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TREE PLANTATIONS FOR REHABILITATING DAMAGED FOREST LANDS IN THE TROPICS

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Introduction

Concerns about tropical rain forests center on the fragility of these ecosystems (Wilson 1988). Paradoxically, forest succession in the moist and wet lowland tropics (*sensu* Holdridge 1967) is extremely rapid (Ewel 1980, Brown and Lugo 1982). Today, the area covered by secondary or 'fallow' forests that result from human conversion of primary forests is expanding faster than the area covered by any other tropical forest ecosystem (Lanly 1982). Successional forests appear to have a significant role in the restoration of soil fertility (Bartholomew *et al.* 1953), species composition, and forest biomass in deforested tropical lands (Brown and Lugo 1990). A key decision for land managers who must restore the productivity of damaged tropical forest lands is whether to let natural processes do the restoration job or intervene with management actions that have the potential to be costly.

I believe that natural succession is the best and fastest restoration procedure available for those rain forest environments where damage to soil and the biota has not been irreversible (Lugo 1988). Speed of succession, measured as biomass accumulation, is perhaps the best indicator of how damaged a site is. Natural succession will be faster where human damage to the ecosystem is lower. However, many tropical environments are characterized by slow succession even in the absence of human damage because of limiting factors; *e.g.*, too dry, too wet, too cold, or low fertility (Ewel 1980). When limiting factors other than those caused by humans retard succession, land managers face the additional decision of whether or not to attempt to accelerate the natural recovery process.

For the purposes of this discussion I am excluding all situations where natural succession is the preferred alternative over human intervention, or where forest successions are naturally slow due to limiting factors other than those caused by human impacts on the ecosystem. Instead, I have focused attention on damaged sites where human intervention is required to assure forest ecosystem rehabilitation, The degree of damage that I address corresponds to Goodman and Bray's (1975) 'derelict land' category. These are lands that are incapable of beneficial use without treatment. Techniques for rehabilitating damaged sites in the temperate zone are given in Hutnik and Davis (1973), Bradshaw *et al.* (1978), Johnson and Bradshaw (1979), Cairns (1980, 1988), and Fox (1984), Bradshaw (1988). No such information is available for tropical ecosystems.

Natural conditions in the lowland moist and wet tropics can either accelerate or decelerate the speed of ecosystem rehabilitation. On the positive side, the greater diversity of species improves the probability of finding the right combination of plants to re-stock a damaged site, and favorable year-round plant growth conditions increase the speed of recovery in most tropical ecosystems. On the negative side, once vegetation is removed from a site, damage is exacerbated by the fast rate of erosional

Ecosystem Rehabilitation, volume 2: Ecosystem analysis and synthesis
edited by Mohan K. Wali, pp. 247–255

processes in high rainfall areas, particularly in tropical mountain regions. Thus, delays in rehabilitation actions could reduce management options. Ecosystem rehabilitation can also be limited by biotic interactions that are more complex in the moist and wet tropics. For example, seed predators may hinder tree regeneration, or insects and diseases may attack stressed trees. Research is needed to evaluate the relative importance of factors that accelerate or decelerate forest rehabilitation in damaged tropical lowland sites.

An ecosystem rehabilitation model

I use rehabilitation in the context described by Bradshaw (1988) and Lugo (1988). The objective of rehabilitation is to restore the productivity of the land without regard to how the rehabilitated system compares with the original one. Rehabilitating damaged ecosystems is the inverse of stressing them (Lugo 1988) because the initial objective is to increase net primary productivity. However, stress can be used in rehabilitations that require slowing down one process in order to accelerate another (*e.g.*, slowing down herbivores to increase net primary production).

There are four types of rehabilitation (R) activities: (1) reducing environmental stressors (R-1), (2) adding materials (R-2), (3) accelerating or decelerating ecosystem processes (R-3), and (4) changing site conditions (R-4)(Lugo 1988). The cost of these interventions is suspected to be higher in R-3 and R-4. The simplest and least costly rehabilitation activity is to reduce or control a stressor (R-1) such as fire, overgrazing, or cutting. A second and more costly activity (R-2) involves adding species (by planting or seeding), water, fertilizers, or soil to the site. An example of R-3 would be accelerating seed input to a site by attracting seed vectors such as birds or bats. In damaged sites R-4 can be accomplished by changing drainage and topography, or reducing light input by shading.

A land manager must be able to overcome all the energy drains and barriers that prevent damaged forest lands from supporting forests that function at a prescribed rate of productivity. Because it would be so difficult to know what the original starting conditions were in any particular site, and because even if they were known, it is difficult to force a complex system to develop towards a particular state (Ewel 1983), land managers are left with few criteria by which to evaluate the success or failure of a forest rehabilitation. I propose that the establishment of a self-maintaining forest where there was none before be used as a criterion for evaluating the success of rehabilitation projects in damaged tropical forest lands. A self-maintaining forest is the one whose dominant species reproduce and remain dominant on the site.

One example of a tropical forest rehabilitation

Uhl (1988) studied the rehabilitation of forest cover in forest lands that had been damaged by conversion to pasture in Brazil. Forest succession had repaired the damage fairly rapidly in lands where the conversion to pasture did not degrade the site. In some lands, however, excessive soil compaction, repetitive weeding and use of fire, large distance to arborescent seed sources, excessive seed predation, and harsh microclimate prevented re-establishment of the forest cover. Uhl found that the three main limiting factors to forest rehabilitation were (1) lack of seeds, (2) seed predation, and (3) seedling mortality due to harsh environmental conditions.

Actions required to rehabilitate these forests correspond to increasing the rate of natural seed dispersal, reducing the stress associated with the activity of seed predators so that seed supply increases, and changing the microclimate. Overcoming these limitations will be costly unless natural processes can be utilized to do the job. For example, seeds could be dispersed by bats, birds, or other animals if these organisms are somehow assured access to and from natural forest stands and into the damaged site. Seed predators would have to be biologically controlled. Overcoming microclimatic difficulties will be expensive at the landscape scale. All actions are possible, but long periods of time would be required to rehabilitate large areas.

In extreme examples such as the highly degraded Brazilian pastures or in devastated lands such as mined areas, planting of trees may be a quicker route to forest rehabilitation. This approach is also costly, but once a species is identified as suitable for the conditions of the site in question, forests re-establishment occurs faster than it would through natural succession. If time is important (*e.g.*, to avoid further site damage caused by soil exposure), tree plantations may be an economical and ecologically acceptable alternative to natural succession. In discussing rehabilitation approaches for the damaged pasture sites in Brazil, Uhl (1988) considered human dispersal of seeds, transport of forest soils to damaged sites, use of new types of seed vectors, and plantings. Given the costs involved in these strategies, he suggested that a necessary first step was the establishment of some predator-resistant, stress-tolerant tree species.

Advantages of rehabilitation with tree plantations

Any tree species (native or exotic) that is adapted to damaged sites can and should be planted to accelerate forest rehabilitation. For the planting to be successful, the silviculture of the species should be known. Unfortunately, silvicultural understanding of most tropical tree species is usually poor. Forestry research has favored testing of exotic over native tree species. It is thus likely that an exotic tree species previously proven in local trials has a better probability of accomplishing Uhl's first critical step than a native species.

The main advantage of using exotic tree plantations to rehabilitate damaged sites is their likelihood of success. Many studies document the success that exotic species have in marginal habitats (*c.f.*, Ewel 1986, Vermeij 1986). Because of their success as invaders of damaged sites, many naturalized or escaped plant species are perceived as pests by those who do not realize that these plants are exploiting new environments to which they are better adapted than native species. The following quote from Ewel (1986, p.228) underscores this point: 'Species invasions often reflect the condition of the community being invaded rather than uniquely aggressive traits of the invader.' As environmental conditions change, other native species should enter the site. However, if the altered environment condition persists, the exotic species usually remains dominant.

Tree species (native or exotic) can be selected according to their adaptability to damaged sites. Plantations in these localities will have the following additional adplantation and natural forest sites showed that seasonal changes in litter storage do not affect the relative ranking of plantation vs. forests in terms of litter accumulation (Lugo 1989). Plantations that were watered and fertilized (those with ages of 5.5 yr) accumulated more biomass and nutrients in a shorter time than the ones that were not watered or fertilized. Because fertilizers and irrigation are expensive, tree plantings in damaged sites near human settlements could be irrigated with sewage effluent from human dwellings. This assumes that the sewage receives primary and secondary treatment before application. Sewage effluents would fertilize sites and provide water, both of which stimulate tree growth, and accelerate nutrient and biomass accumulation, thus increasing the number of tree species that could be cultured at the site. Care is needed to avoid water supply contamination by the effluent.

Each different tree species maintains a characteristic rate of nutrient return to, and accumulation in, the forest floor when grown in the same climate and soil (Cuevas and Lugo, unpublished, Lugo *et al.* 1990b, Wang *et al.*, unpublished, Table 1). In an experiment with 10 species in Puerto Rico, Cuevas and Lugo (unpublished) found that the return of biomass and nutrients by litterfall was under species control rather than under environmental control. Apparently the adjustment of these ecophysiological processes to site variations are limited to narrow ranges in each species. This may be one reason why high nutrient-demanding species fail to grow in nutrient-poor soils or why low nutrient-demanding species do not compete well in nutrient-rich soils. However, trees that use nutrients efficiently become progressively more independent of site conditions as they reach maturity (Bowen and Nambiar 1984). Most of the nutrient uptake is done early in the life of the tree, a circumstance that could be used advantageously in damaged sites by fertilizing trees when nutrient uptake is at a maximum. However, experience with tree fertilization in tropical plantations is not extensive, and more research is needed.

It may be argued that nutrients in the large litter mass of exotic tree plantations (Table 1) are unavailable to native understory vegetation that may eventually replace the exotic trees. The results listed in Table 2 show this to be untrue because understory development in unmanaged plantations is significant. In fact, litter mass and nutrient turnover in these plantations is high (Cuevas and Lugo, unpublished, Lugo 1989) although the rate of nutrient turnover is slower in plantations than in paired natural forests (Lugo 1989). The decomposition of biomass and turnover of nutrients may be accelerated in damaged sites by seeding the soil and litter with mycorrhizae and soil and litter fauna. Preliminary counts of these and other organisms in pine plantations in Puerto Rico, however, suggest that they colonize the plantation even without artificial seeding.

Plantations in the moist and wet tropics do not remain as plant monocultures (Table 2). Immediately after establishment, the competition of native plants with the plantings is intense, a situation that requires frequent weeding to protect seedlings. Later, native trees invade the understory and eventually penetrate the canopy of the plantation (Lugo 1989). Most of the understory species listed in Table 2 are native tree species. The plantations from which the data were taken had been established on sites damaged by agricultural activity. However, if these sites had sustained greater damage, there would have been reduced levels of native species invasions, at least initially. Increased success of invasions of plantation understories by native species should then occur after site conditions change due to the accumulation of litter and

Table 2. Stem density and species of understory plants in 14 tropical tree plantations in the Luquillo Experimental Forest. Sampling area was 100 m^2, and all plants with diameter ≥ 0.5 and < 4 cm were measured. Results are representative of the plantations but conservative because all plantations were periodically weeded (Lugo 1988, Lugo *et al.* 1990b). Also, older plantations had additional tree species (ingrowth) with dbh > 4 cm.

Platation species	Plantation age (yr)	Stem density (No/0.1 ha)	Number of understory species
Anthocephalus chinensis	26	2,450	20
Eucalyptus patentinervis	27	4,400	26
E. saligna	25	2,330	20
Hernandia sonora	27	8,270	28
Hibiscus elatus	27	2,900	30
Khaya nyasica	27	4,790	27
Pinus caribaea	9	2,510	17
	23	3,980	16
	27	2,400	24
P. elliottii	27	3,120	29
Swietenia macrophylla	22	6,270	26
	26	2,420	29
	54	10,680	31
Terminalia ivorensis	24	6,460	31

soil organic matter on the forest floor, changes in soil structure, and the modification of microclimate by tree cover.

Measuring and assuring success of rehabilitations on damaged sites

The successful use of plantations in rehabilitating a native forest on damaged sites will depend on the establishment and growth of native species in the understory of plantations. This in turn depends on the rate at which the plantation modifies site conditions. If the site is so damaged that its modification by the plantations is slow, the project will end up with a self-sustaining exotic ecosystem. If damage is not extreme, a native forest should replace the exotic one. Another alternative would be that a new ecosystem would be formed consisting of a combination of native and exotic species (Ewel 1986).

The presence of exotic tree species in rehabilitated forests should not be construed as a failure because the goal of rehabilitation in damaged sites is the establishment of self-sustaining forest ecosystems where there were none before. The final species composition is ultimately dictated by site conditions, which are beyond the control of land managers. Obviously, the best assurance to maintaining pure native forests is not to damage the site in the first place!

If sites are highly damaged, however, and if they require planting, the prospects of success can be enhanced by taking the following steps: (1) intensive planning and careful species selection, (2) involvement of local people, (3) assure availability of resources, facilities, and the will to complete the project, (4) provide continuous organizational support, (5) focus on areas with the best opportunities for tree growth, (6) use of multiple seeding of plants, animals, and microorganisms, (7) recycle sewage to enrich the soil and supply water for the trees, and (8) keep a research focus for the program.

Research needs

Research should generate alternative methods for rehabilitating damaged forest land. Plantation research with a focus on ecological implications to site rehabilitation has not been extensively conducted in damaged tropical sites. Limited information is available on how tropical tree species behave on damaged sites, and the silvicultural needs of most tree species remain unknown, However, there are many examples of successful tree establishment under these conditions. Research is needed to improve understanding of the impact of tree on sites; on the required timing for planting, fertilizing, and caring of trees to maximize their effect on site rehabilitation; and of the possibility of interplanting combinations of native and exotic tree species in damaged sites. Studies of faunal diversity and succession on damaged sites and plantations are also urgently needed. More studies on seed-bank dynamics such as those of Young *et al.* (1987) are needed, and these must be supplemented with studies of seed vectors and ways of increasing their effectiveness in damaged sites.

Acknowledgements

This study was done in cooperation with of the University of Puerto Rico. I thank S. Brown, D. Chinea, and C. Uhl for reviewing the manuscript.

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bc_iitf_1992_lug0003