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Research paper

Facilitation among plants: A strategy for the ecological restoration of the high-andean forest (Bogotá, D.C.—Colombia)

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ABSTRACT

Ecosystem invasion by the exotic legume *Ulex europaeus* (common gorse) impede the establishment of native vegetation by creating a closed canopy and its high resprouting capacity following a disturbance. Over a nine month period, plant–plant interactions between the native legumes, *Lupinus bogotensis* (shrub) and *Vicia benghalensis* (herb), and the native tree species *Solanum oblongifolium* and *Viburnum tinoides*, were evaluated in a zone close to the Chisacá reservoir in Bogotá, Colombia; that had previously been invaded by *U. europaeus* for at least 60 years. Experimental treatments corresponded to the identity of the native legume species and their sowing densities (high, medium and low), based on distance between individuals: 30, 60 and 90 cm respectively. The native tree species were sown at the same density in all plots (25 individuals, 50 cm between each other). Variables measured in all planted native tree species were: total height, basal diameter and number of leaves or branches. Both native tree species performed best with *L. bogotensis* at low and medium sowing densities, where the greater establishment of native species indicated a net positive interaction. Growth and survival were higher in all cases when compared with the control plots. There was evidence of facilitation by the native leguminous plants in all the treatments (index of interaction > 0), with the exception of *V. benghalensis* at high sowing density with *S. oblongifolium*. We conclude that facilitation between plants can be employed as an effective strategy for the reestablishment of native vegetation and could thereby initiate recuperation of the high-andean forest by reactivating the process of dynamic succession.

1. Introduction

Plant–plant interaction directly influences ecosystem structure and dynamics, and is responsible for the presence or absence of certain species (Padilla and Pugnaire, 2006). In recent decades, the determinant role of facilitation has been recognized as a positive interaction that directly affects the performance, distribution and metabolism of the species involved (Brooker et al., 2008; Bruno et al., 2003). Negative interactions, in particular competition, have been a central theme in the study of ecology, but it is clear that organisms can also improve the performance of their neighbors by modifying the environment in a manner that provides benefits for other species (Bertness and Callaway, 1994; Callaway, 2007; Hunter and Aarssen, 1988). For this reason, it is important to expand the study of interaction beyond that of mere competition, and consider also the effects of facilitation for a better understanding of ecosystem and ecological restoration processes.

An example of facilitation between plants is the nurse plant effect, which refers to the positive influence of adult plants on the germination and establishment of seedlings or young individuals under their canopy, effect that occurs because of the amelioration of extreme environmental conditions (Gómez-Aparicio et al., 2004; Holmgren et al., 1997; Padilla and Pugnaire, 2006). The use of certain species as nurse plants with the capacity to modify and improve the environment, within a restoration process in very degraded areas or those of extreme environmental characteristics, increases the probability of achieving rehabilitation and restoration goals (Castro et al., 2002; Padilla and Pugnaire, 2006). For example, this strategy has been used in temperate forests

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(Blanco-García et al., 2011; Dulohery et al., 2000; Yoshihara et al., 2010).

In the study area, the ecosystem of reference is the high-andean forest (located between 2700 and 3300 m asl). This region has had a 150 years old history of intensive use, related mostly with potato cultivation and cattle raising. Also there are forestry plantations of exotic species (*Pinus patula* and *Cupressus lusitanica*) and the presence of the common gorse (*Ulex europaeus*) that was introduced in the 1950s to act as live fencing to protect the area surrounding the reservoir. The gorse is currently one of the main environmental problems in the ecosystem, due to its invasive nature that has lead to the elimination of native plant communities, the local extinction of many species, and the difficulties associated with its control and eradication (León and Vargas-Ríos, 2011). Activities for restoration are therefore urgently required to ameliorate and recover the ecosystems services that native vegetation provides. The study area is part of the rural zone of Bogotá, the capital city of Colombia.

The objective of the present study was to evaluate the effect of two native leguminous species of different habits, a shrub *Lupinus bogotensis* and the herb *Vicia benghalensis*, planted at three densities (9, 16 and 81 individuals per plot), on the development of the two native tree species *Solanum oblongifolium* (Solanaceae) and *Viburnum tinoides* (Adoxaceae) based on the observed interaction between pairs of species (each legume with each native species). From this, we expected to find evidence of facilitation by the leguminous, mainly by the shrub, at the medium density. In the higher density was more likely to detect competition for the limited space shared by the species, while in the lower density could be no direct or evident effect. In low densities, plants will not fully occupy the growing space available and in high densities may result in intense competition that inhibits the growth and yield of individual plants (Burton et al., 2006; Harper, 1977). A plant with fewer, smaller, or more distant neighbors will have a greater relative growth rate than a similar plant with larger, closer, or more numerous neighbors, and size differences will be enhanced over time (Bonan, 1988). Interaction between the leguminous and native species was evaluated by measuring growth parameters. Based on this approach, the following hypotheses were proposed: (i) *L. bogotensis* and *V. benghalensis* will act as nurse plants of the two native species, (ii) young individuals of *S. oblongifolium* and *V. tinoides* will present greater growth in plots of medium density of leguminous, and (iii) the different growth patterns of the leguminous will produce a differential effect on the development of *S. oblongifolium* and *V. tinoides*.

2. Materials and methods

2.1. Site and species of study

Experimental plots were established in an area of 1.23 ha in the proximity of the Chisacá reservoir at El Hato, Usme, Bogotá (3120 m asl, 4°23′02.8″ N; 74°09′58.7″ W) (Fig. 1, also map in Google Earth on KML). The area was cleared entirely from the invasion of *Ulex* with manual and mechanical removal (rake and plowing with tractor) and controlled burns to prevent its rapid recolonization. The zone has a bimodal pattern of precipitation, with the wettest period between April and July and another peak of high precipitation between October and November. Average precipitation was 707.5 mm in 2009 and 1153.7 mm in 2010 (El Hato weather station). The multiannual average temperature is 10.7 °C (La Regadera weather station, between 2002 and 2004), with highest temperatures occurring between October and May and lowest between June and September. As a result of these patterns, the greatest hydrological deficit is seen in the period December to March, when frosts can occur, severely affecting many of the native species of the region as well as crops. The driest months recorded during this study were December 2010 and January–February 2011.

The reference ecosystem is high-andean forest, with an annual average precipitation of between 900 and 1500 mm and an average annual temperature of between 9 and 12 °C. Typical mature vegetation includes species such as *Weinmannia tomentosa*, *Hedyosmum bonplandianum*, *Myrsine dependens*, *Oreopanax bogotensis*, *Tibouchina grossa*, *Macleania rupestris* and *Drimys granadensis*, among others (Montenegro and Vargas-Ríos, 2008; Mora et al., 2007). Pioneer species that are ideal for initiating the restoration includes *Vallea stipularis*, *Weinmannia microphylla*, *Verbesina crassiramea*, *Viburnum triphyllum* and those considered in this study, *S. oblongifolium* and *V. tinoides* (Mora et al., 2007).

In this study, the facilitator species or nurse plants are: *L. bogotensis*, a leguminous and rapid-growing shrub species, with a short life cycle and tolerance to nutrient-poor environments; this species is a nitrogen fixer and forms seed banks in the soil (Ávila and Vargas-Ríos, 2009; Díaz-Espinosa and Vargas-Ríos, 2009). And *V. benghalensis*, an herbaceous species that features creeping growth and a short life cycle; this species is heliophilous and resistant to drought and frost (Díaz-Espinosa and Vargas-Ríos, 2009). The beneficiary species are: *S. oblongifolium*, a pioneer tree of andean distribution; this species is zoochorous, produces many seeds of high viability and rapid germination and can grow on the edges of roads and exotic plantations (Ávila and Vargas-Ríos, 2009), and *V. tinoides*, a late pioneer tree of andean distribution; this species can grow up to eight meters in height, is perennial, heliophilous and ornithochorous (Barrera-Cataño et al., 2010). All species were propagated in a nursery using seeds taken from local plants, and later transplanted in the plots. Species and study site in different times of the research are shown in Fig. 2.

2.2. Experimental design and data analysis

Fifty-two 3.5 m × 3.5 m plots were established throughout the zone, providing a total experimental area of 637 m^2. In each plot a combination of each leguminous species (*L. bogotensis*–*V. benghalensis*) with each native species (*S. oblongifolium*–*V. tinoides*) was sown, varying the sowing distance (and therefore the planting density) between leguminous individuals. The two native species were sown at the same distance (50 cm) between individuals in all plots, giving a density of 25 individuals in each case, with two control plots per species. The treatments correspond to each leguminous species and its density in relation to the sowing distance between individuals (Table 1), distribution of treatments in plots was aleatory. In control plots only the native species were sown at the density mentioned above. In the whole experiment 650 individuals of each native species were sown, along with 848 individuals of each leguminous species, making a total of 1300 native and 1696 leguminous individuals.

Over a nine month period (October 2010–June 2011), the following variables were recorded from each individual of *S. oblongifolium* and *V. tinoides*: height (cm), measured from the base of the stem to the tip of the longest leaf; diameter (mm), taken at the base using a caliper; and number of leaves in *Solanum* and branches in *Viburnum*. Analysis of the data for each of the variables was performed with time series analysis in a mixed effects model. All analysis was conducted using the statistical package R 2.14 (R Development Core Team, 2011).

The interaction between two plants, either conspecific or not, is typically derived from differences between individuals growing alone vs. growing with other plants (Armas et al., 2004). The magnitude of this interaction can be estimated by the index of magnitude of interaction RII = (Bw − Bo)/(Bw + Bo). It represents the ratio of the