Figure 2. Rustic filters in one of the axolotl refuges in Xochimilco. The rustic filters improve water quality and keep out non-native fish. Note the chinampa in production on the left. Photo by Homan González

The refuge program aims to conserve both this salamander and traditional agriculture. We are generating a market for farm products that will include the cost of saving local culture, Xochimilco, and axolotls. Restoration of the axolotl is a complex process that must be discussed among stakeholders (such as local government, fishermen, and tourists) in order to produce multiple actions and a monitoring program. Declining axolotl populations in the wild do not leave much time or room for mistakes. But a good restoration process will bring not only increased axolotl populations but also other benefits from a functioning wetland and better market opportunities for chinamperos.

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Tropical Dry Forest Landscape Restoration in Central Veracruz, Mexico

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Until recently, it was thought that native tropical dry forest (TDF) in central Veracruz was completely gone. Fortunately, recent research using Landsat images and ground-truth verification showed the presence of TDF remnants. There is still 7% of the original forest in the region, although one-third is secondary vegetation (F. López-Barrera, Instituto de Ecología A.C., pers. comm.).

Tropical dry forest landscape restoration has been carried out in only a few places. The most integral restoration experience started in Parque Nacional Santa Rosa, Costa Rica, which was expanded to become Area de Conservación Guanacaste, a region ten times larger (Janzen 2008). Other restoration efforts are being carried out on the Pacific coast of Panama (Griscom et al. 2009), Paraná River Valley in Central Brazil (Sampaio et al. 2007), Hojancha and Cañas in Costa Rica (Fonseca-González and Morera 2008), the Ayuquila River watershed in Jalisco (Ortiz-Arrona et al. 2004), and the Tembembe river in Morelos, Mexico (Bonfil et al. 2004). Most TDF restoration experiences indicate that besides establishing native species plantations, restorationists should rely on the resprouting ability of the trees characteristic of these forests (Griscom et al. 2009) and different management techniques to facilitate this natural regeneration capacity (Sampaio et al. 2007). We recognize that natural tree regeneration is not only the least expensive method possible; it is also a tool for designing restoration efforts (Janzen 2008, Viera and Scariot 2006).

This study is part of Project ReForLan, which focuses on the restoration of dryland forest landscapes for biodiversity conservation and rural development in Latin America (Newton 2008). Our goal was to test restoration techniques and identify the main constraints to forest restoration. The two objectives were to define a reference system through the determination of forest structure and tree species composition, and to define a set of tree species to be used in restoration efforts.

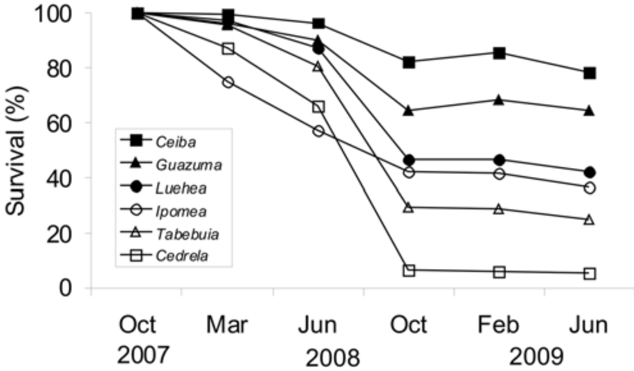

Figure 1. Survival percentages (October 2007–June 2009) for six tree species planted in restoration experiments in central Veracruz, Mexico. Survival of cedro (*Cedrela odorata*) was significantly lower than other species (one-way ANOVA, $F = 3.7$, df = 5,18, $p = 0.02$).

The study area is located in central Veracruz, Mexico (19°17'N, 96°26'W, 100–250 m asl). The climate is hot and dry. Mean minimum and maximum temperatures are 19.8°C and 30.7°C, respectively. Total annual precipitation is 966 mm (range: 502–1,466 mm). The dry season extends from October to May. Soils are mainly Cambisol and Vertisol. In this region, land is mainly used for cattle ranching, generally on a small scale by private landowners; but for common land tenants (ejidatarios), the main activity is growing corn and other crops, such as papaya, bean, green chili, watermelon, sugar cane, and mango. This area is rich in history related to pre-Hispanic settlements (600 to 1500 A.D.) and the Mexican Independence (19th century). In addition, the region includes an important observation point, the River of Raptors, for one of the largest annual migrations of raptors in the world.

The TDF reference system was determined through the selection of ten forest remnants and five early successional sites, 1 to 72 months after the last abandonment, with different land use histories (Williams-Linera and Lorea 2009, Williams-Linera et al. 2010). Vegetation structure was characterized in terms of density, basal area, and height for canopy trees (≥ 5 cm dbh) and understory woody plants (< 5 cm dbh). Mean density was 1,014 ± 104 and 2,532 ± 2,272 individuals/ha, with basal area 30.2 ± 2.11 m^2/ha and 1.96 ± 0.12 m^2/ha, for canopy and understory vegetation, respectively. The forest mean height was 10 m and reached a maximum of 15 m. The early successional sites had a basal area and density ranging from 0.40 to 3.88 m^2/ha and from 900 to 5,450 individuals/ha, respectively.

We recorded 122 woody plant species in the forest fragments (Williams-Linera and Lorea 2009). In the early successional sites, 45 woody species were recorded. Some species were represented only in forests or fallows, but 20 tree species were growing in both early secondary and mature forest sites (Williams-Linera et al. 2010), indicating that mature forest species were entering the successional process at very early stages.

Next, we assessed local knowledge and preferences through workshops, field visits, key informants, informal interviews, and specimen collection to determine tree species that were economically and ecologically valuable resources for restoration. This process identified 75 species as useful, rare, valuable, or important for wildlife (Suárez et al., forthcoming). Using the lists of tree species in forest or fallows as well as those often mentioned locally, we selected six native tree species for the restoration experiments. Two were timber species, one was used as forage, and the other three displayed potential to be used for such nontimber forest products as firewood, ornamentals, handcraft manufacture, and the growth of an edible mushroom that is very popular locally (Table 1).

We established four restoration trials to evaluate the establishment and growth of these six species in fallows with different degrees of disturbance. The early successional sites for the restoration experiments were fenced with barbed wire to exclude livestock. Seeds were collected in the study area and germinated in the local nursery where seedlings stayed four to six months prior to transplant. In September 2007, 960 seedlings were transplanted to four 12 × 20 m plots per site, with individuals 2 m apart. Plant survival and growth in basal diameter and height have been monitored every four months.

Seedling survival was statistically similar among species, except for cedro (*Cedrela odorata*) (Figure 1). After the first dry season, survival of all species was greater than 55%, a result similar to that of restoration studies in pastures in central Brazil, where survival was greater than 60% (Sampaio et al. 2007) or 35%–77% (Vieira et al. 2007). After the second-year dry season, survival was the lowest for cedro (5.1%) and the highest for pochote (*Ceiba aesculifolia*; 78.3%) and guácimo (*Guazuma ulmifolia*; 64.3%) (Figure 1).

The relative growth rate in height (RGR_h) was statistically similar among species, whereas in diameter (RGR_d) it was different among species (Table 1). Cedro had the highest RGR_d. Cedro, despite its excellent growth performance, appeared unable to adapt to drought conditions, as has been previously reported (Ortiz-Arrona et al. 2005). Guácimo maintained a high survival percentage because of its resprouting ability; with the rainy season, some apparently "dead" individuals resprouted, as has been reported in other forests (e.g., Viera and Scariot 2006, Griscom et al. 2009). Pochote grew slowly because its stem top frequently breaks during the dry season, recovering when it rains.

Each tree species may contribute something different to the restoration effort. Results of transplant experiment suggest that all selected species can be used for restoration; however, each species requires different site conditions for transplanting. Timber species (cedro and roble, *Tabebuia rosea*), which are the most important ones for local people, are severely drought intolerant. Therefore, they need to be planted near isolated trees that help to maintain humidity.

Table 1. Tree species used in restoration assays in the TDF of central Veracruz, Mexico, and their mean (± SE) relative growth rate in height (RGR_h), and diameter (RGR_d) during 19 months. The RGR_h was similar across species (one-way ANOVA, $F = 2.27$, df = 5,67, $p = 0.06$), and RGR_d was significantly different ($F = 6.47$, df = 5,67, $p < 0.0001$).

Use	Common name	Species	Family	Relative Growth Rate: Height (cm/cm/y)	Relative Growth Rate: Diameter (mm/mm/y)
Timber	Cedro	*Cedrela odorata*	Meliaceae	0.54 ± 0.21	0.66 ± 0.10
	Roble	*Tabebuia rosea*	Bignoniaceae	0.41 ± 0.07	0.41 ± 0.09
Forage	Guácimo	*Guazuma ulmifolia*	Sterculiaceae	0.29 ± 0.14	0.50 ± 0.06
Nontimber forest products	Pochote	*Ceiba aesculifolia*	Bombacaceae	0.09 ± 0.12	0.19 ± 0.05
	Patancán	*Ipomoea wolcottiana*	Convolvulaceae	0.35 ± 0.12	0.39 ± 0.07
	Algodoncillo	*Luehea candida*	Tiliaceae	–0.01 ± 0.14	0.28 ± 0.02

To avoid seedling mortality, sites with some tree or other canopy cover have been recommended because they offer a milder environment and moister soil than open sites (Viera and Scariot 2006). In contrast, pochote and guácimo are drought tolerant and may be used in disturbed areas with no woody vegetation; their resprouting ability allows establishment and survival in extremely dry conditions. Local people are not enthusiastic about nontimber species, but they are important for restoration by changing the microenvironment, providing suitable conditions for other species of economic importance to establish later.

The procedures used for TDF restoration must be adapted to this particular environment, instead of following techniques developed for temperate or moist forests (Viera and Scariot 2006). Seedling transplant represents one option; however, since primary species are present at early successional sites, it is worthwhile to consider the possibility of restoring TDF through passive restoration via natural colonization. Our next objective will be to determine whether secondary succession is efficient in the recovery of original vegetation. If not, we would enrich successional sites with nonresprouting species or some primary forest species that cannot be dispersed at early successional sites. Additionally, restoration should be implemented to strategically connect remnant forests, successional sites, and historical landmarks that may promote tourism and thus boost the local economy.

Acknowledgments

This research was funded by the European Community under INCO Project ReForLan (CT2006-032132).

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