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EDITED AND REVIEWED BY
Manfred J. Lexer,
University of Natural Resources and Life Sciences Vienna, Austria

*CORRESPONDENCE
Bonnie G. Waring
b.waring@imperial.ac.uk

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Editorial: To plant, rewild, or ignore? Linking forest restoration methods to long-term ecological trajectories and ecosystem services

Sarah J. Wilson[1], Bonnie G. Waring[2]*, Matthew Fagan[3], Meredith Root-Bernstein[4] and Leland K. Werden[5]

[1]School of Environmental Studies, University of Victoria, Victoria, BC, Canada, [2]Grantham Institute on Climate Change and the Environment, Imperial College London, London, United Kingdom, [3]Department of Geography and Environmental Systems, University of Maryland, Baltimore County, Baltimore, MD, United States, [4]UMR CESCO, CNRS, Muséum National d'Histoire Naturelle, Paris, France, [5]Department of Environmental Systems Science, ETH Zürich, Zurich, Switzerland

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Editorial on the Research Topic
To plant, rewild, or ignore? Linking forest restoration methods to long-term ecological trajectories and ecosystem services

A recent surge of interest in natural climate solutions has spurred multinational commitments to reforestation across the globe (Seddon, 2022). Large scale forest restoration is invoked as a solution to many pressing environmental problems, including climate change (Bastin et al., 2019; Waring et al., 2020) and biodiversity loss (Aerts and Honnay, 2011). There is broad consensus that forests must be protected and restored to maintain key ecosystem services. However, there is much less certainty about which kinds of restoration interventions will most effectively guide forest recovery. Forest restoration methods span a broad gradient of management intensity: active/assisted recovery (which often involves some form of tree planting or direct seeding); assisted natural regeneration (encompassing techniques such enrichment planting or removal of competing species); and passive/natural regeneration (which involves little to no direct intervention). Additionally, "rewilding" is an umbrella term for interventions that seek to restore self-regulating ecosystem processes, e.g., by re-introducing keystone species (Perino et al., 2019). How might we determine which sites require intensive intervention to enable ecosystem recovery, and which have the capacity to regenerate naturally? What are long-term implications of these choices for forest dynamics? How do social conditions mediate forest conservation (or clearing) as regrowing forests mature?

The papers in this Research Topic explore the linkages between restoration methods and restoration outcomes, embracing a wide array of methodological approaches and inter-disciplinary perspectives. Collectively they address two of the main challenges restoration practitioners face: the technical challenge of how to restore ecosystems to meet specific goals, and the ecological and socioeconomic challenges of ensuring that restored forests persist on the landscape. They demonstrate that choosing the "right" restoration

intervention requires an in-depth understanding of the local site conditions, and the landscape context in which sites are situated. Clear goals for restoration are important for deciding on an acceptable timeframe, degree of predictability, and level of recovery.

From selecting tree species or cultivars, to selecting restoration sites, choosing an approach that fits local conditions and responds to specific goals is paramount. Ray et al. discuss how intra-specific genetic diversity affects how forests respond to disturbance and climate change. They conclude that although natural regeneration-based approaches might fit some contexts and goals, tree breeding programmes can be a powerful tool in contexts where goals are more specific, depend on a given timeframe, or where forest recovery requires a high degree of resilience in the face of a changing climate. They can also help to create more predictable forest recovery trajectories in a given context.

How quickly and how completely forests recover in a given site will also determine how much intervention is needed, and therefore whether passive restoration is a viable option. Recovery depends on both landscape and site characteristics. Werden et al. used a trait-based approach to compare the outcomes of a gradient of restoration interventions across multiple tropical forest sites. Using plots with similar land use histories, they show that assisted restoration interventions (establishment of mixed-species plantations or tree islands) accelerated the recovery of plant functional richness in comparison with naturally regenerating areas. This finding sheds light on an important debate about the role of management in accelerating tropical forest recovery. Often, naturally regenerating tropical forests tend to have higher biodiversity than actively restored forests, implying that forests recover best with minimal intervention (Crouzeilles et al., 2017). However, the most intensive restoration interventions are generally carried out on the most degraded sites, which by nature require more attention (Reid et al., 2018), leading to biased comparisons among different restoration methods. By directly testing different restoration approaches at the same suite of sites, Werden et al. show that planting tree islands that attract dispersers is (1) more effective than natural regeneration alone and (2) just as effective as more intensive restoration approaches in facilitating the functional recovery of degraded tropical forest.

Wendt et al. also emphasize the role of natural dispersal in mediating forest recovery, showing that large seeded, animal-dispersed tree species become more abundant over the course of stand development in a secondary wet tropical forest, and tend to dominate in older regenerating forests. This suggests that the dominant dispersal syndrome of a tree community can be a good indicator of long-term forest recovery, and highlights the key role of frugivores in propelling forest succession. A lack of frugivores in the landscape because of past hunting, habitat fragmentation, or lack of nearby forests might mean that more intensive interventions are needed to fully restore biodiversity and certain forest ecosystem services in the future.

Núñez-Hidalgo et al. consider a case where knowledge about the current dispersal mechanism of a unique and endangered palm endemic to Chile (*Jubaea chilensis*) is lacking. It is not clear what the historical disperser of this palm is, but it may have been camelids (currently extirpated) or extinct megafauna. In their analysis of contemporary biotic interactions between the palm and its probable current disperser, the rodent *Octodon degus*, they show that there is a spatial association between *Octodon degus* burrows and natural palm regeneration at both large and small scales. The likely mechanism is that stored palm seeds that are not eaten by *O. degus* later germinate, but the interactions between *O. degus* and other seed predators (humans and introduced rodents) are unknown. This study emphasizes the importance of basic research to better understand and therefore conserve the dispersal mechanisms and biotic interactions by which rare and understudied plants regenerate.

Equally important for persistent forest recovery is the social landscape. Holl et al. unpack the concept of "abandoned land," i.e., land that is often presumed to be available for restoration based upon remote sensing datasets. But what a satellite "sees" as abandoned land at a particular snapshot in time could actually be productive land in fallow, for example. Or such land may be unused now, but could be rapidly brought into production again should markets or demographics shift. Understanding the drivers of past forest clearing as well as land governance and access rights is critical to understand how and why forests are converted to agricultural land, and whether regenerating forests will persist in the future. This type of due diligence is also necessary to avoid unintentional "green grabs," through which local communities' access to their customary land is usurped by national or international institutions (Corson and MacDonald, 2012).

Research, planning and engagement: the way forward

Understanding local site conditions and landscape context is vital to determine which restoration approach is most suitable in a given context to meet specific goals. A blend of scientific study and local knowledge can provide a holistic picture while engaging local stakeholders. Indigenous peoples and local communities often play vital roles in forest protection and regeneration (Haenssgen et al., 2022; Alejo et al., 2021), but are too often excluded from dialogues about how best to implement large-scale restoration projects (Seddon, 2022). The Auckland University of Technology Living Laboratories program described in this Research Topic (Buckley et al.) provides an example of Indigenous communities and scientists working together to design experiments and interventions that address climate change and biodiversity loss. These long-term ecological experiments will inform best practices for reforestation in Aotearoa New Zealand, and were co-designed with Ngāti Whātua o Orākei, Ngāti Manuhiri, Ngāti Pāoa, Te Whangai Trust, and the Auckland Council. Although nascent, these partnerships present a promising model through which forest restoration efforts can make use of scientific insights as well as Indigenous and traditional knowledge to collectively set meaningful goals for restoration, locate it on the landscape, and quantify system recovery using project-tailored ecological, social, cultural, and economic indicators.

The contribution from Root-Bernstein et al. also argues for a highly contextual approach to developing more naturalistic

forms of tree-based restoration. They argue that there is scope for moving toward a rewilding-inspired approach to restoration with "foundation plants," that is trees, shrubs, palms, and cacti, focusing on functionalist rather than compositionalist aims, on natural or naturalistic habitat structures and formations, and on spontaneous successional trajectories led by natural processes. However, designing such approaches should consider social histories of land use and current socio-economic contexts and governance challenges. Focusing on the Sahel and the Southern Cone of South America, they point out how ecological similarities and social differences have shaped both how restoration, conservation and rewilding have taken shape in both regions, and how a rewilding inspired approach could be adapted to each region. Comparisons and knowledge exchange between regions may also catalyze new approaches.

The articles in this Research Topic illustrate that the determinants of restoration outcomes span multiple levels of biological organization, from genes to communities to ecosystems; as well as social considerations including governance, land use patterns, and community needs. Too often, projects fail to invest in the research required to plan restoration to meet specific goals. Deep, strategic planning is required to best match local and regional contexts with the array of approaches available. It is imperative that adequate funding and resources are provided to understand the local and landscape context before interventions are undertaken. Co-creating restoration approaches with Indigenous peoples, local communities, and scientists can serve to engage people, help to set locally relevant goals, and provide the types of knowledge that are required to effectively restore complex ecosystems that will persist into the future.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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