A TROPICAL FOREST AT THE COASTAL LOMAS OF PERU: WHICH SHOULD BE RESTORED A FOG OASIS OR THE LOST GARDEN OF THE INCAS?

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Abstract: The Atiquipa fog oasis is the largest and best preserved fragment of Lomas formation, a unique and highly endangered hot-spot of biodiversity surrounded by the Peruvian coastal desert. The aim of the present research is to support current efforts intended to restore the forest of the dominant tree species *Caesalpinia spinosa*. As a result, chloroplast microsatellite diversity in nine populations across Peru suggests a lack of genetic differentiation. Seedlings recruitment within the best preserved patches of forest was a rare event, and planted and irrigated individuals exhibited differentially higher growth rates. The historical survey confirms the existence of this forest by the end of the sixteenth century but also proves that Atiquipa was a major settlement on the Inca trail. Preliminary results are coherent with the view of this extraordinary forest as a manufactured landscape, which supports, to date, the initial reforestation project for conservation and sustainable use.

Keywords: semi-natural forests, cultural systems

Introduction

Humans, while pervasive and destructive, can produce and help to maintain diverse ecosystems (Egan and Howell 2001). In Europe, semi-natural and cultural-natural systems are understood as conservation and restoration targets. In Central and South America, scientific interpretation of tropical forests, however, has swung from pristine wilderness to cultural parkland. This fundamental perspective change does not compromise the relevance of restoration efforts aimed at preserving biodiversity and re-establishing the supply of environmental goods and services, but it drastically alters diagnosis of the key limiting processes. In 2002, a UNDP/GEF project supported reforestation of the Atiquipa Lomas, the largest and most diverse remnant of the Lomas formation, a globally unique fog-dependent ecosystem located along the Atacama and Peruvian Coastal Desert. In 2006, an FBBVA project supported reappraisal of the knowledge of the dominant tree species, *Caesalpinia spinosa* (Mol.) Kuntze, to implement an effective adaptive management of these restoration efforts. We reasoned that if this forest were an untouched fragment of Lomas formation (non-influenced by human activities) then the fog oasis of the Atiquipa Lomas would have acted as refugia favouring population genetic divergence, and plant recruitment and performance would have exhibited patterns of specialization to the fog regime of this particular ecosystem (see Dillon et al. 2003). If these hypotheses were rejected, our conservation and restoration approaches should shift toward an active role of humans in shaping this ecosystem.

Figure 1. Fog oasis at the costal Lomas of Atiquipa (Peru).

Materials and methods

Leaf samples were obtained from 10 to 31 individuals in 9 populations of *Caesalpinia spinosa* representing the main regions comprising the range of this species. Plant material was stored in silica gel until DNA extraction. DNA was extracted by using the Kit DNAeasy (Quiagen). In order to identify polymorphic chloroplast microsatellite loci, we tested ten consensus primer pairs developed for grapevine and *Caesalpinia echinata*. Microsatellite polymorphisms were detected following the procedure described by Arroyo-García et al. (2002). Every sample was analysed at least twice to ensure genotype reproducibility. Genetic differentiation between populations and within was calculated within the analysis of molecular variance (AMOVA)

In the Atiquipa Lomas, we studied a remnant stand of the fog oasis (preserved area) and an area that was reforested in 2003 with seedlings raised from local seeds (reforested area). These seedlings were watered weekly for two years. In November 2007, at the transition from the wet to dry season, structural photoprotection was assessed by measuring leaflet angle and recording simultaneously incident PAR intensity, air temperature, relative humidity, and soil water content.

We also compared the photosynthetic pigment contents (chlorophylls a, b, and VAZ) and morphometric traits (SLA, total number of leaves) of fully-expanded leaves of 5-

year-old seedlings recruited in the preserved area, in the reforested area, and planted in this latter area. In these plants we analysed growth and internode allometry, an its relationship to the distance from the nearest adult tree.
In 2008, demographic population structure was assessed in 3 50x50 m plots replicated in each area.
Fifteen historical documents were reviewed to identify records of pre-Columbian activity at the Atiquipa Lomas.

Results and discussion

Genetic variability was extremely low, despite the wider range of primers used in comparison to previous studies on *Caesalpinia echinata* (Lira et al. 2003). Two alleles were found at each of the polymorphic chloroplast microsatellite loci which were combined to give a total of four haplotypes. The haplotypes found in Atiquipa (2 out of 4) were shared at least with other 6 populations which is in consonance with the fact that within-population variance accounted for most of the total variance (over 90%) and with the lack of any link between the occurrence of these haplotypes and the Lomas habitat. These results discard the hypothesis of population divergence associated with the ecological isolation expected in a fog oasis surrounded by the Peruvian coastal desert. Our findings suggest that the study populations are either the result of a selection process (e.g. as a cultivated plant) or of vegetative propagation through ramets. Both possibilities are likely. First, cultivar selection in *C. spinosa* is critical for optimizing harvest timing, efficiency and quality (Villanueva 2007), and second, the study species is spread not only by seeds but also by underground sprouting of roots (field observation).
Leaflet angle was extremely responsive to air relative humidity ($R^2 = 0,57$, $P < 0,001$). Leaflets were completely closed below 30% RH. Physiological photoprotection, in terms of VAZ on chlorophyll basis, was in the range of previous values reported for tropical tree seedlings. Seedlings recruited in the preserved and reforested area did not differ in functional traits or growth patterns, despite the latter are at longer distances from adult trees and likely experience a drier environment. Planted seedlings were, however, taller with larger stem diameters at the base, and longer and thicker internodes. These results suggest that *C. spinosa* behaves as a drought stress avoider with an opportunistic use of water. Thus, watering during the dry season improves growth performance but this tree species does not respond to differences above a water availability threshold. These results are congruent with the broad ecological amplitude of *C. spinosa* as a crop, and do not evidence symptoms of specialization to the particular fog regime of the Lomas ecosystem.
Demographic structure, both in the preserved and reforested areas, was characterized by a conspicuous gap between adult trees (over 4 m height) and the rest of the individuals whose 90^{th} percentile was 0.58 and 1.17 m, respectively. The greater height of juvenile plants at the reforested area is possibly associated with a greater frequency of underground sprouting after physical damaged. Density of juvenile plants was 28 plants ha^{-1}, both in the preserved and the reforested areas, although adult tree density was three times higher in the former. These results suggest that seedling encroachment is a rare and recent event (over 80% of the seedlings in the preserved area seems to be less than

6-year-old). Therefore, recruitment seems to be limited by seed supply as a consequence of pod harvest, by past herbivore pressure, or more likely, by the loss of the seed dispersers that would have facilitated germination. It is known that the seeds of *C. spinosa* require prolonged water immersion, sandpapering or even immersion in sulphuric acid (de la Cruz 2004), and that in Inca times, domestic camelids were abundant in this region.

Although many travellers have described the Lomas ecosystem, very few visited the Atiquipa Lomas. Likely, the first description of the *C. spinosa* (Yara) forest in this location was by the Jesuit Bernabé Cobo in 1.620, about 90 years after the Spaniards arrived in Peru. The wealth of archaeological evidences testify that there was a major settlement in the Atiquipa Lomas that was on the Inca trail from Cusco to the Pacific coast (Linares 1990).

Conclusions

Our findings suggest a link between pre-Hispanic civilizations and the existence of the *C. spinosa* forest in the fog oasis at the Atiquipa Lomas. This species may have been introduced by humans and its regeneration favoured by domestic cattle. Hundreds (perhaps thousands) of years later, the *C. spinosa* forest, as an efficient fog catcher, is crucial for the functioning of the best preserved fragment of the Lomas ecosystem. Its conservation and restoration seems to require the implementation of sustainable practices that emulate the outcomes of the ancient use.

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