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Natural regeneration in the context of large-scale forest and landscape restoration in the tropics

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ABSTRACT

Large-scale and long-term restoration efforts are urgently needed to reverse historical global trends of deforestation and forest degradation in the tropics. Restoration of forests within landscapes offers multiple social, economic, and environmental benefits that enhance lives of local people, mitigate effects of climate change, increase food security, and safeguard soil and water resources. Despite rapidly growing knowledge regarding the extent and feasibility of natural regeneration and the environmental and economic benefits of naturally regenerating forests in the tropics, tree planting remains the major focus of restoration programs. Natural regeneration is often ignored as a viable land-use option. Here, we assemble a set of 16 original papers that provide an overview of the ecological, economic, and social dimensions of forest and landscape restoration (FLR), a relatively new approach to forest restoration that aims to regain ecological integrity and enhance human well-being in deforested or degraded forest landscapes. The papers describe how spontaneous (passive) and assisted natural regeneration can contribute to achieving multiple social and ecological benefits. Forest and landscape restoration is centered on the people who live and work in the landscape and whose livelihoods will benefit and diversify through restoration activities inside and outside of farms. Given the scale of degraded forestland and the need to mitigate climate change and meet human development needs in the tropics, harnessing the potential of natural regeneration will play an essential role in achieving the ambitious goals that motivate global restoration initiatives.

Abstract in Portuguese and Spanish are available with online material.

Key words: ecosystem services; forest and landscape restoration; mosaic restoration; spontaneous natural regeneration; sustainable land use; wide-scale restoration.

> The best way of reforesting large areas is to take advantage of the capacity of many forests to recover naturally.
>
> David Lamb (2014, p.68)

ACROSS THE TROPICS, DEFORESTATION FOLLOWED BY POOR LAND-USE PRACTICES have led to the transformation of formerly biodiverse and productive tropical forest ecosystems into degraded lands with low agricultural productivity, reduced supply of ecosystem services, and unsuitable habitats for most native species. Less than half of the world's tropical forests remain standing (Lewis *et al.* 2015), and protection of existing reserves and conservation areas is not sufficient to safeguard biodiversity or to provide the levels of ecosystem services required by growing human populations (Harvey *et al.* 2008, Chazdon *et al.* 2009, Houghton *et al.* 2015, Martínez-Ramos *et al.* 2016a). Restoring forest cover and functionality in areas where tropical forests have been lost or degraded is, therefore, a pressing need at a massive scale. More than 1 billion hectares of degraded forest and woodlands in the tropics provide opportunities for various forms of restoration (Laestadius *et al.* 2012).

Restoring forests and landscapes at large scales must provide multiple social and ecological benefits. Forest restoration can provide benefits for millions of people that depend on tropical forests and their surrounding landscapes for their livelihoods, cultural traditions, and well-being. Forest restoration also plays a critically important role in mitigating global carbon emissions, safeguarding the quantity and quality of water supplies, and preventing soil erosion and flooding (Rey Benayas *et al.* 2009, Hall *et al.* 2011, Locatelli *et al.* 2015, Chazdon *et al.* 2016). Many species that are currently restricted to small areas of intact forest will benefit from expanding forest cover and greater availability of resources in regenerating and restored forests.

This Special Issue is devoted to understanding how natural regeneration of tropical forests and trees can contribute to large-scale efforts to restore forests within landscapes and to increase tree cover on farms. Despite rapidly growing knowledge regarding the extent and feasibility of natural regeneration and the environmental and economic benefits of naturally regenerating forests in the tropics, tree planting remains the major focus of restoration programs (Chazdon 2014). Natural regeneration is often ignored as a viable land-use option. A deeper understanding of the societal and ecological challenges facing natural regeneration across the tropics can provide a basis for more cost-

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effective restoration planning and landscape management projects that aim to achieve a wide range of long-lasting social and environmental benefits. In addition, more costly establishment of tree plantations can be targeted within those areas where natural regeneration capacity is low and where economic benefits derived from timber and non-timber products from plantations meet the needs of local stakeholders.

The need to elevate the role of natural regeneration in large-scale forest and landscape restoration was the focus of an international workshop held at the Botanical Garden in Rio de Janeiro, Brazil, from 19 to 21 November, 2014 (conference proceedings can be accessed at http://www.fao.org/documents/card/en/c/0a10acbd-3db4-4646-8a33-c4486c40de38/). The International Institute for Sustainability (IIS), International Union for Conservation of Nature (IUCN), World Resources Institute (WRI), and PARTNERS (People and Reforestation in the Tropics Research Coordination Network) organized this workshop, whose participants signed the Rio Call to Promote Natural Regeneration in Forest and Landscape Restoration and pledged to form a global natural regeneration partnership to take action (Appendices S1–S3). A further outcome of the workshop was the plan to develop this Special Issue to provide foundational literature to synthesize ecological and social research and case studies on the role that natural regeneration can and should play in large-scale restoration initiatives in the tropics.

The issue is highly pertinent, as the momentum for large-scale restoration is building rapidly, but not rapidly enough to counter the growing areas that need it. The Bonn Challenge (2011), Hyderabad Call (2012), and New York Declaration (2014) articulate a proposed goal of 350 million hectares under restoration by 2030. These goals support Aichi Target 15 of the United Nations Convention on Biological Diversity, which states that "by 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks have been enhanced, through conservation and restoration, including restoration of at least 15 percent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification" (CBD 2010). They also align with the 2030 Agenda for Sustainable Development adopted by the United Nations General Assembly in September 2015, which includes a set of 17 Sustainable Development Goals (SDGs) to end poverty, fight inequality and injustice, sustainably manage natural ecosystems, and reduce risks of climate change. But aspirations and commitments are not going to do the work of restoring forests. It is time for serious action.

HOW TO RESTORE AND AT WHAT SCALE?

The leading question now is not "Should we restore forests and landscapes," but "how can we bring about restoration that is feasible, affordable, and that provides multiple benefits to society?" The scale of the need goes far beyond what can be achieved solely through the practice of ecological restoration. Ecological restoration assists the recovery of an ecosystem that has been damaged or destroyed (SER 2004). The goal of local restoration is to achieve a self-sustaining, spatially delimited ecosystem that is on a trajectory toward recovering the ecological properties and species composition of the pre-disturbance, or "reference" ecosystem.

In contrast to the limited spatial focus of ecosystem-based restoration, global restoration initiatives tend to advocate a landscape approach, incorporating large spatial extents with multiple ecosystem types and multiple forms of land-use types, ownership and governance, often in landscape mosaics where production and conservation are balanced with areas of different types of forests (Fig. 1). Ecological restoration is, therefore, one component embedded within a landscape approach. A landscape-scale approach includes natural ecosystems (often of different types), cultivated areas with crops and agroforests, and passively and actively restored areas enveloping farms, communities, villages, and urban areas. At the landscape level, the goal of forest and landscape restoration is to regain ecological functionality and enhance human well-being across degraded landscapes (Maginnis & Jackson 2005, Lamb 2014, Adams *et al.* 2016, Latawiec *et al.* 2016). These efforts include increasing and diversifying tree cover on farms that are actively being used for crops or grazing, as with farmer-managed natural regeneration (Lazos *et al.* 2016, Reij & Garrity 2016). Therefore, there is no "reference" landscape; it is what we make of it.

A key feature of Forest Landscape Restoration (FLR) is that a combination of forest and non-forest ecosystems, extractive land uses, and restoration approaches can be accommodated within a landscape to balance sustainable food production, ecosystem service provisioning, and biodiversity conservation (Chazdon *et al.* 2015, Strassburg *et al.* 2016). Conservation, restoration, and sustainable extractive land use must all contribute to long-term and beneficial social and ecological outcomes. Achieving a balance of different ecosystem services minimizes conflicts and tradeoffs at the landscape scale (Mukul *et al.* 2016), but is

FIGURE 1. A mosaic landscape in the buffer zone of Pico Bonito National Park in Honduras. Productive land uses are mixed with patches of native vegetation and remnant forest fragments (Photo by Robin Chazdon).

dependent on stakeholder participation and active engagement in planning restoration interventions (Adams *et al.* 2016, Lazos *et al.* 2016). Landscape-scale restoration has become a point of convergence between forestry, agroforestry, agriculture, conservation, and landscape ecology; however, issues of governance and integrated landscape planning continue to pose major challenges (Sayer *et al.* 2013, Guariguata & Brancalion 2014, Reed *et al.* 2016, Reij & Garrity 2016).

RESTORATION APPROACHES

Restoration approaches can be viewed along an intervention spectrum from spontaneous natural regeneration (passive restoration) on one end to soil preparation and tree planting (active restoration) on the other end (Holl & Aide 2011). Assisted natural regeneration (ANR) is a common practice with intermediate levels of intervention and direct cost. As described by Shono *et al.* (2007), assisted natural regeneration methods are designed to accelerate succession by augmenting natural recruitment or removing or reducing barriers to spontaneous forest regeneration. These methods can include weeding, protection from fire or grazing, enhancing natural seed dispersal, and enrichment planting with desirable tree species. Enrichment planting is particularly useful in areas with patchy or low levels of naturally regenerating tree seedlings and is also referred to as "mixed restoration" (Fig. 2; Brancalion *et al.* 2016). Farmer-managed natural regeneration (FMNR) is another mode of assisted natural regeneration in drylands that returns tree cover on cultivated or grazed farmland without tree planting (Weston *et al.* 2015, Reij & Garrity 2016).

Within the context of FLR, restoration approaches depend strongly on the scale of activity, the severity and extent of former land use, proximity of remnant forests, and local human population density. Restoration approaches also depend on who owns the land in question and who depends on it for sustenance (Chazdon *et al.* 2015). *Wide-scale restoration* opportunities involve areas with less intensive land use where a single type of intervention is applied (IUCN and WRI 2014). These areas typically have a population density below 10/km^2, and they account for 21 percent of restoration opportunities worldwide (Laestadius *et al.* 2012). Approaches suitable for wide-scale restoration include mixed-species plantations or assisted or spontaneous natural regeneration. In areas with higher population density (10–100/km^2) and more intensive land use, *mosaic restoration* opportunities encompass larger areas and utilize a combination of interventions that are spatially mixed with agricultural land uses within the landscape matrix (Fig. 1). Mosaic restoration opportunities are widespread and comprise 80 percent of the opportunities within tropical regions. These interventions can include agroforestry, increasing tree cover on farms through planting or assisted natural regeneration, small woodlots, ecological restoration plantations, protection forests on steep slopes and riverbanks, or assisted natural regeneration in patches, corridors, or buffer zones.

Under favorable conditions, harnessing the natural regeneration potential of the site to begin the restoration process greatly reduces costs and can, therefore, permit larger areas to be restored (Chazdon & Guariguata 2016). Within human-modified landscapes, "passive" or "spontaneous" restoration does not occur within a vacuum of human agency. Ultimately, land-use decisions by landowners or farmers determine whether spontaneous natural regeneration initiates or persists within a landscape. In the context of planning and prioritizing forest and landscape restoration, natural regeneration is a potential intervention that permits the self-organizing process of species colonization to initiate forest restoration and create successional trajectories. Beyond the establishment phase, long-term management of naturally regenerated areas is needed to protect them from fire, grazing animals, and overharvesting of timber and non-timber products. As noted by Zahawi *et al.* (2014), passive restoration is not without costs.

FIGURE 2. Assisted natural regeneration involving killing grass with herbicide and planting nursery-grown seedlings in an area with low density of native trees in a forest and landscape restoration project at Pontal de Paranapanema, São Paulo, Brazil (Photo by Robin Chazdon).

THE ECONOMIC COSTS AND BENEFITS OF RESTORATION

The costs of restoring forests and landscape functionality vary widely and depend on many factors intrinsic and extrinsic to the landscape. Decisions regarding the type and spatial extent of restoration approaches strongly affect these costs and depend on the extent of degradation of the land and its potential for natural regeneration (Lamb 2007, Chazdon 2008, Holl & Aide 2011, Bechara *et al.* 2016). Active interventions including site preparation, weed control, planting, and active maintenance of tree seedlings are the most costly; direct per-hectare costs for full planting schemes can range from US$ 1,400 to 6,600 (Instituto Escolhas 2016, Nawir *et al.* 2016). Direct seeding and planting tree islands are less costly active interventions. The goal of active restoration is to plant trees or seeds to initiate the first stages of tree establishment, to stimulate a trajectory of natural regeneration that would otherwise not be able to colonize or establish spontaneously. In some cases, small groups of planted trees (nuclei) can be as effective but less costly than extensive plantations in stimulating natural regeneration (Cole *et al.* 2010, Bechara *et al.* 2016). Commercial tree plantations that are maintained free of natural regeneration in the understory are forms of reforestation, but do not satisfy the definition of ecosystem restoration. Nevertheless, these types of plantations can be a component of FLR within a mixed-use landscape mosaic.

Direct costs and opportunity costs are not the only economic issue affecting restoration decisions. Benefits can also be quantified and assessed in monetary and other terms (Verdone 2015, Reij & Garrity 2016). Based on the rates of biomass growth and market prices for timber, crops, and carbon, researchers calculated that each hectare of restored forest in Ghana would produce between US$ 2,250 and US$ 13,000 per hectare in direct economic benefits to the local and national economies over a 20-yr period (Verdone 2014). In drylands of Latin America, natural regeneration of abandoned pastures yielded between US$ 62 and US$ 7,440 per hectare over 20 years through the sale of carbon, non-timber forest products, timber, and tourism (Birch *et al.* 2010). In the state of Queensland, Australia, economic returns from carbon farming using assisted natural regeneration in pastures were similar to returns from agricultural land use even with low and moderate carbon prices, and carbon farming was more cost-effective than with plantations (Evans *et al.* 2015). Considering returns from timber and non-timber products from restored forests, the Bonn Challenge of restoring 150 million hectares of degraded and deforested land could generate net material benefits of approximately US$ 80 billion annually (Verdone 2014). Aside from direct economic returns from restored forests, active restoration creates a supply chain that supports jobs, professional consultancies, seed collectors (Urzedo *et al.* 2016), and a nursery industry focused on propagating seedlings native tree species (Brancalion *et al.* 2013, Gregorio *et al.* 2016, Fig. 3). The Atlantic Forest Restoration Pact of Brazil calculated that restoration of 12 million hectares of forest across the country would generate between 112,280 and 190,696 jobs, depending on the percentage of area restored through planting versus natural regeneration (MMA 2013). Diverse types of "reforests" within landscapes and regions also provide for a variety of income streams that can increase resilience to market and climate shocks.

FIGURE 3. Boxes, each with a mixture of 50 native tree species, await transport to restoration sites at Câmara Nursery in São Paulo State, Brazil (Photo by Robin Chazdon).

OVERVIEW OF THE SPECIAL ISSUE

Here, we assemble a set of 16 original papers that provide an overview of the ecological, economic, and social dimensions of FLR and describe how spontaneous, assisted, and farmer-managed natural regeneration can contribute to achieving multiple sustainable benefits. Forest and landscape restoration is centered on the people who live and work in the landscape and whose livelihoods will benefit and diversify through restoration activities. It is as much, if not more, about the socioeconomic benefits as the environmental benefits. Given the scale of degraded forestland, it is likely that harnessing the potential of natural regeneration may be the only way to achieve the ambitious goals that motivate global restoration initiatives. Understanding the local and landscape factors that influence the capacity for natural regeneration in different geographic and societal contexts is, therefore, a fundamental line of socio-ecological research. Researchers are also beginning to conduct comparative studies of the outcomes of natural regeneration compared to planted forests and agroforests for provision of ecosystem services, livelihood enhancement, and conservation of biodiversity (Adams *et al.* 2016, De Souza *et al.* 2016, Elliott 2016, Gilman *et al.* 2016).

In Section 1, two papers share broad perspectives on the prospects and challenges for natural regeneration as a tool for large-scale FLR. Chazdon and Guariguata (2016) discuss the features and advantages of natural regeneration as the most cost-effective approach to large-scale FLR and focus on the key ecological, economic, social, and legal conditions that favor natural regeneration in landscapes. They examine case studies of large-scale natural regeneration and suggest ways to enable natural regeneration to become a more effective tool for implementing large-scale FLR. Adams *et al.* (2016) review the effects of large-scale restoration on local livelihoods and find mixed socioeconomic effects on local livelihoods depending on other variables, such as availability of off-farm jobs, household characteristics, land productivity, land tenure, and markets for forest products and ecosystem services. The study underscores that the sustainability of FLR will depend on the adoption of flexible rules and incentives to implement and sustain reforestation.

Section 2 focuses on ecological aspects of natural regeneration in different geographical contexts and includes an overview of geographic variation of future climates on successional trajectories and FLR outcomes. Martínez-Ramos *et al.* (2016b) present a framework for assessing local and landscape effects on natural regeneration potential and on demography of pioneer trees in wet lowland regions of Chiapas, México. They also demonstrate that a simple landscape metric based on land use can be used to predict attributes of secondary forest regeneration across a landscape. Lu *et al.* (2016) examine biotic and abiotic factors that influence the abundance and diversity of seedling regeneration in shifting cultivation fallows in tropical lowland forest of Hainan Island, China. The importance of different factors varied during forest succession; soil water content and landscape factors have the greatest impacts on seedling regeneration during early stages of regrowth, whereas light availability and soil nutrients were more important factors in older forests. In East Africa, Omeja *et al.* (2016) consider the effects of regenerating forests on mammal populations in Kibale National Park, Uganda. Their study highlights the recovery of trees and mammals during the past 20 years and emphasizes the importance of natural regeneration for restoring tree and mammal diversity in this important conservation area. In the final paper of this section, Uriarte *et al.* (2016) review the literature on effects of climate change, including changing disturbance regimes, on tree demography during natural regeneration, an important issue for predicting successional trajectories and FLR outcomes under future climates. Their review highlights the importance of regional context in predicting successional trajectories and FLR outcomes under future climates and identifies major research gaps in our understanding of how second-growth tropical forests will respond to future climates.

Section 3 focuses on linkages between natural regeneration and landscape restoration in practice. Gilman *et al.* (2016) report on an experimental study in Costa Rica that compares the first 5 years of post-pasture forest regrowth in replicated plots with tree plantings (four levels of species richness) and without tree plantings (natural regeneration only). After 5 years of monitoring, they found convergence of restoration trajectories and similarity of floristic community diversity and composition across all treatments, demonstrating the viability of natural regeneration for rapid restoration of forest biodiversity in this region. Catterall (2016) synthesizes information regarding the role of non-native species in natural regeneration. Her global literature review shows that both native and non-native species can facilitate or inhibit natural regeneration and that species' functional roles are more important to regeneration trajectories than their biogeographic origins. A case study from eastern Australia illustrates some details of these processes, and in particular how invasive non-native trees can potentially facilitate post-pastoral regeneration of rain forest diversity. Elliott (2016) concludes this section with a look at how aspects of natural regeneration and assisted natural regeneration can be automated using new drone-based technology. Low-cost UAVs (drones) and new imaging devices can perform tasks used in assisted natural regeneration, including site monitoring, maintenance of natural regeneration, and species enrichment through aerial seeding.

Section 4 features three papers that focus on the integration of large-scale natural regeneration with farms, agricultural production, and regional planning. Latawiec *et al.* (2016) address how different ecological, biophysical and socioeconomic factors correlate with the success of natural regeneration based on a meta-analysis of forest restoration studies in the tropics. They also use a case study of large-scale natural regeneration in the Brazilian Atlantic Forest to identify areas where active and passive restoration approaches should be implemented. Across the Atlantic Ocean in a dryland setting, Reij and Garrity (2016) describe the practice and widespread adoption of farmer-managed natural regeneration (FMNR) in sub-Saharan Africa and illustrate how assisted natural regeneration is improving livelihoods, lives, and landscapes in dryland ecosystems. Brancalion *et al.* (2016) examine 42 restoration programs in three biomes of Brazil and describe the extent to which natural regeneration is being applied in these programs, based on the first 5 years of implementation of restoration plans. Their study reinforces the importance of legal frameworks that require an evaluation of the potential for natural regeneration over a period of up to 4 years prior to making recommendations regarding the best practices for restoration in mandated areas.

Section 5 features four papers that focus on the linkage between natural regeneration, livelihoods, and ecosystem services. Mukul *et al.* (2016) assess the co-benefits of fallow regeneration in shifting cultivation systems in the Philippines for biodiversity and carbon storage. Strassburg *et al.* (2016) investigate the benefits of natural regeneration for climate change mitigation, sediment retention, and biodiversity conservation in a spatially explicit way at very high resolution for a region within the Atlantic Forest of Southeastern Brazil. De Souza *et al.* (2016) describe the ecological outcomes and livelihood benefits of managed agroforests and second-growth forests in Southeastern Brazil. Agroforests and managed second-growth forests showed remarkable potential to contribute to the overall goals of FLR programs, by re-establishing forest structure, with evident benefits for carbon sequestration, soil protection, water infiltration, and habitat provision for wildlife, while hosting a rich array of native species, including many threatened, complementing biodiversity conservation in adjacent protected areas and serving as buffer zones and improving local livelihoods by supplying market valuable and culturally important plants. Lazos *et al.* (2016) summarize lessons from recent literature on stakeholder involvement within reforestation efforts and present findings from a multiple-stakeholder workshop organized in west-central Mexico, where local stakeholders express their choices on how to navigate trade-offs among different reforestation intervention strategies (agroforestry/silvopastoral, natural regeneration, native species reforestation, commercial plantations). The paper highlights the need for an adaptive strategy to stakeholder engagement through continuous evaluation of FLR outcomes. Uriarte and Chazdon (2016) conclude the special issue with a summary of the main findings and present the framework of a research agenda to support the more widespread adoption of natural regeneration in forest landscape restoration in the tropics.

MOVING FORWARD

We hope that this special issue has a catalytic effect on the science, practice, and evolving culture of FLR across the tropics. The extensive reviews compiled here indicate major gaps in our knowledge and provide clear directions for new lines of research within and across traditional disciplines (Uriarte & Chazdon 2016). At the same time, there is an urgent need for researchers to work alongside policy makers, non-government organizations, and multiple stakeholders to incorporate natural regeneration along with other forms of restoration into national restoration policy, implementation, and institution building at different governmental levels. In moving forward with the global restoration agenda, it is important to promote conservation practices and sustainable agricultural land uses that provide economic benefits for smallholders, while fostering the potential for natural regeneration of forests within production landscapes. These practices provide hope for the conservation of native biodiversity and the production of multiple ecosystem functions and services that benefit all of society. The integration of productive land uses with different forms of forest restoration at the landscape scale remains a major challenge, which may require reconstructing the institutional base of agriculture, environment, and forestry sectors within national and regional governments to align land-use policies in ways that promote adaptation and mitigation of climate change and address the needs of a still-growing human population. Coalition building, collaborative actions, effective communication, adaptive management, and long-term thinking are key steps to rebuilding landscapes in ways that will bring multiple benefits for society, biodiversity, and the environment for many years to come.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article:

APPENDIX S1. Rio Call to Promote Natural Regeneration in Forest and Landscape Restoration.

APPENDIX S2. Acordo do Rio para Promover a Regeneração Natural na Restauração de Florestas e Paisagens.

APPENDIX S3. Acuerdo de Río para Promover la Regeneración Natural en la Restauración de Bosques y Territorios.

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