

Can we manage tropical landscapes? – an answer from the Caribbean perspective

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Abstract

Humans have used Caribbean island landscapes for millennia. The conversion of wild lands to built-up lands or to agricultural lands in these tropical countries follows predictable patterns. Conversion of moist forest life zones and fertile flatlands is faster than conversion of wet and rain forest life zones and low fertility steep lands. In Puerto Rico, these trends are leading to increased built-up areas, environmental surprises, and increased dependence on external subsidies. Changes over the past 50 yr also include a reversal in deforestation and increase in forest patch size in spite of increasing human population density. Present forests have different species composition than the original ones but are indistinguishable in physiognomy and basic function. The reversal of deforestation and forest fragmentation trends, if accompanied by an understanding of the forces that cause the reversal, can result in the development of tools for landscape management. Tropical landscape management requires understanding and application of natural resilience mechanisms of ecosystems, greater use of ecological engineering approaches to infrastructure development, enforcement of zoning laws, enlightened economic development policies, and an understanding and agreement of a conservation vision among all sectors of society. Mixing species in new combinations to form new ecosystems is a necessary step in the development of future landscapes.

“Landscapes have always changed over time, but we sense, somewhat uneasily, that the processes now at work are more powerfully focused and possibly irreversible.” “Our present assumption is that generally tropical lands are much more sensitive and less resilient than those in the temperate zones.” “...the long-term world trend in land uses is a cascading loss in capacity (i.e., degradation) in every broad category of land use.” J.F. Richards 1990, p 176 and 177.

Introduction

The early development of the modern field of landscape ecology was concerned with the fragmentation of landscapes and used the theory of island biogeography to explain the potential effects of dominant landscape processes on biodiversity (Burgess and Sharpe 1981a; Zonneveld and Forman 1990; Risser 1995). It stands to reason that an increasing human population will fragment and degrade landscapes and eventually jeopardize their capacity to sustain people (Woodwell 1990; Barrow 1991). This process is glo-

bal in nature and has already occurred in portions of the temperate zone (Turner et al. 1990; Meyer and Turner 1994) but is believed to be more prevalent in the tropics where human populations are growing at a faster rate than in any other part of the world (Barrow 1991).

Tropical deforestation and fragmentation are processes that are occurring at high rates in the tropics and appear to be the greatest threats to the conservation of tropical biodiversity (Laurance and Bierregaard 1997). Can we manage these processes? Can we reverse their direction? Or are they relentless

events that continue unchecked until some irreversible threshold of degradation is reached? Addressing these questions at continental scales is a daunting task not only because of size considerations but also because of the poor information base on natural resources for tropical countries. These problems need attention at smaller size scales without compromising the need to address all levels of the social and ecological hierarchies that influence landscape patterns and processes. The ideal surrogate is the island landscape (Beller et al. 1990).

Caribbean Islands are generally small (< 10,000 km²) but are a microcosm of the ecological interactions between people and tropical landscapes (cf. Ambio (1981)). These islands are topographically and ecologically diverse, have sustained human habitation for several millennia, and their social and natural systems have been extensively studied. Analysis of Caribbean island landscapes provide insights for sustainable human activity and are case studies for understanding tropical landscapes in general. Moreover, Caribbean island landscapes are a harbinger for the future of other tropical landscapes for two principal reasons:

1. recovering secondary forests from a large-scale deforestation event are now about 60 years-old—older than most tropical mainland secondary forests now responding to similar events (Prendergast et al. 1997).
2. Coastal zone urbanization provides an advance view of extensive urbanization of tropical landscapes.

My focus is mostly on Puerto Rico, where the processes of landscape change are progressing through the cycle of deforestation, fragmentation, degradation, partial recovery, and urbanization (Photos 1–3). However, I also draw information from the Caribbean region as a whole as well as from Costa Rica, Peninsular Malaysia, and Sri Lanka where relevant landscape-scale data are available. My objective is to develop suggestions for conserving tropical landscapes based on the changes that occurred in Puerto Rico and the Caribbean during the 20th century. I use the term conservation as synonymous to management (i.e., wise use *sensu* Leopold (1933)) and different from preservation, which is part of the conservation activity.

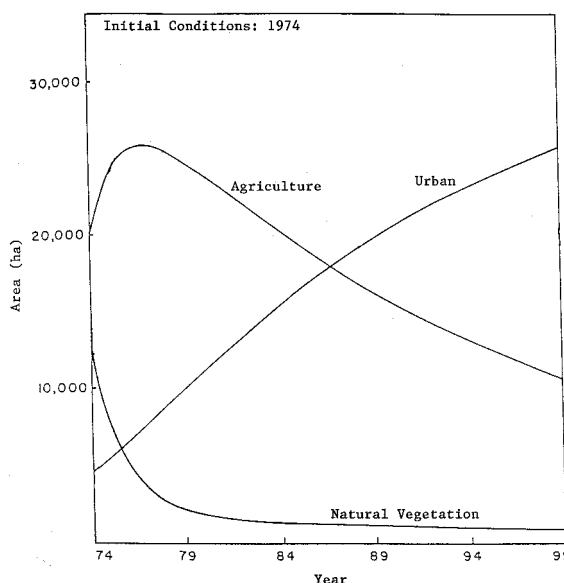


Figure 1. Land cover changes predicted to occur in northeastern Puerto Rico using data from the 1970s (Lugo 1982).

The prevailing landscape change paradigm

In the 1970s, I modeled land cover change for Puerto Rico, calibrated it with data for the northeastern portion of the island, and simulated the trends in land cover to the year 2000 (Lugo 1982). The simulation showed rapid urban expansion at the expense of natural areas (Figure 1). The same trend in land cover change occurred in Costa Rica (Sader and Joyce 1988; Hall 2000). This pattern of land cover change represents the prevailing paradigm for tropical landscapes in general.

Two generalizations resulted from the analysis of land cover and land use trends in Costa Rica (Tosi and Voertman 1964; Sader and Joyce 1988; Hall et al. 2000a), the Caribbean islands in general (Lugo et al. 1981; Lugo 1996), and Puerto Rico (Lugo 1982).

1. Landscapes that require lower effort to support human activity develop first and to a greater degree than landscapes with a high cost of development. For example, development of landscapes with flat topography and nutrient-rich soils in moist climates is much faster than in landscapes with steep topography, nutrient-poor soils, and unfavorable climates, especially once roads improve accessibility (Sader and Joyce 1988; Harrison 1991; Veldkamp 1992; Chomitz and Gray 1996; Hall et al. 2000b).

2. Some tropical and subtropical life zones (*sensu* Holdridge (1967))—moist forest and dry forest—are developed first, while others are developed to a lesser degree—montane wet forest, montane rain forest, rain forest, and very dry forest.

These generalizations help explain why, in spite of high human population pressure, some forest types are subjected to less deforestation and fragmentation than others in volcanic Caribbean islands (Lugo et al. 1981). Remaining forest cover in these islands is correlated with elevation. Forests survive at the highest elevations where the climate is wet and accessibility more difficult. Flat, non-volcanic islands have very little remaining forest cover, e.g. Barbados, Antigua.

Improving the tropical landscape change paradigm

Forest fragmentation in Peninsular Malaysia

We gained insights into landscape development processes in the tropics by studying the changes in forest area, fragmentation, and biomass content of tropical landscapes in Peninsular Malaysia (Brown et al. 1994; Iverson et al. 1994; Brown et al. 2001). The study used large-scale forestry inventories to estimate changes in forest area between 1972 and 1982. We found that the area of tropical forests declined by 17 percent over the ten-year period but the biomass of the forests declined by 28 percent. Primary forests declined in area by 23 percent and in biomass by 35 percent while disturbed forests declined in area by 7 percent and in biomass by 19 percent. The disproportionate reduction in forest biomass relative to rate of deforestation was due to land degradation measured by the degree of landscape fragmentation. Human access to forests increased due to their fragmentation defined as the perimeter to area ratio. Change in stand biomass (y) correlated inversely with the change in forest fragmentation (x): $y = -9.33 - 1.67x$; $r^2 = 0.7$, $p < .05$; Lugo and Brown (2001)). Better access to forests allowed people to reduce forest biomass without affecting forest cover. Surprisingly, information from Sri Lanka on landscape-level species richness in logged forests shows no difference between moderately disturbed and mature forest stands (Lugo and Brown 1996).

Three insights resulted from the Peninsular Malaysia and Sri Lanka analysis.

1. Changes in land cover alone do not adequately portray the changes occurring on the landscape because land cover provides no information for what is happening below the canopy of forests or inside the systems identified by remote sensing.
2. Changes in forest biomass, biodiversity, and successional state can occur without significantly disturbing forest canopy.
3. Changes on the landscape are not always negative. For example, species richness in Sri Lanka was sustained in spite of moderate stand disturbance, and the increased level of forest fragmentation observed in Peninsular Malaysia between 1972 and 1982 increased the carbon sink function of forest stands (Brown et al. (1994, 2001); Iverson et al. 1994).

Reversal of deforestation and fragmentation in Puerto Rico

The prediction for land cover trends for Puerto Rico based on the prevailing paradigm of land cover change in the tropics and using conditions in the 1970s (Figure 1) was not correct. I predicted a loss of forest area, an increase in urban area, and a slight decrease in agricultural area. Today, Puerto Rico has a larger forest area than it did in the 1970s (Franco et al. 1997). Urban area increased as predicted, but the area of agricultural lands declined more steeply than predicted (Thomlinson et al. 1996; Ramos 1996; Ramos González 2001). Urban land development in Puerto Rico was clearly associated with a conversion of agricultural lands (del López et al. 2001; Ramos González 2001). I incorrectly predicted the patterns of land cover change because I failed to anticipate the collapse of agricultural activity in the island.

In 1978, the dominant vegetation in Puerto Rico's subtropical moist forest life zone was pasture (Ramos and Lugo 1994). Pasture expansion followed a collapse of sugar cane cultivation. Forest areas increased steadily from about 13 percent in 1948 (half of this forest area was coffee plantations), to about 32 percent in 1990 (Birdsey and Weaver (1982, 1987); Franco et al. 1997). Rudel et al. (2000) found that this rate of reforestation was proportionally higher than anywhere on Earth during the second half of the 20th century. Work in progress shows the following landscape-level trends between 1977 and 1995 for six major land cover types—agriculture and pasture, closed forest, open forest, wetlands, open water, and urban—in northeastern Puerto Rico (Figure 2):

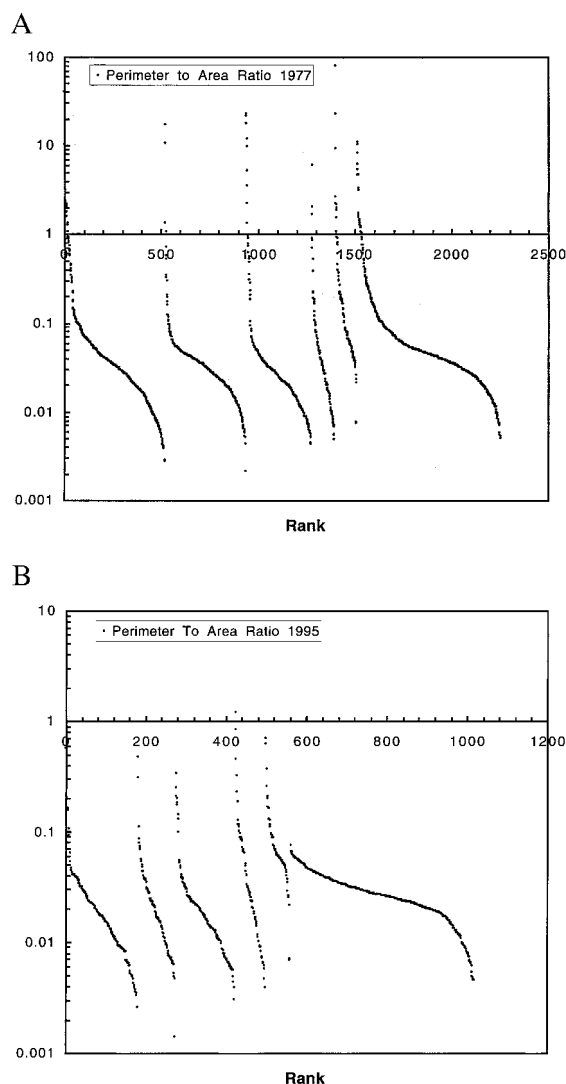


Figure 2. Perimeter to area ratios of fragments of six land cover types in northeastern Puerto Rico in 1977 (a) and 1995 (b). Values are rank ordered from the highest to the lowest ratio for each of the land cover types—from left to right: agriculture and pastures, closed forest, open forest, wetlands (including mangroves), open water, and urban. Data are from land cover maps prepared by L. Velez, T. del M. López, and O. Ramos, USDA Forest Service International Institute of Tropical Forestry. The study area covers 75,000 ha.

1. All land cover types had several fragments with perimeter to area ratios > 1.0 in 1977, but most of these fragments disappeared in 1995.
2. Outlier fragments with very low perimeter to area ratios increased between 1977 and 1995.
3. The distribution of the perimeter to area ratios of fragments changed towards lower values in 1995 in all land cover types, but particularly in the ur-

ban land cover.

4. The total number fragments of land cover types on the landscape decreased between 1977 and 1995. However, the number of urban fragments increased and those of agriculture and pastures decreased.

These results show a reduction in the fragmentation of the landscape because of increased forest and urban cover and a reduction in the cover of agriculture and pastures. The area of land cover fragments reflected the changes in the number of fragments on the landscape (Figure 3). There was a shift towards fragments with higher area in 1995 compared to 1977. The landscape lost fragments with low area, particularly in the urban land cover due to the coalescence of smaller fragments to form larger ones.

Forest patches in protected areas facilitated forest expansion island-wide (Thomlinson et al. 1996; Foster et al. 1999; Lugo et al. 1996; Ramos González 2001). This linkage between remnant forest and more rapid forest recovery occurs over a range of spatial scales from less than one to tens of hectares (Purata 1986; Uhl et al. 1988; Nepstad et al. 1990; Bierregaard et al. 1992; Turner and Corlett 1996) to hundreds of km^2 (Thomlinson et al. 1996; Kramer 1997; Helmer 1999; Foster et al. 1999).

Response of forests

Ecological studies of secondary forests (< 60 yr-old) that developed in abandoned pastures and agricultural lands throughout Puerto Rico found the following.

- Rapid development of basal area, tree density, species richness, and closed canopy (García Montiel and Scatena 1994; Aide et al. (1995, 1996, 2000); Rivera and Aide 1998; Molina Colón 1998).
- Rapid increases of aboveground forest biomass (Aide et al. (1995, 2000); Silver et al. 2000).
- Initial dominance of alien species (Birdsey and Weaver 1982; Molina Colón 1998; Aide et al. (1995, 1996, 2000); Rivera and Aide 1998) followed by a rapid decline of alien species and a dominance of native species (Wadsworth and Birdsey 1985; Molina Colón 1998; Rivera and Aide 1998; Aide et al. 2000).
- New combinations of tree species in mature forest stands (García Montiel and Scatena 1994; Aide et al. (1996, 2000); Molina Colón 1998; Rivera and Aide 1998).

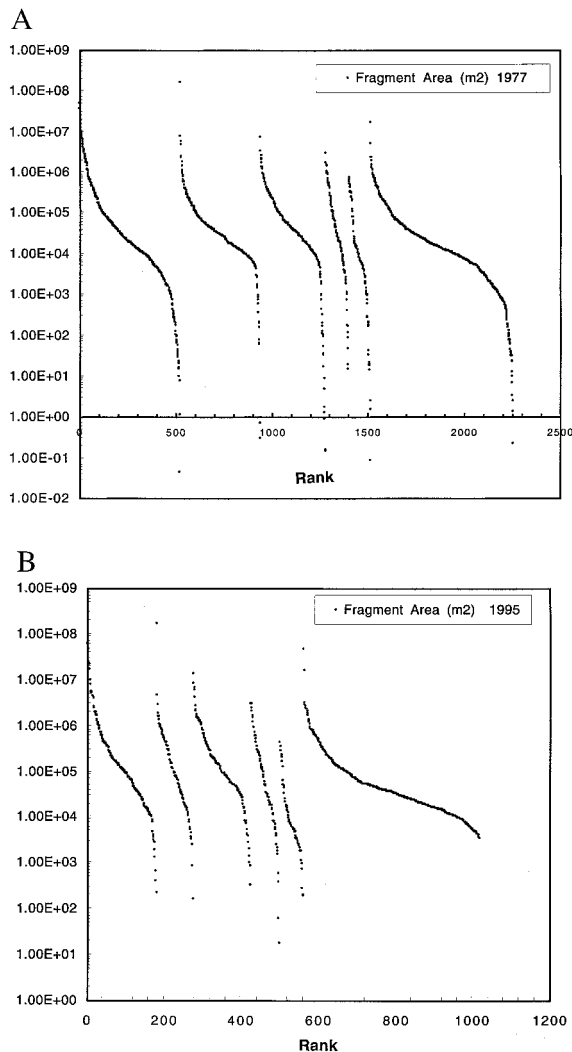


Figure 3. Area of land cover fragments of six land cover types in northeastern Puerto Rico in 1977 (a) and 1995 (b). Values are rank ordered from the highest to the lowest area for each of the land cover types—from left to right: agriculture and pastures, closed forest, open forest, wetlands (including mangroves), open water, and urban. Data are from land cover maps prepared by L. Velez, T. del M. López, and O. Ramos, USDA Forest Service International Institute of Tropical Forestry. The study area covers 75,000 ha.

- Above and belowground carbon sinks (Lugo et al. 1986; Aide et al. (1995, 2000); Silver et al. 2000).
- Low extinction rates of plant and avian species (Lugo 1988a).
- Restoration of high species richness on lands previously used for agriculture (Birdsey and Weaver 1982; Zimmerman et al. 1995; Molina Colón 1998; Aide et al. (1996, 2000)).

- A lower frequency of rare species in recovering patches relative to remnant patches of undisturbed natural stands (J.K. Francis, USDA Forest Service, personal communication).

However, land abandonment does not assure forest recovery. If past land uses such as mining, resulted in severe land degradation, forests might not regenerate and extreme measures are necessary to jump-start forest succession (Parrotta and Turnbull 1997). Research started in Puerto Rico during the 1930s to resolve problems of tree regeneration in severely degraded lands (Wadsworth 1995). More recently, Aide et al. (1995, 1996) found that site degradation slowed the rate of succession in abandoned pastures for about 10 to 15 years in terms of biomass accumulation and tree species establishment. Lugo (1988b) termed these delays in site rehabilitation a “time tax” in recognition that land degradation is costly to reverse and the payment is usually the additional time that natural or subsidized processes require to restore site productivity.

There are unanswered questions regarding the length of time required for certain characteristics of old-growth forests to reappear in recovering secondary forest stands. For example, how long will it take for the re-establishment of rare species or the regeneration of mature forest species? The regeneration of large seeded species appears limited by seed dispersal (Wunderle 1997) and seed predation (Uhl et al. 1988). We also do not know the length of time required for the development of large cavity trees in these forests which are needed for nesting of primary forest animals such as parrots. However, the age of secondary stands in Puerto Rico is only about 60 years and many of the old growth features of forests occur in stands with ages of over 300 years. Nevertheless, the agricultural uses of the Puerto Rican landscape during the first half of this century were such that the time tax for some of the structure and functional characteristics of forests appears to have been short. Stands over 40 years old are difficult to tell apart from mature ones in terms of physiognomy and structure (Aide et al. 1996).

In summary, land cover changes that occurred in Puerto Rico during the second half of the 20th century were associated with the recovery of healthy tropical forests with different species composition from the original. The human legacy on the landscape is not readily lost. Species composition changes induced by humans remain unaltered for many decades even after the passage of several major hurricanes



Figure 4. Picture 1. Deforested landscape in central Puerto Rico circa 1970. Photo by Frank H. Wadsworth.

(Zimmerman et al. 1995; Willig et al. 1996). The human legacy on the landscape impacts species composition and remains present for centuries in the form of naturalized species. Naturalized species comprise about 30 percent of the tree species in Puerto Rico (Liogier 1990). Human legacies also include species extinctions, an irreversible process with cascading effects on whole community structure and dynamics, and losses in old-growth forest characteristics, which require a long time to recover. Clearly, the landscape always reflects the legacy of all its past users. In terms of the basic structure and function of forests, however, the human legacy generally does not appear to last more than half a century after abandonment. Highly degraded lands are the exception and require longer time to recover.

Human population and forest recovery period

Human population density in Caribbean islands has always been high in comparison with tropical continental areas (Lugo et al. 1981). In Puerto Rico for example, human population density increased from 220 /km² in 1912 (Murphy 1916), to 330 /km² in 1970 (DNR 1975) and 455 /km² today. This doubling of population density coincided with a fundamental change in the economic activity of the island from agrarian to manufacturing and services, population migrations to urban centers, and an increase in forest area (Rivera Batiz and Santiago 1996; Lugo (1991, 1996)). During the agrarian era early in the century, the center of population distribution almost coincided with the geographic center of the island (Roberts 1942). Today, most people live near the centers of commerce, industry, and transportation, and the population center has shifted to the coastal zone near the San Juan Metropolitan Area (DNR 1975). The shift



Figure 5. Picture 2. Secondary forests that developed in previously deforested sites in Puerto Rico circa 1980. Photo by Ariel E. Lugo.

in population distribution was a critical element in allowing forest recovery to occur (Rudel et al. 2000).

Environmental surprises

The behavior of complex systems is hard to predict. Our ignorance of this behavior results in surprises, particularly at landscape levels (Holling 1986; Bright 2000). Some significant environmental surprises have been part of the dramatic changes in human activity and land cover in Puerto Rico and elsewhere in the Caribbean over the last century. Some have so far defied explanation, i.e., the bleaching of coral reefs (Peters 1997; Richardson 1998; Bright 1999) and the decline in amphibians even in pristine areas of the islands (Joglar and Burrowes 1996; Stallard 2001). The decline of the parrots (Snyder et al. 1987) and the effort required to sustain the low populations of endangered species is another consequence of the defores-

tation event that took place in the Caribbean. Other events are predictable, such as the consequences of large-scale urbanization of the coastal zone. Nevertheless, Puerto Rico faces serious toxic and solid waste disposal problems and major water pollution (ground and surface waters) island-wide (Hunter and Arbona 1995). Another unforeseen problem is the increased vulnerability of life and property when located in harm's way of disturbance events such as floods, droughts, and landslides. The intensity and frequency of these events can increase with inadequate land uses and poorly designed infrastructure.

Lessons for landscape management

The Puerto Rico case study suggests the following lessons for tropical landscapes:



Figure 6. Picture 3. Urbanization of prime agricultural lands in the coastal zone of Puerto Rico circa 1990. Photo by José Colón.

- The proportion of space occupied by land cover types such as forest, agriculture and urban, is a function of the human economic activity and periodic large-scale natural disturbances such as hurricanes or drought. This appears to be a general principle of landscape ecology (Meyer and Turner 1994).
- Shifts in economic activity can reverse deforestation and fragmentation trends.
- When human uses of the landscape reverse to less pressure on the land, tropical forests quickly respond and can recover a canopy within a few decades.
- A time tax associated with a slower rate of site recovery can occur in highly degraded lands.
- Some legacies of human activity remain embedded on the landscape for a long time, e.g., species composition, but these don't appear to hinder common ecosystem functions.
- Old-growth stand characteristics require > 60 yr. to develop.
- Small forest fragments on the landscape act as catalytic agents of recovery and accelerate the reversal of deforestation and fragmentation.
- Population growth is compatible with forest recovery or reversal of fragmentation.
- Costly environmental surprises are part of the response of complex landscapes to environmental change.

Is Puerto Rico unique?

There are five caveats to the Puerto Rico case study. First, it can be argued that the resilience of Caribbean forests is due to their natural adaptations to frequent disturbances by hurricanes (Scatena and Larsen 1991) and that such resilience is not typical of other tropi-

cal forests. While it is true that Caribbean forests thrive in natural disturbances of all kinds (hurricanes, landslides, droughts, storms, volcanic eruptions, earthquakes, etc., Tomblin (1981)), they are not unique among other tropical forests. Ecologists are increasingly discovering frequent patterns of disturbance regimes in all types of forests, including tropical ones (Sousa 1984; Pickett and White 1985; Foster et al. 1998a). In the Amazon basin for example, drought (Nepstad et al. 1998), fire (Hammond and ter Steege 1998), and windstorms (Nelson et al. 1994; Foster and Terborg 1998) are important natural components of the disturbance regime of those forests.

Second, the island substituted its agricultural economy for an industrial and service economy. While the island was not self sufficient in food production during the 20th century, this substitution reduces its agricultural capacity and makes it unlikely that Puerto Rico will be self-sufficient in the near future. This is an important consideration when assessing the long-term effects of landscape changes and the impacts of increasing population density. Clearly, the sustainability of Puerto Rico's development depends on securing outside sources of food, fossil fuels, and subsidies for all the goods its economy does not produce (Lugo 1996).

Third, the Puerto Rico scenario of landscape change is unlikely to occur on all tropical countries because of reduced access to technology and it might be unrealistic to shift the burden of feeding and subsidizing tropical countries to other countries. However, the value of the case study is that it shows that degradation trends in tropical landscape dynamics are reversible. The lessons learned from this reversal, when applied selectively throughout the tropics, can achieve a balance between deforestation and reforestation and reverse forest fragmentation.

Other tropical locations experienced reversal of deforestation and fragmentation (Finegan 1996). The most notorious one is eastern Amazonia, the *sine qua non* example of tropical forest loss and fragmentation (cf. 1975 and 1985 satellite images in Meyer and Turner (1994)). Recent satellite images of the region show forest regeneration and reduction in fragmentation after human abandonment of previously deforested lands (Moran et al. 1996; Moran and Brondizio 1998; Tucker et al. 1998). The reforestation of lands deforested by the Maya in Central America is another example of long-term natural forest recovery in the tropics (Lamb 1966; Gómez-Pompa and Bainbridge 1995). Everywhere in the world where humans re-

duced pressure on the landscape, forests recovered and there is less fragmentation (Burgess and Sharpe 1981b; Odum and Turner 1990; Foster 1992; Kramer 1997; Staaland et al. 1998).

Clearly, the Puerto Rico example is not unique in the tropics, except for reductions in population density as happened with the demise of the Maya. Forests and high human density are, for now, co-existing in Puerto Rico as they do in New England, where the same process of landscape change and human population change occurred (Foster 1992; Motzkin et al. 1996; Foster et al. (1997, 1998b); Foster and Motzkin 1998; Fuller et al. 1998).

Fourth, the landscape changes that occurred in Puerto Rico are not a result of planning. Forests regenerated spontaneously influenced by the pollination and seed dispersal activity of wind, water, and animal groups such as birds, bats, insects, and ants (Wunderle 1997). Forest recovery occurred as a by-product of political and socioeconomic change and not from a conscientious decision to improve the mix of land uses and land cover of the island. Nevertheless, the fact that socioeconomic and political decisions impacted the landscape so dramatically offers an opportunity for learning and improving the effectiveness of the change process that occurs when a particular sector of the economy reverses direction.

Fifth, there are hidden costs to the "Puerto Rico solution" to reforestation and reduced fragmentation. Unexplained surprises to coral reefs (Peters 1997; Richardson 1998; Bright 1999), amphibians (Joglar and Burrowes 1996), and parrots (Snyder et al. 1987) represent hard-to-quantify environmental costs. Water pollution costs are quantifiable, and so far, the strategy is to allow the natural environment to absorb all human wastes (Hunter and Arbona 1995). Increased damages to life and property due to natural disturbances are costs currently subsidized by federal and state governments. However, as the infrastructure becomes more vulnerable due to poor land uses and global change, the costs of disasters are likely to increase. Finally, the increased dependence of the island on external subsidies to maintain its economy is a long-term cost to the island's sustainability.

Management of tropical landscapes

The Puerto Rico case study provides insights for the management of whole landscapes. It shows that reversing the direction of landscape change is possible.

A large increase in population density did not prevent forest regeneration nor reduced fragmentation. Therefore, deforestation and fragmentation are not unidirectional processes in the tropics. By understanding the forces that cause landscape processes to reverse in direction, we discover tools for managing landscapes.

Tropical forests facilitate landscape management because after perturbation, they are sufficiently resilient to recover much of their structure and function when given an opportunity. However, there is coupling between landscape conservation and economic development. While population increase is not necessarily a dominant factor in the determination of how a landscape is to develop, human activity must be managed both in terms of where it occurs and the nature of the activity so that representative areas in development-prone environments can be conserved. Failure to anticipate all the costs of development, including surprises, lead to short and long-term consequences to the economy and health of the landscape.

The role of zoning

It appears that even under high population densities, there can be sufficient room for most land cover and land uses, including natural areas and open spaces. However, as human pressure increases, the rate of change can accelerate and jeopardize the required balance among competing uses and lead to environmental surprises. Under these circumstances, there is a need for increased regulation.

Zoning is a tool available to development planners for ordering and directing human activity. Zoning districts such as those delimiting urban growth boundaries, may concentrate development in certain areas, but they don't appear to slow development of forests and agricultural lands at regional scales (Kiline and Alig 1999). Puerto Rico has strong zoning laws and zoning agencies which have had mixed records of success in urban zones. Protection of the Caribbean National Forest (CNF) in the rural northeastern sector of the island benefited from these laws.

The CNF, congruent with the Luquillo Experimental Forest (LEF), is a treasured natural reserve in Puerto Rico. To assure its protection, the Planning Board established a buffer zone around the periphery of the forest in 1983 (Lugo et al. 2001). The effectiveness of this special zoning regulation is now under study, but the establishment of a buffer zone is a mechanism to provide smooth transitions between mature natural

areas and the expanding urban zones (Batisse 1996). In contrast, Shafer (1999) views buffers as failures of regional planning. However, in the absence of any planning, buffers have a conservation value. Our preliminary assessments of the changes in the landscape in the periphery of the CNF/LEF shows a ring of expanding urban areas around the periphery of the forest, a tendency that is worrisome (Lugo et al. 2001).

A land cover that requires increased attention is the prime agricultural land type. Their location and suitability to conversion to other uses endanger these lands. In Puerto Rico for example, the percentage of urban land cover changed island-wide from 11.3 in 1977 to 14.4 in 1994 (del López et al. 2001). About 42 percent of that growth was on prime agricultural lands. Their conservation requires strong regulation measures such as zoning. It is in these situations when the long-term interests of society collide with short-term interests of entrepreneurs, where society needs to develop consensus on what is available for development and what is not.

However, more critical than the laws and zoning regulations is the will to enforce them. At high population densities and fast rates of development, the pressure to expand built-up areas is enormous and many times critical and sensitive areas are negatively impacted to the detriment of those that invade them. Examples are built-up areas in flooding zones, fire-prone regions, landslide prone areas, etc. It is possible to reduce risks to human life and property by using knowledge of the spatial distribution of disturbance regimes. Actions derived from this knowledge represent another management strategy with landscape implications. Natural systems or ecologically engineered ones are available options to accomplish this goal (Odum (1962, 1996)).

Focusing human power

The quotes at the beginning of this article express concern with the projection of human power on landscapes, a process that leads to landscape fragmentation and deterioration. The quote suggests that tropical forests are fragile and not sufficiently resilient to recover from conversion. Richards (1990) apprehension is a realistic assessment of current trends among human-dominated landscapes over vast portions of Earth (Barrow 1991; Meyer and Turner 1994). However, there is no *a priori* reason to believe that human use of energy and knowledge will always lead to degradation.

Elsewhere I argued (Lugo (1995, 1998); Lugo and Brown 1996) that properly guided human use of technology, knowledge, and energy reverses damages to the biosphere and moves us towards sustainability, even if that goal is unattainable as long as we depend on fossil fuels (Hall et al. 1986). Such reversal of affairs requires a shift in the conservation and development paradigms that have led to a separation of humans from the rest of the biosphere.

At least two different views of the relation between humans and nature need implementation. One deals with our attitude towards species and the other our views of future scenarios of land use and land cover change. With regards to species, value judgments hinder our capacity to take advantage of nature's powerful force of self-design or self-organization (*sensu* Odum (1988, 1995)). Species are categorized and valued as alien, naturalized, native, or endemic. In this list endemic species are particularly valuable from a genetic point of view and do require maximum protection. The other categories lack a fundamental distinction other than time of arrival to the landscape. "Saving all the parts" (*sensu* Leopold (1993)) remains a sound working principle of biodiversity conservation. However, this principle is consistent with "mixing the parts" in novel ways to accomplish management goals, design new ecosystems, and assure the sustainability of future landscapes. As humans continue to modify landscapes and cause global change, it will become increasingly difficult and costly to maintain a status quo on species composition of ecosystems. In fact, species composition is always changing and we should take advantage of these changes. We can design new interface ecosystems that can substitute much of our gray infrastructure and production systems while reducing establishment and maintenance costs and conserving biodiversity.

Land degradation processes are serious problems requiring serious consideration. However, many interpret any change in landscapes as degradation or as part of a general decline in the quality of ecosystems. However, if landscapes are dynamic systems that respond to changing environmental conditions, perhaps we could use this responsiveness to our advantage. Can design of landscapes satisfy the needs of an increasing world urban population while conserving at the same time the world's biodiversity?

So far, landscape management approaches in the tropics have been limited to the establishment and preservation of natural reserves. The size and shape of preserves and their interconnection by corridors

receives significant scientific attention (Prendergast et al. 1997). The rest of the landscape receives less scientific attention, as if somehow human presence means that the landscape is lost without possibility of conserving it. Paradoxically, Pimentel et al. (1992) found that a large fraction of the world's biodiversity resides in managed landscapes, i.e., agricultural, urban, etc. Humans cannot escape their responsibility for active conservation of biodiversity (Lugo 1998). Conservation activity should focus on all of the landscape: rural and urban. Protecting biodiversity is an imperative of all human activity. The challenge is to somehow re-orient human uses of landscapes to meet human needs while conserving biodiversity in a declining fossil fuel scenario. Odum and Odum (2001) termed this challenge the "prosperous decline."

Pulsed scenarios of the future offer more hope than declining ones but the prevailing paradigm is the declining scenario. Reversing the general conviction of the inevitability of a decline scenario is difficult and counterintuitive with the declining fossil fuels and continued increasing demands from people. However, the inevitable exhaustion of fossil fuels forces us to seek alternative energy sources or else be part of the finale of a boom-bust cycle of human civilization. A prosperous decline requires increased use of natural systems and of ecologically engineered and restored ones to buffer and subsidize human activity. Research on the capability of tropical landscapes and the behavior of complex systems will facilitate future management of landscapes. In addition, the education process will have to incorporate research results and use them to foment public debate. Open public discussion and a consensus on the need for conservation, makes possible building a collective will to direct changes in the landscape, show concern for all lands, and hopefully achieve some measure of sustainability for human activity.

Tropical landscapes can be managed if we take advantage of the flexibility that ecosystem resilience and self-design affords us and if we accept that in order to maintain human activity on Earth we will have to depend on a whole new suite of ecosystems with species compositions different from those of our natural areas. Simultaneously, the application of science to the art of development and regulations requires greater attention (Haber 1990; Ruzicka and Miklos 1990). The situation we find ourselves in was best summarized by Forman and Collinge (1996), p 563: "...science and humankind have crossed a threshold, whereby a spatial solution for conserving biodiversity

in landscapes and regions has emerged. Working out its complete form is an exciting frontier, because this solution will rapidly become central in future land-use planning, conservation, design, management and policy.”

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