes (Soler Esteban et al., 2012, 2013; Muñoz and Simonetti, 2013). Guanacos were an essential subsistence resource for hunter-gatherer societies from the earliest occupations around 10,000 years ago (Borrero, 1999), and abundant archaeological information indicates that they used *Nothofagus* forests during the last 6400 years until arrival of European people (Gusinde, 1931; Orquera and Piana, 1999; Tivoli and Zangrando, 2011). These facts show that guanacos and *Nothofagus* forests have coexisted and co-evolved for thousands of years. Some authors suggest that high stocking rates of sheep (*Ovis aries*)

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introduced by Europeans in Tierra del Fuego reduce forage availability to guanacos, promoting over-use of forests (Raedake, 1982; Muñoz and Simonetti, 2013; Moraga et al., 2015) and therefore affecting natural regeneration dynamics of the latter (Pulido et al., 2000; Cavieres and Fajardo, 2005). However, some authors affirm that sheep did not displace guanacos, and both can coexist in the same area (Iranzo et al., 2013).

Current silvicultural prescriptions for commercial harvesting of lenga (*Nothofagus pumilio*) forests are mainly based on canopy openings that stimulates natural regeneration by modifying soil moisture and light availability at ground level (Martínez Pastur et al., 2014). The most widespread silvicultural method applied to lenga in Southern Chile is shelterwood cutting (Rosenfeld et al., 2006). Abundant establishment and fast growth of seedling occur after cuts (Martínez Pastur et al., 2011a), but tree regeneration during the regeneration phase is highly vulnerable to climate-related damage (freezing or desiccation) (Martínez Pastur et al., 2011b), competition with understory plants (Martínez Pastur et al., 2014; Henn et al., 2014) and browsing by guanacos and domestic herbivores (Soler Esteban et al., 2012; 2013). Synergistic effects among these risk factors may occur, with the added problem of tree blown down by severe wind storms (Rebertus et al., 1997).

Browsing by guanaco is identified as one potential cause for silviculture failure at large scale (Pulido et al., 2000). To counteract this, different initiatives have been proposed and implemented to control them. In Chilean forests of Tierra del Fuego, two strategies are used, as in other temperate forests (e.g. Beguin et al., 2009): (i) exclosures by wire fencing of forests at the regeneration phase, and (ii) hunting to reduce guanaco population. However, there are not quantitative results to demonstrate the effectiveness of these control strategies to diminish the guanaco's browsing impact on lenga forests. Therefore, the aim of this work was to determine the effects of fencing and hunting over natural regeneration of harvested lenga forests. The following questions were addressed: (i) do exclosures influence density, quality and growth of seedlings in the initial stage of regeneration in harvested forests (<1.3 m height)?; (ii) do exclosures influence density and quality of saplings in the advanced stage of regeneration in harvested forests (>1.3 m height)?; (iii) does hunting reduce browsing damage and improve regeneration growth?; and (iv) what is the magnitude of climate-related injuries (freezing or desiccation) compared to browsing damage?

2. Materials and methods

2.1. Study site

Lenga forests naturally regenerate by wind-dispersed seeds. Seedlings are mid shade-tolerant. They can survive under closed canopy in the understory strata for long periods of time (up to 10 years). However, the seedlings greatly increase height growth under open canopies (Martínez Pastur et al., 2007), as those environmental conditions generated by harvesting. Silvicultural methods for these forests in southern Patagonia include long regeneration periods (15–20 years), which are followed by several thinning interventions before the end of the forest management cycle (70–100 years) (Rosenfeld et al., 2006; Martínez Pastur et al., 2009).

The study area (aprox. 1000 ha) was located in a pure lenga forest on Tierra del Fuego Island (Chile) (53°40′ to 53°45′ S, 69°08′ to 69°10′ W), where a private company harvested primary forests through shelterwood cuttings (Martínez Pastur et al., 2009). Shelterwood cuttings are usually carried out in two stages: (i) a first cut, which leaves dominant trees (30–40 m^2 ha^{-1} basal area) evenly distributed in the harvested area to stimulate the natural regeneration establishment and growth under an open canopy, and (ii) a final cut, which removes all remnant trees after regeneration reaches 1.3 m height and successfully covers most of the harvested area. The climate is characterized by short, cool summers and long, snowy winters with frequent occurrence of frosts. Only three months per year have daily temperatures above 0 °C, and the growing season extends approximately five months (November to March). Rainfall, including snowfall, reaches up to 600 mm yr^{-1}. Annual wind speed outside forests is 8 km h^{-1} in average, reaching up to 100 km h^{-1} during storms (Martínez Pastur et al., 2009).

2.2. Guanaco natural population and hunting

On Chilean Tierra del Fuego, the guanaco population collapsed by mid-1970s as a result of hunting, competition with sheep and habitat degradation, declining to 7000 individuals (Moraga et al., 2015). However, in the following years, guanaco population greatly increased (× 8), reaching approximately 57,000 individuals in 2011 (Skewes Ramm and Aravena Bustos, 2011). For this reason the Chilean government authorized some companies to hunt guanacos, to reduce browsing and damage on harvested forests and to sell their meat (Moraga et al., 2015). During 2010–2011, 4500 adult individuals were hunted in the steppe-forest ecotone (Skewes Ramm and Aravena Bustos, 2011), in which the study area is included, where density was estimated in 2.1 ind km^{-2} (Montes et al., 2000). It must be considered that Tierra del Fuego is shared between Chile and Argentina, and guanaco range freely all over the island.

2.3. Fencing treatments

Two guanaco exclosures (AREA 1 and AREA 2) delimited by wire fences of 2.25 m high were analysed in this study (Annex 1A). Fences were constructed by 14 horizontal wires with a barbed wire in the top, and wooden poles every 1 m. Exclosures were established in two sites harvested by the first cut of a shelterwood cutting but with a different later history. AREA 1 was harvested in 1994; however remnant structure was affected by a wind storm in 1998 that blown down almost all trees in the area, so the forest operator also extracted the timber logs of the fallen trees. AREA 2 was initially harvested in 1990, and final cut was applied in 2004. Both sites were considered especially sensitive and threatened by guanaco browsing by the forest operator, therefore fences were established in 2002 in AREA 1 (260 ha), and in 2006 in AREA 2 (9 ha). At the time of this study (December 2011), regeneration was at the initial stage (< 1.3 m high) in AREA 1, and at the advanced stage (> 1.3 m high) in AREA 2. In both sites, outside exclosure situations were analyzed near fenced areas, which had identical history and similar climate conditions to inside exclosure situations.

2.4. Forest structure and regeneration measurements

Sampling was conducted at the beginning of the growing season. Plot layout was organized in sections along fences (Annex 1B), with a paired sampling design inside and outside exclosures. In AREA 1, four sections were surveyed, with 20 plots each (10 inside and 10 outside exclosure), totalizing 80 plots (4 × 10 × 2). In AREA 2, six sections were surveyed, with 6–8 plots each (3–4 inside and 3–4 outside exclosure), totalizing 40 plots (6 × 3–4 × 2). Length and width of each plot were variable in size, to include enough area until compulsory count 20 seedlings or saplings (> 3 years old).