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# Loss in Species Caused by Tropical Deforestation and Their Recovery Through Management

The loss of species as a result of deforestation and degradation of tropical forest lands is widely discussed. Models based on island biogeography theory are used to evaluate the relationship between extinctions of species and deforestation. The analysis shows that natural resiliency causes the models to overestimate the rates of species extinctions for given intensities of deforestation. There is an opportunity to couple natural processes with management activities to reduce species extinctions and restore species richness to degraded lands. As an example we show how tropical monoculture tree plantations can foster diverse native forests in areas previously deforested. The central point is that well-directed human actions provide us with the means to conserve biodiversity and restore it in locations previously degraded.

## INTRODUCTION

The classic monograph by McArthur and Wilson (1) on island biogeography visualized the number of species on an island as a balance between species gains by immigration and losses through extinction. Using this simple concept, McArthur and Wilson developed a quantitative theory to explain the number of species in islands at species steady state. Today the species-area relationship, upon which island biogeography theory is based, is used to estimate the extinction of species as a result of deforestation of tropical forest lands (2, 3). Little attention is given to the other side of the equation (gains of species on a site) to arrive at a better estimate of the actual number of species present following human modification of the landscape (4, 5). Our objective is to discuss both the losses and gains of species in damaged lands with particular attention to the opportunities for augmenting the numbers of species per unit area through management. We focus on the importance of managed forest stands as species refugia and more importantly, as tools for restoring species richness in degraded sites. Studies in Caribbean island coffee plantations suggest that these human-managed ecosystems served as refuges for orchids (6) and avifauna (7) when high deforestation rates had consumed and/or fragmented available natural habitat.

## MANAGEMENT FOR SPECIES DIVERSITY

An important area of study in ecology is succession, or the changes that occur in ecosystems as they mature. A working hypothesis for which there are few exception—i.e., highly stressed ecosystems—is that as ecosystems mature, their net primary productivity decreases and their respiration, ecosystem metabolism, and species richness increase (8). In fact, ecologists suggested that the overall biotic complexity of ecosystems increases as net primary productivity decreases (8). The inverse relation between ecosystem complexity and net primary productivity explains why monocultures are necessary when the management objective is to maximize net yield and profit. In fact, most agricultural and silvicultural prescriptions for maximizing yield involve the simplification of the ecosystem, by whatever means necessary, including weeding or poisoning of any species that may compete with those favored for their high yield and low respiration. In these cases, human labor, fossil fuels, and technology substitute for ecosystem metabolism and in so doing assures a measure of ecosystem stability.

Taken to the extreme, these techniques have given management a poor image in relation to current interests in maximizing biodiversity. The conflict between management for high-yield and maintaining biodiversity cannot be reconciled in high yield systems such as clonal forestry or hydroponic agriculture, because the measures taken to increase yields are extreme and the biota is reduced to almost uniform genetic material. As a result, management and monocultures are commonly viewed as irrelevant to the solution of preserving, conserving, or restoring biodiversity in the landscape.

It is unfortunate that extreme application of management systems that result in high biomass yields have led to a general repudiation of management activities with regards to the conservation of biodiversity. We propose that management activities, including the use of monoculture tree plantations, can be useful for restoring the species composition of damaged sites. To put management activities in context we will discuss first the relationship between species extinctions and deforestation.

## DEFORESTATION AND SPECIES EXTINCTIONS

The relationship between deforestation and species extinctions, using the species-area model of McArthur and Wilson (1) is shown in equation 1 where: S = the number of species, A = the area, and C is a parameter that depends on the taxon, its population density, and biogeographic region.

$$S = CA^Z \quad \text{(equation 1)}$$

The shape of the species-area curve is determined by Z (Fig. 1), a factor that is $\leq 0.7$ (9). Most regions of the world are characterized by Z factors between 0.16 and 0.39. Islands tend to have Z factors of about 0.35 while comparable continental areas have Z factors of about 0.20 (9). However, the Z factor increases as the area under consideration becomes smaller. For Caribbean islands, tree and plant species-area curves, covering up to 1500 $km^2$, had Z factors of 0.12 and 0.23 for trees and all plant species, respectively (10). Other examples, using tree species data for even smaller areas, had Z factors of 0.67 and 0.68 for dry and wet forests and 0.47 for lower montane rainforests (11).

The predicted magnitude of the extinction of species in relation to the loss of forest area is a function of the Z factor (Fig. 1). The model is very sensitive to Z and thus allows for a wide envelope of extinctions given a similar magnitude of deforestation. Unfortunately, an understanding of the factors that affect the value of Z is still incomplete (9). Nevertheless, when Z values are low (< 0.20), the model predicts that more than 50% of the land area can be deforested before the slope of the extinction curve increases rapidly with increasing deforestation (Fig. 1). Conversely, at high Z values (> 0.60) the model suggests extinction rates that are almost proportional to deforestation rates. For the model to predict rates of species extinctions that are faster than the rates of forest loss, the Z factors must be much higher than empirical data suggest possible.

Limited data for bird and plant species for the island of Puerto Rico (4, 12) suggest that the model in Figure 1 overestimates extinction rates even when Z values as low as 0.15 are used. Brash (12) reported an extinction of 11.6% of the avian species of the island after a loss of 99% of the primary forests and a net deforestation of 90%. The implication is that the rate of species extinctions cannot be explained by changes in area of forests alone. Other factors come into play and the net result of these is that the species-area model appears to overestimate extinction rates.

An obvious explanation for the overestimation of extinctions by species-area curve models is the implicit assumption that deforestation results in lands that are biotically sterile, which of course is rarely true. Moreover, human pressure on the land is variable and after abandonment, species can reinvade sites through successional mechanisms. In addition, as discussed by Williamson (9), the species-area approach has limitations that reduce its usefulness for detailed explanations of biotic phenomena. For example, the curves are based on single taxa, and it is likely that assemblages of species will exhibit different relationships with area than do individual taxa because the curves are not additive. Habitat diversity, a key factor in the explanation of species richness in islands, is not accounted for in the species-area models except for the implicit assumption that larger areas have more habitats. These considerations make it clear that the biology and rate of species extinctions caused by human activity are different phenomena than that implied using only species-area models.

The discussion above suggests the need for better models for predicting species extinctions due to human activities such as deforestation. Clearly, research is needed on the mechanisms that cause resistance to the loss of species following disturbances. Meanwhile, we must take action to reduce species extinctions and where possible, restore lost biodiversity.

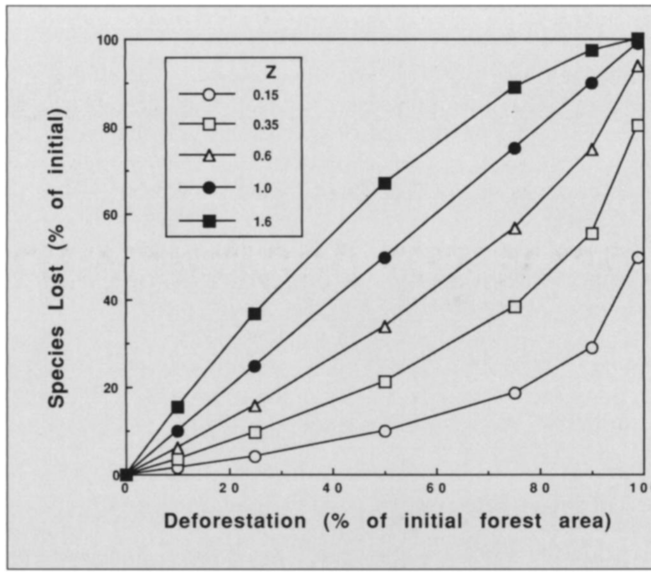



Figure 1. Relationship between deforestation and loss of species to extinction using different slopes (Z factor) for the species-area curve shown in equation 1.

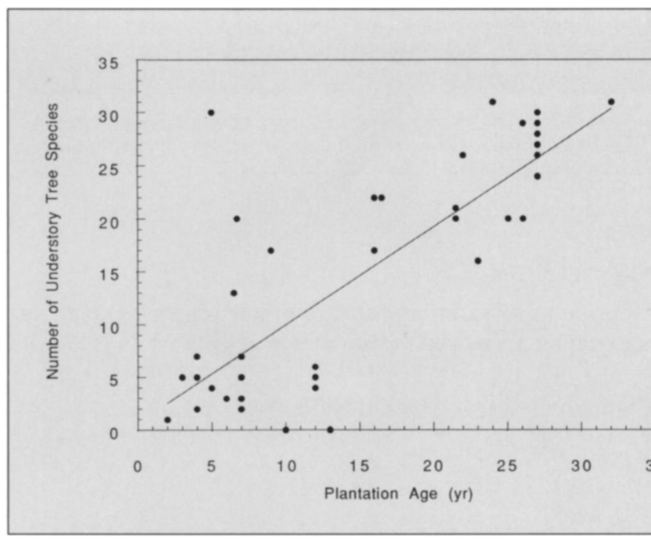



Figure 2. Relationship between number of understory tree species in tree plantations and the age of the plantation. Data sources and discussion in the text. The relationship for these data is y = 0.74 + 0.93 x, ($r^2$ = 0.62).

## TREE PLANTATIONS AS FOSTER ECOSYSTEMS FOR DIVERSE FORESTS

Tree plantations usually consist of fast growing, light-demanding tree species that have valuable wood properties or other useful product such as latex, resins, or tannins. These plantations are often established on degraded lands where agricultural activity is no longer possible due to declines in soil productivity. We have noticed in our studies of tree plantations in Puerto Rico and in a review of the literature mostly from India, that species-rich understories of native trees develop inside plantations and that the species composition of these understories change over time (5, 13–23). Under conventional plantation management, considerable effort is exerted to control or eliminate understory colonization by vegetation.

Our proposal to use plantations to accelerate successional processes and increase biodiversity requires a broadening of conventional management objectives. While management for high overstory wood yields will continue to be important in order to recover investments in plantation forestry, management practices that facilitate natural successional processes and the development of species-rich understories would be a primary management goal.

Data from the above sources showed that the number of understory species in plantations increased at a constant rate for approximately 30 yr (Fig. 2). These data were for 44 plantations in Puerto Rico and India ranging in age from 4 to 32 yr. Rainfall among sites ranged from 500 to 3800 mm $yr^{-1}$. Sampling area for the understory ranged from 30 to 250 $m^2$ and the minimum size recorded for understory species ranged from seedlings to large saplings. We obtained the same relation when we analyzed the data by country, and therefore we pooled the data for the two countries. In spite of the wide range of variation in the way data were collected, the relationship in Figure 2 is highly significant ($p < 0.0001$) and provides evidence of the value of plantations for restoring species richness in degraded sites. We found no relationship with site parameters such as rainfall and elevation, nor with respect to plantation species, which included *Eucalyptus* spp., *Pinus* spp., *Leucaena leucocephala, Dalbergia sissoo, Acacia catechu, Casuarina equisetifolia, Senna siamea, Anthocephalus chinensis, Hernandia sonora, Hibiscus elatus,* *Khaya nyasica, Swietenia macrophylla, Terminalia ivorensis,* and *Grevillea robusta.*

The accumulation of species in plantations leveled off after 35 yrs in Puerto Rico. In contrast, available plantation data from India suggest that the number of species in the understories decreased after 35 yrs. It is unclear whether the apparent decline in species richness beyond 35 yrs in Indian plantations is due to natural factors or management activities intended to curtail natural successional processes in the plantation understory. Our proposal includes using the overstory plantation trees once the understory is fully developed so that a new and diverse forest of native species can develop in the previously degraded plantation site. Under this type of management, we don't expect a reduction in tree species diversity in the older stages of the forest. Moreover, because the planted species are usually shade intolerant, their regeneration is unlikely in the newly established native forest.

**Management practices that facilitate natural successional processes and the development of species-rich understories would be a primary management goal. Photo: C. Folke.**

Similar data in Brown and Lugo (24), for secondary forests undergoing natural succession, suggest that plantations accumulate species as fast as secondary forests but secondary forests begin at higher levels of species richness (Fig. 3). This was surprising to us in light of the fact that most of the plantation data are for degraded sites while those in Brown and Lugo are for natural successions on abandoned agricultural sites; generally, shifting cultivation. On severely degraded sites, plantations appear to serve as successional catalysts, accumulating species at markedly higher rates than would be the case in their absence (20, 21). Ecological characteristics of plantations that favor understory biodiversity are presented in Box 1.

There are difficulties and risks associated with the use of plantations to rehabilitate degraded lands. For example, research is needed on species selection to avoid failures and excessive expenses in site preparation and planting. If exotic species are used, there is a danger of the species escaping and invading natural areas. Proper species selection and adaptability trials minimize these risks. As with all management activities, cost is always a factor as is the need not to abandon treatments before they achieve the planned goal.

## MANAGING CHANGES IN BIODIVERSITY

Humans are changing the landscape and altering the ecological balance that prevailed prior to the onset of large-scale, intensive human activity. Species extinctions, habitat loss, and degradation of landscapes and ecosystems have understandably been viewed with alarm and have raised public consciousness of the need to

**Box 1.**

**Ecological characteristics of plantations that favor understory biodiversity. Based on research in Puerto Rico (15, 16, 20, 21, 27–30).**

**Changes in microclimate.**

Moderate fluctuations in understory temperature and humidity.

Provide more favorable light environment for seed germination and seedling development.

**Changes in Soil Physical and Chemical Properties**

Physical stabilization/reduction of erosion rates.

Increase soil organic matter and cation exchange capacity.

Increase available soil nutrients through litterfall, decomposition, and soil microbiological processes such as nitrogen fixation and mycorrhizal activity.

**Changes in Habitat Diversity**

Increase habitat for seed dispersal agents (birds, mammals, reptiles).

Increase structural complexity of ecosystem, thereby increasing niche space for both animal and plant species.

**Box 2.**

**Management actions that increase the number of species on biologically impoverished, or degraded, sites**

Recycling of sewage and other nontoxic organic wastes through degraded sites to increase soil organic matter, stimulate soil microbial activity, and accelerate natural succession.

Use of proven reclamation techniques in mining areas and/or derelict industrial and urban sites.

Diversification of habitats within agricultural landscapes through adoption of agroforestry systems, maintenanace of vegetation in uncultivated corridors, or tree islands between fields, along roads and waterways and around wetlands and other uncultivated sites,

Multiple seeding of deforested, severely degraded sites.

Use of tree plantations as foster ecosystems for native tree species.

Control of fire, unregulated livestock grazing, and excessive fuelwood collection to allow natural recovery processes to enhance biological diversity.

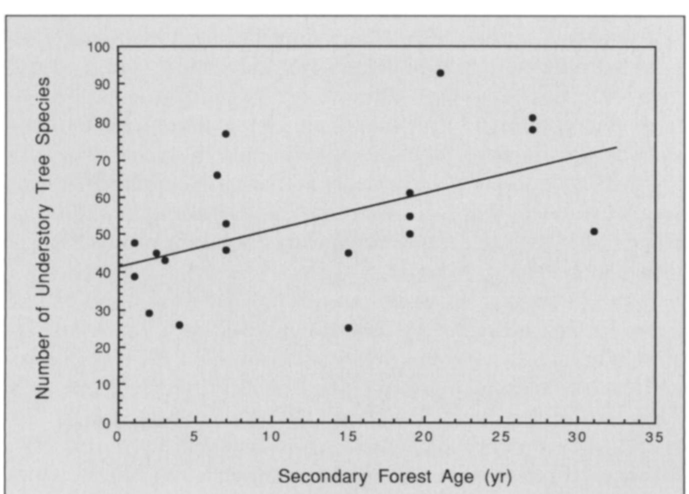
Improving soil fertility, particularly soil organic matter.

**While we must curtail many of the senseless human activities that needlessly destroy the ecological balance of Earth, we must also turn our attention to positive actions that reverse the negative impacts of humans. Photo: G. Nycander.**

preserve critical habitats and conserve Earth's biological heritage. While we must curtail many of the senseless human activities that needlessly destroy the ecological balance of Earth, we must also turn our attention to positive actions that reverse the negative impacts of humans. With regards to biodiversity, it is clear that the models that we use to anticipate the future condition of the biota (Fig. 1) provide a wide range of scenarios that depend on the species-area relationship (Z value) at each location. Given the geographical variability of the Z value and the limitations of the approach, forecasting changes in biodiversity becomes highly problematic. Moreover, these models appear to overestimate the number of extinctions because they don't take into consideration ecological resiliency, habitat variability, nor the ability of humans to reverse trends in species losses through management.

We suggest the use of plantations as one possible mechanism to restore diverse ecosystems in degraded lands. There are other actions that can be used to restore or maintain biodiversity in managed landscapes (Box 2). However, our main point is that land management offers an opportunity for humans to redirect the changes in biodiversity and in some cases to reverse negative trends.

**Figure 3. Relationship between number of tree and understory species and age of secondary forests. The relationship is y = 41.89 + 0.97 x ($r^2$ = 0.26). Data were for 22 plots ranging in age from 1–31 yr in tropical wet to dry forest life zones resulting from abandonment of agriculture, mostly shifting cultivation. Only plots with areas of ≤ 0.05 ha were selected to be more in line with the plantation data. All data are from Brown and Lugo (24).**

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