Unexpected Outcomes and Adaptive Restoration in Michoacan, Mexico: A Cautionary Tale from Sites with Complex Disturbance Histories

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ABSTRACT

Near the Paricutín volcano in the state of Michoacán, México, agricultural lands were covered with volcanic ash when the volcano erupted multiple times between 1943 and 1952. These lands persist today as barren and mostly devoid of vegetation. Restoration of these lands is limited by high ground surface temperatures during the dry season (close to 70°C at noon) and other factors such as damage by herbivores and storm run-off. We used mulch to overcome the main barrier represented by the high ground surface temperatures, which allowed for the reintroduction of the dominant native pine species. When we did not mulch, and particularly during dry years, pine mortality was close to 100%. This led to the unanticipated consequence of a shrub, *hierba de golpe* (*Eupatorium glabratum*), establishing in the sites where the planted trees had died. The shrub, although native, precludes the establishment of other native plant species and creates conditions that are even more of a challenge to restoration. The most efficient measure for restoring sites invaded by hierba de golpe is the elimination of the shrubs and with them the layer of volcanic ash. This case study illustrates the importance of approaching restoration as an adaptive management practice because unexpected outcomes are unavoidable, particularly in sites with complex histories of disturbance.

Keywords: adaptive restoration, disturbance, *Eupatorium glabratum*, mulching, volcanic ash

Introduction and Study Site

Case studies of restoration efforts often focus on changes in one or more attributes targeted by a restorationist and report on how those attributes have improved in some way. Very few reports focus on limiting factors that prevent restoration from advancing its goals altogether, although considerable insight has come from cases where goals were at least partially met (NRC 1992). How to assess the outcome of a restoration is still in debate (Ruiz-Jaen and Aide 2005), and although the need for a definitive assessment of a restoration effort is understandable under certain circumstances (for example, when restoration is implemented by legal mandate), any such assessment will be challenged by the dynamic nature of ecosystems. Another option is to follow the change over time of several ecosystem attributes relevant to particular restoration goals (Callaway et al. 2001), and to reassess the course of action depending on the effectiveness of various restoration measures taken. Efforts can continue as planned or follow a new course to correct for any deviation from the desired path. This "adaptive restoration" approach allows for a more efficient use of resources and learning as the restoration proceeds (Zedler and Callaway 2003).

We began an adaptive restoration project five years ago with the Comunidad Indígena de Nuevo San Juan Parangaricutiro (CINSJP) in the Northeast region of the State of Michoacán, Mexico. Pine and oak-pine forests dominate the area. The dominant pine species are smooth-barked Mexican pine (*Pinus pseudostrobus*), Montezuma pine (*P. montezumae*) and, to a lesser extent, *P. teocote.* The dominant oak species are netleaf oak (*Quercus rugosa*), *Q. crassifolia* and *piptza* (*Q. crassipes*). Areas over 2,800 meters above sea level are dominated by sacred fir or *oyamel (Abies religiosa*). The CINSJP practices sustainable forestry on most of the 11,694 hectares of communal lands, and several products are obtained from the forest, including timber and pine sap (Velázquez et al. 2003). Some areas are reserved for ecotourism and biodiversity conservation. Research has played an important role in the development of the community's management practices (Velázquez et al. 2001). Native pine planting for sustainable forestry and later for biodiversity conservation started almost 20 years ago (Jaffee 1997). The current sustainable forestry program is the result of a research effort aimed at characterizing the forested lands of the community. Adaptive restoration

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has been a key part of the research program, supporting the development of plant survival techniques and restoration site selection criteria. Restoration research began as a collaborative effort between the researchers and the community in 2001, funded by a gift from Ed Weigner through the Institute for Environmental Studies of the University of Wisconsin–Madison. The community provided pine plants and labor. The research grant provided monitoring equipment and other materials. Subsequently, the costs related to ongoing research have been covered by the Mexican Science Council (CONACYT), and the community continues to provide plants, materials, and labor.

Reforestation has been successful in areas clear cut before the sustainable program was implemented and on agricultural lands not heavily eroded. Restoration has also been attempted in areas affected by the eruption of the Paricutín volcano, which appeared in a corn field practically without warning in the early 1940s and was active for nine years, from 1943 to 1952. The eruption of the Paricutín completely destroyed the town of San Juan Parangaricutiro, which was subsequently relocated outside the disturbed area. Lava flows and volcanic ash covered forests, agricultural lands, and orchards. The impacts ranged from complete elimination of vegetation in the areas covered by lava to various levels of disturbance caused by volcanic ash deposition.

Vegetation has recovered best in areas that had canopy cover at the time of the eruption (Figure 1) because the falling volcanic ash mixed with leaf litter and seeds and the canopy later provided shadow for the establishment of understory species. Although vegetation cover and species richness have increased on the volcanic cone and the lava flows (Eggler 1959, 1963, Giménez de Azcárate et al. 1997, Beaman 1960, Rejmánek et al. 1982), other areas are still mostly devoid of vegetation. These places are locally known as *arenales*, or sand pits. Vegetation in

Figure 1. Trees have recovered in areas forested at the time of the Paricutín volcano eruptions, even where large amounts of volcanic ash were deposited. In the photograph, a road cut has exposed the top layer of volcanic ash. The photo shows the dominant native pine species, smooth-barked Mexican pine (*Pinus pseudostrobus*), as well as other species characteristic of the forest understory. Photos by R. Lindig-Cisneros

the arenales lies in scattered patches (Figure 2), each patch consisting of a single or a few individuals of several native shrub species that are associated with up to 46 herbaceous species in their understory (Lindig-Cisneros et al. 2006).

The arenales are challenging for restoration because of the volcanic substrate. Barriers to plant establishment include the depth of the low-nutrient volcanic ash layer that plant roots have to cross before reaching the underlying fertile soil (Alejandre-Melena et al. 2007, Gómez-Romero et al. 2006). The thickness of the volcanic ash layer in the arenales ranges from a few centimenters to 2 m. In addition, the volcanic ash of basaltic origin, almost black in color, can reach close to 70°C (as measured with a surface infrared thermometer at noon in April) during the peak of the dry season.

Experimental restorations are being implemented in the Mesa de Cutzato and the Llano de Pario. One major component of the program is monitoring. Both biotic and abiotic variables have been measured since the beginning of the program. Substrate and air temperatures are recorded at each site with dataloggers. Visits every two months to each restoration site have allowed us to measure several variables, including planted species survival and growth and the identification, number, and canopy cover of spontaneously colonizing plant species. The data allow for a detailed description of site development and for an understanding of the processes behind the outcomes at each site. We were able to document, for example, the impacts on survival of a native legume, elegant lupine (*Lupinus elegans*), of herbivory by small mammals during the months after planting, run-off damage during the late rainy season, and frost damage (Blanco-García and Lindig-Cisneros 2005). Our data also show that the survival rate for pines is correlated with the number of days with ground surface temperatures higher than 50°C during the driest month of April (Figure 3).

Adaptive Restoration of Volcanic Ash-covered Areas

The present case study on adaptive restoration of agricultural fields covered by volcanic ash illustrates how a complex series of events can cause unexpected outcomes and present further challenges for the restorationist. At our site, dry years have been followed by several mild years, and

Figure 2. Open areas, such as agricultural lands, that were covered with volcanic ash by the Paricutín volcano eruptions persist today as *arenales*, sandy sites lacking tree species and closed vegetation. The sandy substrate can reach close to 70°C (158°F) during the peak of the dry season. These high temperatures present the main barrier for plant restoration.

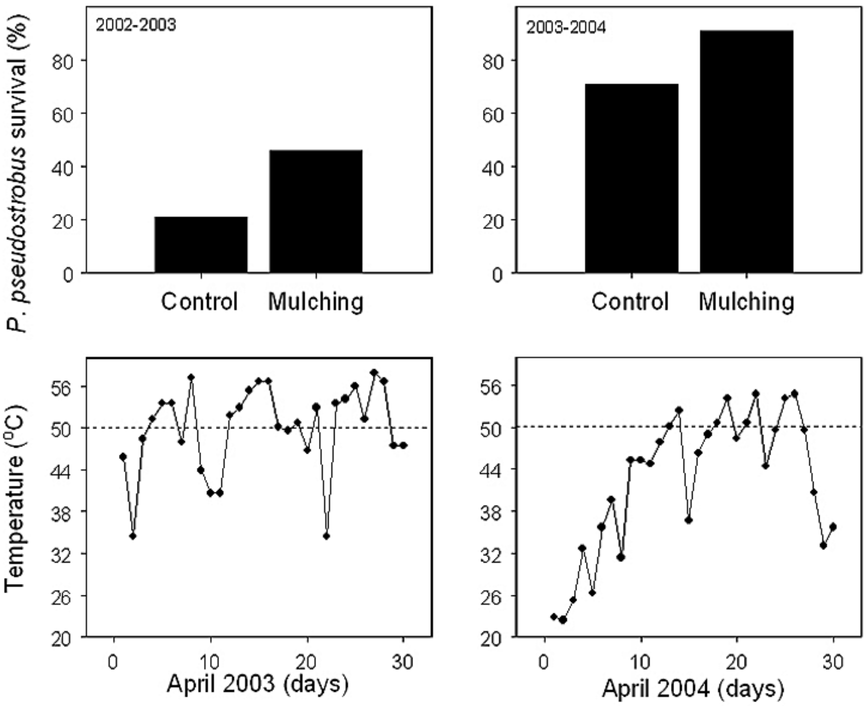

Figure 3. Planted native smooth-barked Mexican pine (*Pinus pseudostrobus*) survival during two different growing seasons and daily high temperatures during the driest month (April). The native pines were planted during July and their survival was correlated with the number of days that exceed 50°C during the following dry season. The growing season of 2002–2003 was particularly harsh (18 days with temperatures higher than 50°C) and was followed by a mild growing season (7 days with temperatures higher than 50°C).

plant survival in restorations varies accordingly. Plant mortality can be particularly high during dry years; the intensity of high temperatures during the dry seasons that have followed restoration plantings is unpredictable. Other limitations to plant establishment include herbivores and run-off damage to small plants and seedlings (Blanco-García and Lindig-Cisneros 2005).

Several strategies have proven useful for increasing plant survival of the dominant native pine species, smooth-barked Mexican and Montezuma pines. To reduce high substrate temperatures we experimented with mulching, adding by hand 4 cm of ground pine bark from the community's saw mill on top of the sand. We tested this approach in experimental restorations during three consecutive growing seasons, 2002–2003, 2003–2004, and 2004–2005. This practice doubled survival rates during dry growing seasons, such as 2002–2003, when substrate temperatures 4 cm below the ground surface exceeded 50°C for several consecutive days in April 2003. Pine survival with mulching was 46%, while without mulching survival dropped to 22%. Mulching increases survival rates 20% on average for mild growing seasons such as 2003–2004 and 2004–2005, when substrate temperatures rarely exceeded 55°C. Survival in these conditions can be as high as 90% compared to 70% without mulching (Figure 3).

In our experimental restorations, smooth-barked Mexican pine plants protected with mulch had 80% survival rates during mild years and 46% survival rates during the hottest year—16% higher than the average for reforestations with this species in Michoacán (Lindig-Cisneros et al. 2002). Age at planting is also an important variable that can increase pine survival. In our restorations, 18-month-old plants had significantly higher rates of survival than younger plants. Low pine survival on restoration sites represents substantial economic losses for the community and can also create conditions that worsen the restoration scenario. *Hierba de golpe* (*Eupatorium glabratum)* is a fast-growing native species than can reach more than 1 m in height after the first year. Hierba de golpe is present in disturbed areas below the tree canopy and other open areas. This species is dominant in the arenales together with false arnica (*Senecio stoechadiformis*) and willow ragwort or *pescadito* (*Barkleyanthus salicifolius*).

Figure 4. A site dominated by hierba de golpe (*Eupatorium glabratum*) shrubs in a failed reforestation effort. Shrubs are interspaced 2 m apart in a regular grid pattern echoing the original pine planting effort. The shrubs colonized at the base of dead pine plants where shelter and pine tree detritus provided improved conditions for shrub germination and early growth.

Figure 5. Removal of hierba de golpe (*Eupatorium glabratum*) shrubs and the top layer of volcanic ash by heavy machinery at a site where the shrub has replaced planted pines. Although expensive, this allows for complete removal of the undesired species and the inhibiting ash layer.

The spatial pattern of existing hierba de golpe plants is striking (Figure 4). Shrubs of this species are interspaced 2 m apart in a regular grid pattern. Monthly visits since 2002 have provided us with the evidence needed to explain the existence of these hierba de golpe "plantations." Hot years causing high pine mortality also trigger massive flowering and seeding of hierba de golpe plants. The pine plants that died as a result of the hot dry year made favorable sites for hierba de golpe seed accumulation and seedling growth because of the litter and fertile nursery substrate left by the dead plants. Under such favorable conditions hierba de golpe seeds can germinate and grow in areas where the volcanic ash layer would otherwise prevent establishment. Although flowering in this species typically occurs during the peak of the dry season, from late March to May, it is common for many of the plants in a population not to set flower every year. When conditions are favorable, however, massive blooming occurs and large quantities of wind dispersed seeds are produced. When mass flowering happens, large areas get covered with seeds that accumulate in small sites protected from the wind, such as stems, rocks or the dead pine trees planted for restoration. Hierba de golpe seeds sometimes accumulate to up to half a centimeter thick. These seeds can germinate immediately when the first rains moisten the soil, usually during June.

Other efforts to reclaim arenales have been affected by hierba de golpe invasions. Peach orchards have almost failed completely because although many peach trees germinated, many hierba de golpe plants became established in the sheltered pit dug for each peach plant and out-competed the peach trees. Hierba de golpe is undesirable because few natives establish under this species' canopy, particularly tree species. Where native species have a chance to establish themselves, hierba de golpe normally does not exceed 30% of any patch canopy cover. The other shrubs common in the arenales, false arnica and willow ragwort, do not prevent native species establishment under their canopies. Once established, hierba de golpe is hard to eliminate and requires extraction along with the top layer of volcanic ash using heavy machinery (Figure 5). This strategy, although expensive, is efficient. Experimental restoration plots show high survival and growth rates for the native pine species that dominate the forests in the region (smooth-barked Mexican and Montezuma pines), and native shrubs and forbs have colonized the area by themselves.

Lessons Learned

Invasion by hierba de golpe, although undesirable, offers a useful case study in adaptive restoration decision making. The arenales have complex histories of disturbance that create conditions not found under natural disturbance regimes in the region. The arenales were large open areas at the time of the eruption, mostly agricultural lands. The combination of a previous human disturbance and a major natural disturbance has created novel conditions for plant establishment and interspecies interactions. When the volcanic ash covered these areas, many species failed to survive under the environmental conditions created by the fine, black-colored sand, especially in large areas lacking canopy cover. Reforestation allowed us to overcome barriers related to germination and early plant survival but conditions remain harsh enough to cause high mortality, even close to 100% during years with hot dry seasons.

That one native species is capable of taking advantage of the conditions created by the failed reforestation effort was an unexpected outcome and the consequence of a series of apparently unrelated events. By approaching restoration in an adaptive management scheme that included close monitoring of restoration sites, we were able to achieve a better understanding of the processes involved in the restoration effort. Because the presence of hierba de golpe cannot be avoided in our sites, using strategies such as mulching, which increases pine survival and supports the establishment of other native plants, is fundamental for future planning and to avoid conditions that hamper further restoration efforts.

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