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PERSPECTIVE

Beyond Deforestation: Restoring Forests and Ecosystem Services on Degraded Lands

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Despite continued forest conversion and degradation, forest cover is increasing in countries across the globe. New forests are regenerating on former agricultural land, and forest plantations are being established for commercial and restoration purposes. Plantations and restored forests can improve ecosystem services and enhance biodiversity conservation, but will not match the composition and structure of the original forest cover. Approaches to restoring forest ecosystems depend strongly on levels of forest and soil degradation, residual vegetation, and desired restoration outcomes. Opportunities abound to combine ambitious forest restoration and regeneration goals with sustainable rural livelihoods and community participation. New forests will require adaptive management as dynamic, resilient systems that can withstand stresses of climate change, habitat fragmentation, and other anthropogenic effects.

Forest succession is a stochastic process resulting from the behavior of component populations and species. Yet, restoration ecologists tend to view forest communities as tightly integrated biological systems, using metaphors for organismal health and development to describe the state of forests throughout the world. Forests are "declining," exhibit "arrested development," are "infested" with invasive species, and may require active "rehabilitation." Although many principles of restoration ecology derive from insights into successional change, guided reconstruction of forests should be clearly distinguished from the natural processes of forest succession, which are not prescribed or directed by humans and often exhibit divergent and unpredictable pathways (*1*).

Both of these processes—assisted restoration and unassisted forest regeneration—are gaining momentum across the world. As a result, global assessments show a recent decline in the net rate of forest loss from 1990 to 2000 and from 2000 to 2005 (*2*). Although the global deforestation rate remains high, 13 million ha/year, forest cover in 18 countries has begun to increase, owing to both afforestation (tree planting on previously unforested land) and natural regeneration (*2*). Natural forests expanded in Bhutan, Cuba, Gambia, Puerto Rico, St. Vincent, and Vietnam from 1990 to 2005, following earlier forest transitions in six European nations and the USA during the 19th and early 20th centuries (*3*, *4*). These increases, however, do not necessarily reflect increasing biomass or carbon sequestration (*3*). For developing countries, the Food and Agriculture Organization of the United Nations (FAO) requires a minimum of only 10% forest cover for land to be classified as forest (*4*), a criterion that would satisfy few forest-dwelling species. Moreover, forest assessment data provide no insights into the recovery of forest biodiversity or ecosystem services lost because of forest conversion or degradation. In many cases, these figures reflect the widespread establishment of plantations, which currently constitute about 4% of total forest area globally. Rates of planting of forests and trees are increasing by 2.8 million ha/year, for purposes of production, as well as for conservation and restoration (*2*). In China alone, 28 million ha of plantations were established from 2001 to 2007 (*5*). Commercial forest plantations can potentially play a role in landscape restoration and faunal conservation, if they are managed as components of a heterogeneous landscape mosaic (*6*, *7*). Unfortunately, forest cover statistics do not clearly reveal changes in the status of degraded secondary and heavily logged forests, which will not recover on their own (*8*, *9*). As classified by FAO, these forests constitute 60% of forest area globally (*2*).

Wherever actions are taken to promote forest restoration and regeneration, new forests emerging in human-impacted landscapes will not match the original old-growth forests in species composition (*10*). But forest restoration can restore many ecosystem functions and recover many components of the original biodiversity. Approaches to restoring functionality in forest ecosystems depend strongly on the initial state of forest or land degradation and the desired outcome, time frame, and financial constraints (Fig. 1). Restoration approaches should take into account the spatial distribution, abundance, and quality of residual vegetation, a strong indicator of the potential for natural regeneration (*11*). Just as forest ecosystem processes decline in a stepwise fashion with increasing human impacts (*12*), restoration approaches can "elevate" a degraded or completely altered forest ecosystem to a higher level of the restoration staircase (Fig. 1). Reclamation may be the only viable option for restoring some levels of biodiversity and ecosystem services in former coal or bauxite mining operations, where abiotic factors, such as soil removal or toxic substrata, limit establishment and growth of native vegetation (*13*). In areas with degraded soils, rehabilitation through planting of carefully selected exotic or native trees can improve soil fertility and restore productive agricultural use, while offering little enhancement of biodiversity. Where agricultural land use has been less intensive and nearby forest patches and faunal dispersal agents can ensure diverse seed rain, the most rapid and least costly path toward restoring forests is through unhindered natural regeneration (*11*, *14*). After 30 to 40 years, natural regeneration following abandonment of pasture and coffee plantations produced secondary forests in Puerto Rico with biomass, stem density, and species richness similar to the island's mature forests (*15*). Direct seeding and planting seedlings or saplings in regenerating forests can hasten recovery of species composition (*14*, *15*). In sites at intermediate levels of degradation, where soils are intact but diverse seed sources are lacking, reforestation with native species, agroforestry, and assisted natural regeneration can augment biodiversity and ecosystem services, while also providing income for rural livelihoods. Such plantings can be incorporated—along with natural regeneration—into management of buffer zones and biological corridors to enhance landscape connectivity and landscape-level biodiversity (*16*).

In both developed and developing countries, forests are being restored by local communities, as well as through state and national programs. Forest rehabilitation projects in the Philippines, Peru, Indonesia, China, North Vietnam, and the Brazilian Amazon River basin promote community organization and improvement of rural livelihoods (*17*). Local knowledge of tree characteristics, planting of diverse species of ecological and economic importance, and integration of rehabilitation programs with regional development strategies are essential elements of restoration success (*17*). Communities from 12 villages in Phuc Sen in Northwestern Vietnam organized to restore limestone forests degraded in the 1960s

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and 1970s by excessive fuelwood and timber extraction. Through planting indigenous tree species and fostering natural regeneration, forests are being restored, water is again flowing to lowland rice fields, and over 30 species of rare or endemic indigenous mammals are returning to the area (*18*). In the Shinyanga region of Tanzania, large areas of dense acacia and miombo woodland were cleared by 1985, transforming the landscape into semidesert. The HASHI program helped local people from 833 villages to restore 350,000 ha of acacia and miombo woodland through traditional pastoralist practices in only 18 years (*19*).

Experimental research is required to determine the most appropriate path toward restoration. In many cases, passive methods can achieve greater success than intensive interventions and are far less costly (*13*). In the northwest Czech Republic, unassisted succession led to more successful restoration of species richness in mine spoils after 20 to 30 years than in technically reclaimed treatments, where organic amendments stimulated the growth of weeds and inhibited establishment of target species (*13*). Restoration techniques involving plowing and mechanical planting may actually slow regeneration of seasonal deciduous forests in Brazilian Cerrado (*20*). There are few rigorous, replicated studies of the effects of different restoration treatments (including unassisted natural regeneration) that account for previous land use, soils, proximity to seed sources, and age since abandonment (*20*). At what position along a forest degradation gradient does "accelerating succession" through planting trees achieve faster recovery of forest structure and composition compared with unassisted regeneration? This question is challenging to address, as the effects of management will vary with the spatial scale of restoration, as well as with synergistic effects of biotic and abiotic stresses from climate change, invasive species, and altered plant-animal relationships (*10*, *13*).

Large-scale forest restoration presents complex and poorly understood implications for the structure and composition of future forests, landscapes, and fauna. Will widespread plantations of a small number of native species—an increasingly popular form of forest restoration in tropical regions—increase biotic homogenization and decrease genetic diversity of planted species (Fig. 2)? Monoculture tree plantations may also facilitate establishment of invasive species and increase susceptibility to species-specific pathogens (*10*). Interventions to promote rapid carbon sequestration through tree plantations will increase the regional abundance of fast-growing, disturbance-tolerant species, which can impact forest dynamics in mature forest fragments (*21*). Emerging forests provide breeding grounds for invasive exotic species, which can rapidly colonize established forests in protected areas (*10*) (Fig. 2). Population explosions of the white-tailed deer (*Odocoileus virginianus*) in recovering forests of the eastern United States provide a sobering example of synergistic effects of widespread forest expansion, reduced predator populations, and spread of invasive species and human disease agents (*22*).

Effects of different restoration approaches on recovery of ecosystem services are also poorly studied, despite wide recognition of the links between biodiversity, functional traits, and ecosystem services (*23*). Incentives for increasing carbon stocks in vegetation provide a major impetus for a wide range of forest restoration interventions, as well as conservation of existing forests. An aggressive global program of reforestation and natural regeneration could potentially restore forests on 700 million ha over the next 50 years (*24*). Fast-growing, short-lived species with low-density wood are favored by many reforestation projects designed to provide carbon offsets, but long-term carbon sequestration is promoted by growth of long-lived, slow-growing tree species with dense wood and slow turnover of woody tissues. These species increase in abundance and biomass throughout the course of

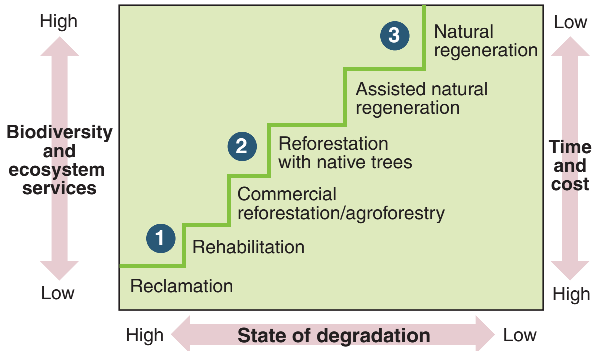

Fig. 1. The restoration staircase. Depending on the state of degradation of an initially forested ecosystem, a range of management approaches can at least partially restore levels of biodiversity and ecosystem services given adequate time (years) and financial investment (capital, infrastructure, and labor). Outcomes of particular restoration approaches are (1) restoration of soil fertility for agricultural or forestry use; (2) production of timber and nontimber forest products; or (3) recovery of biodiversity and ecosystem services.

Fig. 2. A commercial restoration plantation in northeastern Costa Rica. In the foreground are planted individuals of *Acacia mangium*, a fast-growing tree species native to Asia and Australia, which tolerates poor soils. A fast-growing native species, *Vochysia guatemalensis* is also planted here among the *A. mangium* trees. In the background is a fragment of 25-year-old secondary forest. *Euterpe oleracea*, an exotic palm species from Brazil that was cultivated in a nearby plantation has colonized the restoration site (upper right quadrant) and is now invading secondary forests in this area. [Photograph by R. L. Chazdon]

natural forest regeneration (*23*). Short-term solutions are attractive, but forest regeneration and restoration are long-term processes that can take a century or more. Plantations have a high rate of failure if few tree species are planted and they are not well suited to site conditions. Of 98 publicly funded reforested areas in Brazil, only 2 were successful (*25*). It is essential to plan for long-term returns on restoration investments if future forests are to support the wide range of species, species interactions, and ecosystem services present in current forests.

Ambitious efforts are being mounted to restore forests, ecosystem services, and biodiversity throughout the world. The Riparian Forest Restoration Project hopes to reforest 1 million ha of riparian rainforest in the Atlantic Rainforest in São Paulo, Brazil, with up to 800 native species (*25*). Forest restoration efforts, whether at national, regional, or local scales, will take many decades, long-term financing, political will, labor, and personal commitment. In the process, these efforts will also restore new relationships between people and forests. As so clearly stated by William R. Jordan III, a founder of the field of restoration ecology, "Ultimately, the future of a natural ecosystem depends not on protection from humans but on its relationship with the people who inhabit it or share the landscape with it" (*26*).

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PERSPECTIVE

Changing Governance of the World's Forests

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Major features of contemporary forest governance include decentralization of forest management, logging concessions in publicly owned commercially valuable forests, and timber certification, primarily in temperate forests. Although a majority of forests continue to be owned formally by governments, the effectiveness of forest governance is increasingly independent of formal ownership. Growing and competing demands for food, biofuels, timber, and environmental services will pose severe challenges to effective forest governance in the future, especially in conjunction with the direct and indirect impacts of climate change. A greater role for community and market actors in forest governance and deeper attention to the factors that lead to effective governance, beyond ownership patterns, is necessary to address future forest governance challenges.

Central governments own by far the greater proportion—about 86%—of the 5.4 billion hectares of the world's forests and wooded areas. Private and "other" (mostly communal) forms of ownership constitute just over 10% and below 4% of global forests, respectively (*1*). There are important regional variations around these averages [Fig. 1, based on (*1*)]. Official statistics on forest ownership, however, misrepresent the extent of and changes in forest cover (*2*). They also misrepresent the nature and changing forms of global forest governance.

Effective governance is central to improved forest cover and change outcomes. Changing forest governance today is for the most part a move away from centrally administered, top-down regulatory policies that characterized much of the 19th and 20th centuries. Many government-owned forests are managed as common property for multiple uses by local communities and community-based organizations (*3*). Many other forests classified under public ownership are effectively governed as private timber concessions by logging companies (*4*). Civil society organizations and market incentives increasingly play a role in forest governance through certification processes and changing consumer preferences (*5*). At the same time, the growth in the number and size of strict protected areas in the latter half of the 20th century has also meant that ~6.4 million km^2 of publicly owned forests are now under governance regimes that involve greater restrictions on human use and habitation (*6*, *7*) (fig. S1).

In the 21st century, three important forest governance trends stand out: (i) decentralization

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