



Editorial: Enhancing Natural Regeneration to Restore Landscapes

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Editorial on the Research Topic

Enhancing Natural Regeneration to Restore Landscapes

Entering the UN decade of restoration, the time to bring commitments to action is now (UN, 2019). Evidence supports the potential for natural regeneration as a low-cost and effective strategy to restore ecosystems and their services (Chazdon and Guariguata, 2016; Crouzeilles et al., 2017). Natural regeneration ranges from unassisted to actively managed assisted natural regeneration. Unassisted, or passive, natural regeneration implies protection from degradation to allow regeneration to unfold by the ecological process of secondary succession (Letcher and Chazdon, 2009; Zahawi et al., 2014). Assisted natural regeneration implies managing regeneration and accelerate restoration toward specified restoration targets (Hardwick et al., 1997; Shono et al., 2007). Restoration targets may vary from fully functional forest ecosystems to productive agroforest systems. While unassisted natural regeneration has been well-studied, the practices and outcomes of assisted natural regeneration are less known. A range of management practices that enhance natural regeneration are known, but understanding of their success in different contexts is currently lagging, limiting the upscaling of natural regeneration as a restoration practice.

With this Research Topic we aimed to advance our understanding of how natural regeneration can effectively contribute to achieve restoration goals by compiling evidence on (1) processes that drive natural regeneration at the regional scale, and their consequences for spatially prioritizing natural regeneration as a restoration strategy, (2) successional processes driving recovery, (3) how management can enhance natural regeneration to achieve restoration targets, and (4) how external factors shape the restoration potential of natural regeneration.

OCCURRENCE AND PERSISTENCE OF NATURAL REGENERATION

Allowing fields to regenerate is a decision taken by land managers, and is influenced by proximate and ultimate forces that lead to patterns of occurrence and persistence. Understanding where natural regeneration happens and how long it persists is crucial for spatial planning and for predicting and optimizing the benefits of restoration. Schwartz et al. and Espírito Santo et al. use remote sensing approaches to evaluate spatial patterns of land use and land cover changes related to natural regeneration. Schwartz et al. employed a time-series analysis (2001–2014) to identify the occurrence and persistence of naturally regenerated forests across Latin America. They found that

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naturally regenerating forests were 10 times more likely to be cut than to persist, representing a 76% loss in the carbon sequestration potential of restoration, and highlight the need for policies that support farmers in conserving natural regeneration. In a dry-forest region in Brazil, Espírito Santo et al. analyzed forest cover changes from 2007 to 2016 and found that natural regeneration mainly happened in pastures and was more likely in flat regions and in arid climates. Their results suggest a higher potential of natural regeneration in less productive areas, and highlight the importance of developing policies that promote sustainable cattle farming in dry-forest regions.

HISTORICAL LAND USE AND SUCCESSIONAL PROCESSES

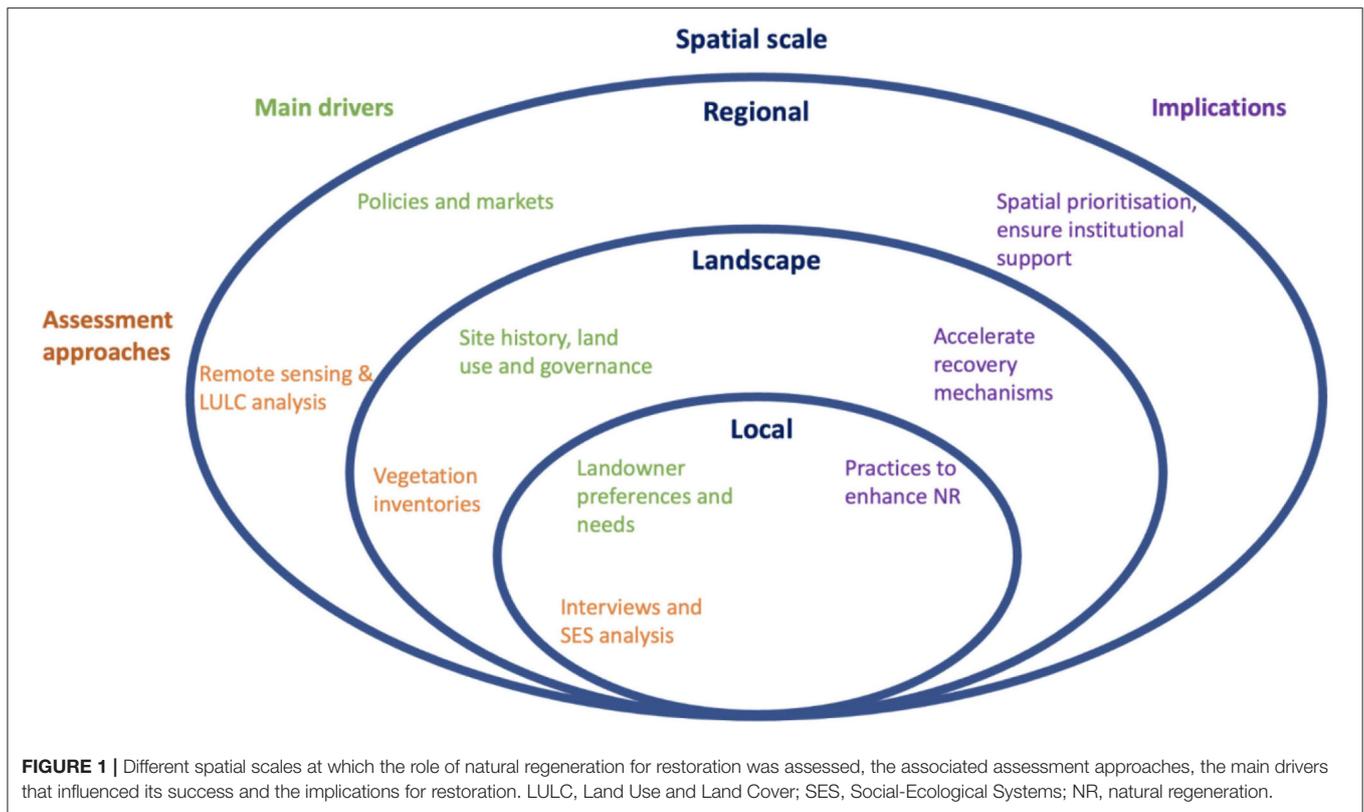
Natural regeneration, or secondary succession, is the gradual build-up of vegetation through biomass accumulation and species turnover over time (Chazdon, 2014). The potential for natural regeneration and the speed of succession depends on the landscape context, previous land-use history and management practices (Jakovac et al., 2021). Having a basic understanding of successional processes helps to identify possible barriers to restoration and how to alleviate those. Siminski et al. highlight the potential of natural regeneration after low-intensity swidden agriculture in the Brazilian Atlantic forest, where species richness increases rapidly during succession. This potential, however may be hampered by degradation, as found by Sanchez-Tapia et al. They show that increased frequency of fire in pasturelands slows down natural regeneration in the Brazilian Atlantic forest and induces dominance of fire-resistant species causing long-term impoverishment of diversity. Preventing fire is therefore recommended to enhance natural regeneration. Natural regeneration may also be impeded by soil disturbance, as was the case on degraded gold mines in Peru (Chambi-Legoas et al.). They found that 19 years after mine abandonment, the regenerating forest still had very different species composition and lower species richness than the undisturbed forest, although the stem density and biomass had recovered more quickly. Structural characteristics usually recover faster than biodiversity because ecological filters limit the ability of certain species to colonize, grow and survive in degraded conditions. Ishaq et al. show how a specific N₂-fixing species (*Parasponia rigida*) is essential for kick-starting natural regeneration after volcanic eruptions in Indonesia. Identifying such species and their traits will help define management practices for favoring or planting target species to enhance natural regeneration. Müller et al. show species composition and functional traits of canopy trees exert a strong influence on what regenerates in the understory of secondary forests. This emphasizes the importance of early successional communities in enhancing or inhibiting natural regeneration and suggests management of early communities could help accelerate restoration. Together, these findings illustrate that enhancing natural regeneration requires time, eliminating inhibiting factors, and favoring conditions and species that accelerate natural regeneration.

LOCAL PRACTICES AND MANAGEMENT TO ENHANCE NATURAL REGENERATION

Enrichment planting is one way to modify successional processes to achieve restoration targets. Palma et al. undertook transplant and sowing experiments of several species in the understorey of secondary forests of different ages in tropical Australia. They found that planted seedlings performed better than exposed or buried seeds, and that all buried seeds germinated. This indicates that in this system, recovery is more limited by seed availability than by seedling establishment conditions, and that enrichment planting is a suitable strategy to enhance natural regeneration. Selecting species and defining adequate management practices can be supported by traditional knowledge of local communities. Schmidt et al. found that enrichment planting was used to enhance restoration in shifting cultivation systems by indigenous communities in the Brazilian Amazon. In Africa, traditional knowledge is also applied in the practice of Farmer Managed Natural Regeneration (FMNR), which is widely promoted as a restoration success. FMNR entails that farmers select and promote naturally regenerated seedlings on active agricultural fields. Chomba et al. carried out a review to compile evidence on FMNR contributing to land restoration and identified a number of knowledge gaps. The authors recommend combining functional ecology and socio-economic assessments to promote a mechanistic understanding of the drivers of the species composition of FMNR and its consequences for ecosystem functions and livelihood benefits. In Tanzania, where FMNR is promoted as a restoration strategy, Moore et al. found that species selection and management practices are driven by farmers' autonomous decisions. This suggests a strong context-dependent effect of FMNR on restoration targets, making it hard to predict and evaluate restoration success across regions but potentially ensuring farmer empowerment.

EXTERNAL INFLUENCES ON THE SUCCESS OF NATURAL REGENERATION FOR RESTORATION

Several authors pointed to the importance of the institutional context for the success of restoration strategies. Chomba et al. highlighted the importance of land and tree tenure policies, landscape governance, and the involvement of external agencies for the promotion of FMNR. Bosshard et al. reviewed market incentives that promote Forest Landscape Restoration and identified that these mostly focus on tree planting and only a few recognized natural regeneration as a restoration intervention. This is probably because the implementation and benefits of tree planting are easier to assess and communicate than those from natural regeneration. These studies highlight the role of institutions and the need for markets and policies to support natural regeneration as a restoration strategy.



CONCLUSIONS AND RECOMMENDATIONS

In this Research Topic we compiled studies from across the pantropics and found diverse evidence of natural regeneration contributing to restoration targets like climate mitigation, biodiversity conservation, soil fertility, agricultural production and livelihood benefits (Chomba et al., Schwartz et al., Siminski et al.). The potential of natural regeneration is large because it builds on ecological memory and traditional practices (Chomba et al., Schmidt et al.) and has the ability to empower land-owners (Moore et al.). The realized potential of natural regeneration, however, depends on a number of factors that cut across different spatial scales (**Figure 1**). At a regional scale, geopolitical and institutional contexts shape where natural regeneration occurs, how long it persists, and who can derive what benefits from it (Chomba et al., Espírito-Santo et al., Schwartz et al., Bosshard et al.). We recommend that market-based incentives for restoration incorporate natural regeneration in their programmes (Bosshard et al.) and that governments ensure landowners have access to benefits derived from restoration efforts (Chomba et al.) in order to guarantee the persistence of natural regeneration in the long-term (Schwartz et al., Espírito-Santo et al.).

At the landscape scale, successional processes govern the speed of restoration vary amongst forest types (Siminski et al.) and are influenced by previous land-use, disturbance history (Ishaq et al., Sánchez-Tapia et al., Chambi-Legoas et al.) and

functional characteristics of species and their interactions (Müller et al.). We recommend that an assessment of the landscape's regeneration potential is conducted in order to define adequate management practices to enhance the success of achieving restoration goals (cf. Lohbeck et al., 2020).

At the local scale, the potential of natural regeneration can be enhanced by land and tree-management practices, which include enrichment planting and favoring of selected naturally regenerating tree species (Chomba et al., Moore et al., Palma et al., Schmidt et al.). Building a portfolio of management practices in different contexts and for different restoration outcomes will facilitate its upscaling. Although knowledge gaps remain on how to enhance natural regeneration for restoration in a given context, we feel that natural regeneration provides an opportunity to learn and adapt practices based on science-based indicators that match pre-defined restoration goals. Natural regeneration includes a range of restoration techniques, should be embraced in its diversity and adapted to local contexts.

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