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Active versus passive restoration: Recovery of cloud forest structure, diversity and soil condition in abandoned pastures

Alma L. Trujillo-Miranda[a], Tarin Toledo-Aceves[a,*], Fabiola López-Barrera[a], Patricia Gerez-Fernández[b]

[a] Instituto de Ecología A. C. Carretera antigua a Coatepec 351, El Haya, Xalapa 91070, Veracruz, Mexico
[b] Instituto de Biotecnología y Ecología Aplicada, Universidad Veracruzana, Veracruz, Mexico

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A B S T R A C T

Tropical montane cloud forest is a priority ecosystem for restoration due to the diversity and ecosystem services it provides and because it is under severe threat. Forest restoration can be achieved by active interventions and/or natural regeneration (passive restoration). However, there has been little comparison of the effectiveness of active versus passive restoration strategies and even fewer studies have monitored the long-term success of forest restoration practices. We assessed the effectiveness of active (mixed plantation with native species) and passive (areas adjacent and non-adjacent to mature cloud forest) restoration strategies implemented in pastures with 21 years of exclosure, and compared these to a mature cloud forest (reference system), in eastern Mexico. In the mature forest and in the areas represented by each restoration strategy, ~15 plots (200 m^2) were established in order to assess forest structure, tree diversity and soil properties as indicators of restoration success. Active restoration proved more effective than passive restoration at recovering forest structure (e.g. higher basal area, tree density and height). Adult tree diversity was similar across all restoration sites and the mature forest, while composition differed greatly between the mature forest and each of the restoration sites, from which the characteristic mature cloud forest tree species were mostly absent. The restoration sites presented very low tree seedling density (0.39 individuals/m^2) relative to the mature forest (1.68 seedlings/m^2), probably due to the higher cover of climbers, ferns, grasses and shrubs found in the understory of the restoration sites (~78%), compared to that of the mature forest (8%). In all of the restoration sites, soil pH was higher, and carbon content in both the soil and litter was lower, than in the mature forest. This denotes a slow recovery of soil properties after use of the land as cattle pasture. In general, the passive restoration site non-adjacent to the forest presented the lowest recovery (lower canopy cover, composition similarity and seedling density), indicating the importance of proximity to seed sources. Our results highlight the need, in both actively and passively restored areas, for management practices such as enrichment planting, in order to assist tree seedling recruitment of key species and recovery of forest attributes. Active and passive restoration strategies could be implemented as complementary strategies for the restoration of cloud forest landscapes.

1. Introduction

Restoration has become a necessary response to the extensive loss and degradation of tropical forests (Lamb et al., 2005; Meli et al., 2017). One ecosystem of global priority is Tropical Montane Cloud Forest (TMCF), which provides important ecosystem services but is severely threatened by deforestation and degradation (Scatena et al., 2010). Every year ~1.1% of the global TMCF coverage is lost (Scatena et al., 2010), mainly through land use change for livestock production and agriculture (Aide et al., 2010). As a consequence, it was calculated that only 28% of the original coverage of TMCF in Mexico remained in 2002 (Challenger and Dirzo, 2009). Faced with this scenario, the design of appropriate strategies for TMCF restoration is of vital importance.

In order to recover the structure and functionality of degraded, damaged or destroyed ecosystems, two general strategies of ecological restoration are recognized: (1) passive restoration, which eliminates the factors of disturbance and permits natural regeneration, and (2) active restoration, which eliminates the source of disturbance and implements strategies to accelerate recovery and to overcome obstacles to that recovery (Holl and Aide, 2011). Rates of natural regeneration through

* Corresponding author.
E-mail addresses: almalucrecia90@gmail.com (A.L. Trujillo-Miranda), tarin.toledo@inecol.mx (T. Toledo-Aceves), fabiola.lopez@inecol.mx (F. López-Barrera), pgerez@uv.mx (P. Gerez-Fernández).

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passive restoration are highly variable and the process can be unsuccessful (Aide et al., 2010) since it depends on multiple factors, including the intensity and type of the previous land management, type of surrounding landscape and resilience of the ecosystem (Guariguata and Ostertag, 2001; Montagnini, 2008; Aide et al., 2010; Norden et al., 2015). In particular, the factors reported as limiting natural regeneration of tropical montane forests following conversion to grazing pastures are: fire (Grau et al., 2010), competition with pioneer species (e.g. grasses and ferns; Ortega-Pieck et al., 2011), decoupling of interactions (e.g. high levels of herbivory and lack of mycorrhizae; Aide et al., 2010), unfavorable microhabitat (e.g. high solar radiation, low fertility, compaction and erosion of the soil; Holl, 1999) and absence of seed dispersers and low propagule arrival rates (Aide and Cavelier, 1994). Lower vegetation recovery has been reported with increased distance to mature forests (Holl, 1999; Muñiz-Castro et al., 2006).

One alternative for accelerating regeneration and overcoming the obstacles described above is active restoration through mixed plantations (Holl et al., 2000). Plantations help to more rapidly develop a canopy, which can inhibit the herbaceous plant stratum and improve microhabitat conditions for establishment of a greater diversity of woody plants, including species of more advanced successional stages (Butler et al., 2008; Zahawi et al., 2013). The trees established in these plantations can also catalyze recovery by attracting disperser fauna, functioning as perches and providing food and refuge (Orozco-Zamora and Montagnini, 2007). Moreover, plantations act to improve the soil conditions below, conferring higher nutrient and organic material contents and protection from erosion (Ruiz-Jaén and Aide, 2005a; Montagnini, 2008).

The active restoration strategy requires much higher investment in terms of cost and time compared to natural regeneration or passive restoration (Holl and Aide, 2011; Chazdon et al., 2017). In some cases, depending on the plantation characteristics (e.g. the identity and number of species planted and the plantation management adopted; Thijs et al., 2014), the successional trajectory of the restored forest can be altered, thus modifying the composition (Holl and Aide, 2011). In contrast, passive restoration can achieve recovery of the functions and composition of the community through the seed bank and seed rain (Guariguata and Ostertag, 2001). However, wide variation exists in the recovery rates of secondary tropical forest, which is attributed to multiple local and landscape factors that generate alternative scenarios and trajectories (Norden et al., 2015). In a recent metanalysis for tropical forests, Crouzeilles et al. (2017) report that natural regeneration is more successful than active restoration in terms of biodiversity and vegetation structure recovery, when four important factors are controlled: forest cover, the time elapsed since restoration started, past disturbance type and annual precipitation. According to the global review of Meli et al. (2017), only 11 studies (7%) of restoration success in both tropical and temperate forests report data pertaining to active and passive restoration strategies evaluated at the same site, thus sharing environmental and management conditions. Moreover, there are few studies that evaluate the success of these strategies in relation to a reference ecosystem (Ruiz-Jaén and Aide, 2005a; Wortley et al., 2013). Such comparison would allow determination of whether the areas under restoration are within the trajectory of recovery of the ecosystem.

Opportunities to evaluate active and passive restoration in the same system can arise through restoration initiatives carried out by landowners, which have been little documented (Holl et al., 2003). Such initiatives have disadvantages, such as the lack of initial characterization of the system, absence of detailed information regarding the practice of active restoration and lack of balanced experimental design. Nevertheless, they are strategies implemented at large scale and provide a valuable opportunity to evaluate the long-term efficiency of applied restoration practices (Holl et al., 2003).

Indicators of the vegetation structure, diversity and ecological processes are used to evaluate the success of forest restoration, since these characteristics reflect the capacity of the restored ecosystems for regeneration and self-maintenance (Ruiz-Jaén and Aide, 2005b). Structural variables, including canopy cover, basal area, height and density of trees, are positively related to the recovery of ecosystem services such as carbon capture, erosion control and provision of habitat for the fauna (Ruiz-Jaén and Aide, 2005b; Suganuma and Durigan, 2015). Species diversity and composition are indicators of successional stage, dispersion mechanisms and ecosystem resilience (Wortley et al., 2013). Furthermore, the density of seedlings and juveniles can indirectly reflect ecological processes such as seed production, dispersion and propagule germination and establishment. Measurements of soil conditions can provide information about the nutrient cycling processes that underpin ecosystem productivity and stability (Herrick, 2000). There is increasing recognition of the linkage between above and belowground ecosystem components and the importance of their integration for restoration ecology (Kardol and Wardle, 2010; Roa-Fuentes et al., 2013).

In this study, we evaluate recovery in an area in which a mixed plantation with native species (active restoration) was established 21 years ago, and areas from which livestock was excluded only (passive restoration adjacent and non-adjacent to a mature forest), comparing these to a mature TMCF as a reference system. We address the following specific question: has active restoration been more effective than passive restoration in terms of recovery of tree structure, diversity and composition and soil conditions? This study will provide a framework to incentivize practitioners to assess and report restoration outcomes and evaluate the ecological benefits and potential trade-offs of two different restoration approaches. Specifically, this study will contribute to the adoption of criteria for defining and assessing ecological success during the TMCF restoration process.

2. Methods

2.1. Study area

The study was conducted on the private ranch “Las Cañadas” (19°11′23″ N, 96°59′11″ W; 1300–1500 m. a.s.l.; Fig. 1), Veracruz, Mexico. Mean annual temperature is 19.1 °C and mean annual precipitation is 2100 mm. The original vegetation of the study zone is TMCF and the soil type is umbric andosol (Geissert and Ibáñez, 2008). Las Cañadas has a total area of 306.7 ha, of which 270.3 ha were deforested in 1950 for livestock production (0.66 head of cattle/ha), while conserving a fragment of the mature forest. The exotic grasses *Brachiaria* sp. and *Cynodon* sp. were introduced into the grazing pastures. After 45 years, the livestock was excluded from the grazing areas and different interventions were made in 1995 (Fig. 1). In this study, we evaluated the following conditions present in four distinct sites:

a) Reference forest (mature forest; MF): fragment of 30 ha of TMCF, maintained from before the year 1950, surrounded by secondary TMCF.
b) Active restoration (mixed plantation; MP): In 36.56 ha, 39,256 trees of native TMCF species were planted: *Fraxinus uhdei* (Oleaceae; 10,000 individuals), *Juglans pyriformis* (Juglandaceae; 5000 individuals), *Liquidambar styraciflua* (Hamamelidaceae; 3256 individuals), *Platanus mexicana* (Platanaceae; 1000 individuals), *Quercus sapotifolia* and *Quercus* spp. (Fagaceae; 20,000 individuals). All of these trees were acquired from nearby nurseries and were approximately 1 to 1.5 m in height on transplantation. Manual clearing was conducted prior to and two years after transplantation in order to reduce competition with grasses. No subsequent maintenance was carried out. All of the species were planted in combination and at a random frequency, apart from *Platanus mexicana*, which was planted at the edges of the river since it naturally forms part of the riparian vegetation (Benítez et al., 2004). This site was located at a distance of 735.4 ± 82.2 m (mean ± S.E.) from the MF.