Title:

Ten golden rules for reforestation to optimise carbon sequestration, biodiversity recovery and livelihood benefits

Running title:

Ten golden rules for reforestation

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AA, KH, PS and ADS conceived the initial outline of the article; ADS and KH led the writing, coordinated the author contributions and prepared the figures; all authors contributed to writing, developing and reviewing the manuscript.

Abstract

Global climate change requires urgent solutions. Ambitious tree-planting initiatives, many already underway, aim to sequester enormous quantities of carbon, partly compensating for the anthropogenic CO_2 emissions that are a major cause of rising global temperatures. However, poorly planned and executed tree-planting could actually increase CO_2 emissions and have long-term, deleterious impacts on biodiversity, landscapes and livelihoods. Here, we highlight the main environmental risks of large-scale tree planting and propose ten golden rules, based on some of the most recent ecological research, to implement forest ecosystem restoration that maximizes rates of both carbon sequestration and biodiversity recovery, while simultaneously improving livelihoods. These are: i) Protect existing forest first; ii) Work

together (involving all stakeholders); iii) Maximize biodiversity recovery to meet multiple goals; iv) Select appropriate areas; v) Use natural regeneration wherever possible; vi) Select species to maximise biodiversity; vii) Use resilient plant material (with appropriate genetic variability and provenance); viii) Plan ahead for infrastructure, capacity and seed supply; ix) Learn by doing (using an adaptive management approach); and x) Make it pay (ensuring the economic sustainability of the project). We focus on the design of long-term strategies to tackle the climate and biodiversity crises and support livelihood needs. We emphasize the role of local communities and their dependence on benefits from successful reforestation programmes that restore ecosystem functioning and deliver a diverse range of forest products and services. While there is no simple and universal recipe for forest restoration, it is now crucial to build on the public and private interest in this topic to ensure interventions provide effective, long-term carbon sinks and maximise benefits for biodiversity and people.

Introduction

Trees, and the forests they form, are highly complex. Their interaction with other plants, animals and fungi, and environmental phenomena such as fires and flooding, has led to the evolution of a remarkable diversity of species, genes, functions and ecosystems. In Amazonia alone, it has been estimated that more than 15,000 tree species occur (ter Steege et al., 2020). Today, trees and forests provide people with invaluable services and benefits (Díaz et al., 2018), as sources of food, medicine, building material, shade, fibre, recreation and as essential reservoirs of carbon, water and nutrients.

The escalating and interconnected threats of biodiversity loss through **deforestation**, global climate change (GCC) and poverty have increased awareness of the mitigating role that forests could play (Brancalion & Holl, 2020). (Key terms in the manuscript are highlighted in bold on their first occurrence and defined in Table 1.) The role of forest **restoration** in GCC mitigation first received global recognition in 2008, when "enhancement of forest carbon stocks" was added to the United Nation's **REDD+** initiative (UNFCCC, 2008) (www.un-redd.org) with measures to ensure biodiversity conservation and community participation (UNFCCC, 2011; safeguards [d] and [e]). In 2011, the Bonn Challenge (www.bonnchallenge.org) was launched, aiming to restore 350 million hectares of forest globally by 2030. To date, 63 participating organizations (mainly national governments) have committed to restoring 173 million hectares. In 2020, the World Economic Forum instigated the latest global tree-planting program – the 1t.org platform – to support the UN Decade on Ecosystem Restoration 2021–30 (www.decadeonrestoration.org/). These initiatives mostly advocate **forest landscape restoration (FLR)** – an approach that aims to “regain ecological functionality and enhance human well-being in deforested or degraded landscapes” (Besseau et al., 2018).

However, concerns are growing that several ambitious initiatives are falling short of delivering on the three key objectives of carbon sequestration, biodiversity recovery and sustainable livelihoods (e.g., Fig. 1; Kull et al., 2019; Lewis et al., 2019). They may have set unrealistically high targets (Fagan et al., 2020) and have unforeseen negative consequences. Potential problems include displacement of native biodiversity, particularly due to the destruction of non-forest ecosystems; increases in invasive species; a reduction in pollinator services (Ricketts et al., 2004); a reduction in croplands and thus food production; disruption of water cycles; an increase in CO_2 emissions from forests (Heilmayr et al., 2020; Holl & Brancalion, 2020), including a reduction in soil organic carbon (Hong et al., 2020; Veldman et al., 2019), and a lowering of albedo in boreal zones, causing temperature rises (Betts, 2000). These negative outcomes are mostly associated with the extensive use of exotic monoculture plantations, rather than restoration approaches that encourage a diverse, carbon-rich mix of native species (Brancalion et al., 2018; Lewis et al., 2019; Heilmayr et al., 2020). Lewis et al. (2019) estimated that only one third of commitments under the Bonn Challenge aim to restore natural forests.

Figure 1. Example of a problematic tree-planting initiative. In the highly degraded but previously mega-diverse lowlands of eastern Madagascar, national authorities released seeds from aeroplanes to cover thousands of hectares with the Australian *Grevillea banksii* R.Br. and other non-native species. The initial intention was to provide communities with a source of firewood to reduce demand on native forests, but there were unintended consequences, such as displacement of croplands and exclusion of native biodiversity by the introduced species, with such species showing potential to become significantly invasive. (Credit: AA).

In naturally forested regions, we propose a 'native-forest approach' to FLR, to increase carbon sequestration and other ecosystem services, accelerate biodiversity recovery and generate sustainable livelihoods. Restored landscapes may include a mosaic of land uses, such as:

i) **Existing native forest**, prioritized for protection, to safeguard carbon stocks, reduce emissions and conserve biodiversity;

ii) **Restored native forest**, to maximise rates of carbon sequestration and recovery of biodiversity and ecosystem services, delivering sustainable economic benefits;

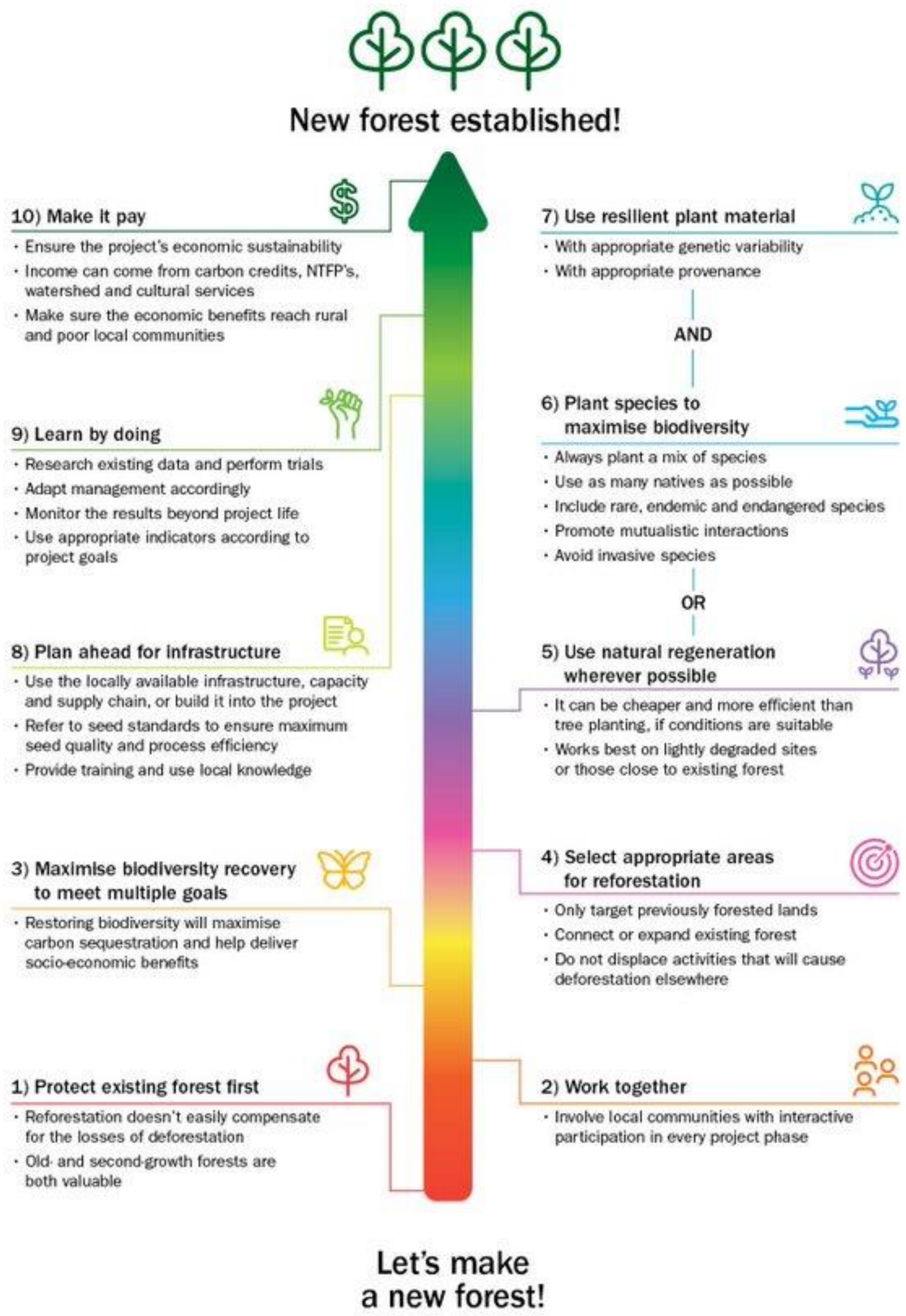
iii) **Livelihood native forest**, to maximise economic benefits to local communities while significantly increasing carbon sequestration, biodiversity and ecosystem services, compared with intensive monoculture plantations;

iv) Restoration and sustainable management of existing agricultural land, including through **agroforestry**, to reduce pressure on native forests;

v) Protected native non-forest ecosystems (e.g. grasslands, savannas, wetlands).

Here, we build on current evidence and our own experience to propose ten golden rules to support the delivery of the native forest elements of our FLR approach (i, ii and iii above), to jointly increase carbon sequestration and deliver benefits for biodiversity, ecosystem services and sustainable livelihoods. Agroforestry and intensively managed plantations are beyond the scope of this paper.

These golden rules (Fig. 2) provide guidance designed to help policymakers, advisors and practitioners of reforestation projects avoid many of the pitfalls of large-scale tree-planting initiatives that are currently causing concern. They are in line with the International Principles and Standards for the Practice of Ecological Restoration (Gann et al., 2019). We use the term '**reforestation**' in a general sense to refer to the creation of restored or livelihood native forests by either tree planting or **natural regeneration (NR)** without tree planting, in areas where forest formerly occurred naturally but has been recently lost.



147

148 **Figure 2. Ten golden rules for a successful reforestation project**. The order of the rules
149 matches the order in which tasks should be considered during project planning and
150 implementation, although some are interdependent and should be considered in parallel. See
151 text for details.
152

The ten golden rules

1. Protect existing forest first

Before planning reforestation, always look for ways to protect existing forests, either old-growth, secondary or planted.

The loss of natural forests continues relentlessly, despite global efforts to arrest it. In the humid tropics, an average of 4.3 million hectares of **old-growth forest** was destroyed each year between 2014 and 2018 (NYDF Assessment Partners, 2019). The New York Declaration on Forestry (NYDF) (https://forestdeclaration.org) aimed to reduce deforestation by 50% by 2020, while the United Nations Sustainable Development Goals aimed to end it by 2020. Not only have both these targets been missed, but tropical deforestation has accelerated by 44% compared with the 13 years before the NYDF in 2014 (NYDF Assessment Partners, 2019). Deforestation on this scale results in huge CO_2 emissions (Seymour & Busch, 2016).

These losses of natural forest are not readily compensated for by reforestation (Brancalion & Chazdon, 2017; Meli et al., 2017; Wheeler et al., 2016), and neither forest protection nor restoration should be invoked as a reason to destroy natural areas elsewhere (Gann et al., 2019). The IPCC acknowledges that "*most* [destroyed] *forest ecosystems will take longer than 100 years to return to the level of biomass, soil and litter pools* [found in forest in an] *undisturbed state*" (Aalde et al., 2006). Recovery of ecosystem services and biodiversity may take centuries, especially the return of rare or endemic species, which are particularly vulnerable to disturbance (Gibson et al., 2011; Rey Benayas et al., 2009). Extinct species, of course, will never return. Such a steep decline in intact forest also threatens indigenous cultures and human health (Watson et al., 2018). Large areas of remnant forest, with healthy, genetically diverse populations of common plant species are essential to support reforestation efforts. They provide seed rain for NR (Rule 4), and a source of seeds, wildings and cuttings for the production of resilient planting stock (Rule 7), and also harbour a more general source of supporting biodiversity, including pollinators.

It is therefore vital to protect remaining natural forests – '**proforestation**', *sensu* Moomaw et al. (2019). Although old-growth forest sustains the highest biodiversity levels, **second-growth forest** now covers most of the global forest area and is of immense value for biodiversity conservation and carbon sequestration (Chazdon et al., 2016; Reid et al., 2019). In the Amazon, carbon sequestration in second-growth forests is 11 times that of old-growth forests, although standing biomass is substantially lower (Poorter et al., 2016). Protection of second-growth forests until maturity is, therefore, crucial to maximizing carbon storage.

Action at both national and local levels is needed to protect forests. Persuading governments and corporations to create and enforce protected areas and legislate against forest conversion can be effective. For example, Brazil's Soy Moratorium and Cattle Agreement achieved some success in reducing soy and cattle-driven deforestation in the Amazon (Nepstad et al., 2014). The first step towards successful protection at the local level is often identification of the drivers of deforestation, among *all* stakeholders (Rule 2). Encroachment may be tackled by developing alternative livelihoods (Rule 10). When fire is a risk, collaborative community groups can take action to raise awareness, organise fire patrols and install fire breaks; while overgrazing can be reduced by controlling livestock density, fencing, or by instigating cut-and-carry feeding systems.

2. Work together

Involve all stakeholders and make local people integral to the project.

The scale and goals of reforestation projects determine their impacts and therefore affect who should be involved. For example, reforestation on smallholder farms can be done without wider stakeholder engagement being necessary. For large-scale reforestation projects, engagement of multiple stakeholders is required to meet the diverse goals of enhancing rural livelihoods, biodiversity conservation, carbon sequestration, watershed protection and provision of other ecosystem services. Stakeholders might be directly or indirectly affected by the project's outcomes and impacts (Erbaugh & Oldekop, 2018) and may include national and local governments, forestry departments, NGOs, civil society, the private sector, landowners, farmers and other land users, as well as universities, botanic gardens, herbaria and other research institutes.

For successful outcomes, it is vital to include local communities from the planning stage through to delivery and monitoring (Bloomfield et al., 2019). They are the key to success and have the most to gain from the project. If their needs are heard and taken into consideration, and they are informed about the environmental issues the project is addressing, they are more likely to support the project and help to deliver successful outcomes in the long term. Simultaneously, provision of labour for land preparation, planting and maintenance provides an opportunity to diversify local employment, thus improving livelihoods. The success of this model has been confirmed by several projects (e.g. Dolch et al., 2015; Douwes & Buthelezi, 2016; Urzedo et al., 2016).

Five levels of community participation in projects have been proposed (Gann et al., 2019), ranging from passive at Level 1 (simply informing stakeholders) to fully active at Level 5 (full support and optional involvement, self-management and succession arrangements). Each level of engagement corresponds with an increasingly positive effect on benefits distribution, knowledge, natural capital, sustainable economies and community well-being. Reforestation project activities should at least aim to involve local communities with interactive participation or self-mobilisation. Passive participation can lead to community hostility and disputes over access rights, which may be manifestations of underlying or deep-rooted issues, such as conflicts over land tenure (Agrawal & Redford, 2009).

It is crucial to note that communities are not homogenous units (Agrawal & Gibson, 1999). They comprise groups of people differentiated by wealth, ethnicity, gender and other socio-economic stratifications, that have different power relations and interests in the reforestation process. For instance, in some countries, men and woman have different rights to land and trees, which affects those with insecure rights, mostly women, from effectively participating in reforestation activities. It is essential to address those inequalities, as well as conflicts between private, communal and political interests. Stakeholders' needs may change over time, so their requests should be reassessed throughout the project and the strategy adapted accordingly (Lazos-Chavero et al., 2016).

Sharing of both the costs (in terms of time, labour and money) and the benefits of reforestation (Rule 10) among all stakeholders should be agreed upon before the first tree goes into the ground (Fig. 3).

Figure 3. Ensuring appropriate engagement. In a community-led reforestation project using local indigenous species in eastern Madagascar, members of the local community work together to restore areas degraded by fire and over-exploitation. (Credit: AA)

3. Maximise biodiversity recovery to meet multiple goals

Restoring biodiversity will facilitate other objectives – carbon sequestration, ecosystem services and socioeconomic benefits.

Rather than being an end goal in itself, reforestation is a means to achieving various goals, typically climate mitigation, biodiversity conservation, socioeconomic benefits (including food security), soil and hydrological stability, and other ecosystem services. These objectives should be defined beforehand to allow appropriate project planning, implementation and monitoring (Chazdon & Brancalion, 2019). Achieving multiple objectives may be possible, but it inevitably means accepting trade-offs (Holl & Brancalion, 2020). Maximising biodiversity and biomass, through the native forest approach, enables multiple outcomes to be delivered at once, while FLR allows different objectives to be prioritised in different zones of the landscape. While trying to maximise all the benefits of the project, it is important to keep in mind one essential goal for every project: do no harm to local communities, native ecosystems and vulnerable species.

Where the main goal is timber production and/or carbon sequestration, plantations of fast-growing monocultures are widely used. However, it has been demonstrated that, in the long term, restored native forests maximise biomass and capture far more carbon, while simultaneously conserving biodiversity (Díaz et al., 2009; Lewis et al., 2019).

Socio-economic goals often include the improvement of economic conditions for local people, including the poorest communities. Many projects rely on agroforestry and exotic timber plantations to meet this objective, but natural, restored and livelihood native forests deliver economic returns as well as environmental co-benefits and should be included in a landscape-wide approach. In timber production, short harvesting cycles quickly release much of the stored carbon back into the atmosphere, negating the initial carbon sequestration. Low-intensity management of livelihood native forests, for example through selective extraction, preserves biomass by allowing long-term carbon sequestration and natural vegetation succession, while also benefitting biodiversity (Crane, 2020; Hu et al., 2020; Noormets et al., 2015). Alternative livelihood measures should be supported in the interim period before harvesting, to avoid the continued conversion of forest with high carbon stocks elsewhere leading to a net emission of CO_2. Biodiverse restored native forests can provide income through carbon credits, **payments for ecosystem services (PES)** and **non-timber forest products (NTFPs)** (Rule 10).

If the main priority of the project is to conserve biodiversity and save threatened species, it is important to prioritize areas and select species that maximize this goal (Rules 4 and 5). Different reforestation approaches, planned at different levels, can be used: (i) Tree level: plant tree species that are prioritised for conservation, such as threatened species, or that provide resources to target animals (Brancalion et al., 2018) or fungi; (ii) Ecosystem level: plant or assist the regeneration of species that will recover the typical composition, structure, and functioning of reference, undisturbed ecosystems, to maximize habitat provision to a diversity of native species; (iii) Landscape level: maximize landscape connectivity by creating forested corridors and stepping stones to link remnant forest patches (Newmark et al., 2017).

Restored native forests can deliver multiple ecosystem services, including water quality and availability (Nisbet et al., 2011), air quality, shade, erosion control, pollination services, and recreational, educational, spiritual, religious or other cultural benefits. Despite the fact that these benefits are often recognised, needed or demanded by local people (Brancalion et al., 2014), they are frequently neglected. The guidelines in this paper aim to maximise ecosystem services, adding increased value to any tree planting or restoration project (Burton et al., 2018).

4. Select appropriate areas for reforestation

Avoid previously non-forested lands, connect or expand existing forest, and be aware of displacing activities that will cause deforestation elsewhere.

Although tree-planting interventions are always implemented at the local scale, site selection usually involves a multiscale approach. With the emerging engagement of multilateral and international organizations in tree-planting initiatives (Holl & Brancalion, 2020), spatial prioritization decisions can be made at a global scale, but most restoration initiatives involve an evaluation at the landscape level or below. Considering a combination of historical, ecological and socio-economic factors at different spatial scales will provide the most effective basis for decisions.

Key questions to ask when selecting an area for reforestation are:

i. *Was the area previously forested and is it now degraded?* Re-establishing a species-rich forest in such a place is beneficial for both biodiversity and carbon sequestration, and helps fight desertification where this is determined by socio-economic factors (Liu et al., 2020). Reforestation in such areas is highly recommended, and the level of tree cover increase should be calibrated with the reference values of tree cover of the target ecosystems, in order to avoid unintended consequences for biodiversity and ecosystem services;

ii. *Has the area been occupied historically by a non-forested biome such as grassland, savanna, non-forested wetland or peatland?* **Afforestation** in such areas depletes both biodiversity and soil organic carbon (Bond et al., 2019; Friggens et al., 2020; Veldman et al., 2015) and must be avoided. For example, grasslands often host high biodiversity and many threatened species, as well as contributing significantly to below-ground carbon sequestration (Burrascano et al., 2016; Dass et al., 2018). Non-forested peatlands contain an even higher amount of soil organic carbon (SOC) that would be released into the atmosphere if trees were planted there (Brancalion & Chazdon, 2017; Crane, 2020; NCC, 2020). Similarly, lands covered by snow at high latitudes reflect an important quantity of sun radiation due to the high albedo, providing a cooling effect on the planet that would not be compensated for by the amount of carbon slowly captured by trees grown in those cold climates (Bala et al., 2007; Betts, 2000). A critical step for tree planting initiatives is therefore to define 'no-go zones', where restoration should focus instead on other non-forest vegetation types;

iii. *What are the wider effects of reforestation in the target area, including impacts on groundwater, biodiversity, climate, ecosystem services and livelihoods?* If the area is dry and water is scarce, trees could reduce the groundwater and river flow, with negative consequences for local inhabitants (Chapman, 2001; Feng et al., 2016). However, in seasonally dry climates, restoring forests on degraded watersheds can help to increase infiltration and reduce surface run-off during the rainy season, reducing extreme fluctuations in streamflow throughout the year (Gardon et al., 2020). In urban areas, trees can be planted to mitigate the direct effects of GCC, providing an additional contribution to the carbon sequestration needed (Parsa et al., 2019) while also delivering other ecosystem services such as the provision of recreational spaces, wildlife habitats, clean air and shade;

iv. *How close is the land to areas of natural forest?* This will affect both the capacity of the site to regenerate naturally (Rule 5) and the value of the reforested site to biodiversity, for example by creating buffer zones, corridors and stepping stones enabling native species to migrate between forest remnants and expand their distribution (Tucker & Simmons, 2009);

v. *Who is currently using the land, how will they be compensated for any income losses, and where will they move their activities?* If these factors are not considered, the land might be retaken at a later stage, or it might cause further deforestation or social conflicts elsewhere (Cuenca et al., 2018; Meyfroidt et al., 2010). Protecting and restoring degraded forest remnants is the safest way to increase carbon stocks and decrease habitat fragmentation without using non-forested land that may already be in use (Brancalion & Chazdon, 2017).

More tools and tailored resources are needed to help guide these decisions. The Restoration Opportunities Assessment Methodology (ROAM) (IUCN & WRI, 2014), for instance, has been used in many countries that have made pledges to the Bonn Challenge, to identify FLR opportunities. The resulting maps identify high-priority areas for intervention and provide a helpful framework for determining what method is best.

5. Use natural regeneration wherever possible

Natural regeneration can be cheaper and more effective than tree planting where site conditions are suitable.

The NR approach to forest restoration spans a spectrum of different levels of human intervention:

i. No intervention, or passive restoration (Chazdon & Uriate, 2016);
ii. Low intervention, including protection from further damage such as grazing or fire, and rewilding, which includes the selective reintroduction of missing fauna to restore natural processes;
iii. Intermediate intervention, including enrichment of naturally regenerated forest by planting missing species and **assisted NR (ANR)** (FAO, 2019; Philipson & et al., 2020; Shono et al., 2007), where weeds are cleared around naturally regenerating trees to accelerate their growth;
iv. High intervention, including applied nucleation or strip planting, where parts of the site are intensively planted to facilitate NR in the rest of the site, and the framework species approach (Rule 6).

When carbon capture and biodiversity enhancement are primary objectives, NR can provide significant benefits over tree planting, if practised in suitable locations. Carbon sequestration in naturally regenerated areas is potentially 40 times greater than in plantations (Lewis et al., 2019) and species richness is generally higher, particularly for forest specialist species (Barlow & Peres, 2008; Brockerhoff et al., 2008; Rozendaal et al., 2019). NR is also significantly cheaper than tree planting, with studies in Brazil showing implementation costs reduced by 38% (Molin et al., 2018) or even up to 76% (Crouzeilles et al., 2019). However, this approach is unsuitable for certain ecosystems, for example the 'old, climatically buffered infertile landscapes' ('OCBILs', *sensu* Hopper, 2009) found in biodiverse regions where natural migration processes are incapable of reinstating ecosystems, for example the southwestern Australian biodiversity hotspot. Such cases require substantial replanting and seeding (Koch & Hobbs, 2007).

Once a land area has been targeted for natural or semi-natural forest cover, the two key questions are: i) *Is the forest capable of returning spontaneously?* and ii) *What level of intervention is required to assist and accelerate the regeneration?* The site's potential for NR will depend on multiple factors, which can be considered at the landscape and site level (Elliott et al., 2013).

At the landscape level, the first step should be to identify and control the factors that led to deforestation in the first place – a task that should involve all stakeholders (Rule 1). One of the most important landscape factors is the proximity of the site to remaining natural forest that will serve as a diverse source of naturally dispersed seed. Crouzeilles et al. (2020) found that 90% of passive regeneration occurred within 192 m of forested areas, while Molin et al. (2018) found best results within 100 m of the nearest forest. The presence of birds and animals in and around a site is crucial for seed dispersal of many plant species. Typically, large wild animals and birds are the first to be locally extirpated, in which case the plants they dispersed may fail to recolonise unless manually introduced (enrichment planting). Another key factor is climate, particularly mean annual precipitation (Becknell et al., 2012). In the Neotropics, biomass recovery in second-growth forests was up to 11 times higher in wetter areas (Pooter et al., 2016).

At the site level, the size of the target area will clearly affect distance to the nearest forest, with central parts of the site being further away than the nearest edges. Different levels of intervention may therefore be required within a single large site. The existing natural vegetation currently present on a site will have the most immediate effect on the regeneration pathway. In a lightly degraded site, a dense community of stumps, seedlings, and a diverse soil seed bank will enable rapid regeneration, especially in humid tropical areas, potentially achieving canopy closure in under a year (Elliott et al., 2013). Advice on the required density of regenerants for NR ranges widely from 200/ha (Shono et al., 2007) to 3,100/ha (Elliott et al., 2013) and depends on climate. Tree crown expansion occurs more rapidly in warm wet climates than in cool, dry climates, so the stocking density required to achieve rapid canopy closure is lower. If the dominant vegetation comprises herbaceous or woody weeds, they will likely out-compete regenerating woody plants and should be controlled through cutting, pressing, mulches, herbicide or controlled grazing, i.e. ANR (FAO, 2019).

Other important site factors are soil quality, topography and hydrological features (Molin et al., 2018). Given the complex interaction of all these factors, the best way to determine the site's suitability for NR and the level of human intervention required is to take an experimental and adaptive management approach (Rule 9).

6. Select species to maximise biodiversity

Plant a mix of species, prioritize natives, favour mutualistic interactions, and exclude invasive species.

Tree planting is needed to restore forest when NR is insufficient (Rule 5). The *International Standards for Ecological Restoration* specify a 'native reference ecosystem' to guide species selection (Gann et al., 2019). In heavily degraded sites, species should be selected based on their ability to establish in unfavourable conditions, which might include compacted soil, drought, and competitive weeds. Native pioneer species are most likely to survive initially, while late successional species can be intercropped with these pioneers, be introduced with successive planting interventions, or may even eventually colonise the site naturally.

The framework species approach to forest restoration in the tropics is a low intensity, highly effective tree-planting option that depends on the selection of a suite of native species with specific functional traits (Goosem & Tucker, 2013). It involves planting the fewest trees needed to complement and promote NR and recapture the site from weeds in two to three years. Framework tree species are characteristic of the reference ecosystem and have: i) high survival and growth rates; ii) dense, spreading crowns that shade out herbaceous weeds; and iii) traits that attract seed-dispersing wildlife (e.g. flowering/fruiting at a young age). Mixtures of 20–30 species (both pioneer and climax tree species) should be planted. Biodiversity recovery depends on remnants of the reference forest type occurring within a few kilometres of the restoration site (as a seed source) and seed-dispersing animals remaining in the landscape (Elliott et al., 2013). A successful case of framework species approach applied in Thailand is shown in Fig. 4.

Figure 4. Example of successful tree planting. The framework species method of forest restoration can be effective even on the most degraded sites, provided intact forest remains nearby. A) August 2012: Siam Cement's limestone mine in Lampang Province, northern Thailand. B) April 2013: after spreading the site with topsoil (60 cm deep), 14 framework tree species were planted, including several *Ficus* spp. and native legumes, to improve soil conditions. Corrugated cardboard mulch mats were also applied. C) February 2015: by the end of the 3rd rainy season, canopy closure was achieved and macaque monkeys started visiting the plot to eat figs, in the process naturally dispersing seeds of other species through defecation. Mean survival across species was 64% and relative annual growth rate averaged 91%. (Credit: Siam Cement Group and SE).

Maximizing biodiversity depends not only on the number of species reintroduced, but also on the functions they perform. Promoting mutualistic interactions, such as those involving native tree species and fungi, seed-dispersing animals, pollinators, and other organisms, is crucial to achieving a resilient, biodiverse restored ecosystem (McAlpine et al., 2016; Steidinger et al., 2019) but its importance is often underestimated.

Rare, endemic or threatened taxa are less likely to colonise through natural succession (Horák et al., 2019), and should therefore be reintroduced at the appropriate stage of forest maturity. This practice will contribute to the survival and conservation of the most vulnerable species. Such species can contribute greatly to carbon stocks, since they tend to be late-successional species with dense wood (Brancalion et al., 2018).

The GlobalTreeSearch database (bgci.org/globaltreesearch.php) lists all known tree species and can generate checklists of native species for each country. Local botanists should be consulted to determine which native species are most suitable for the particular forest type being restored. The Global Tree Assessment (https://www.globaltreeassessment.org/) aims to deliver tree conservation assessments for all tree species by the end of 2020. This will help identify threatened species that can be included in restoration projects.

In livelihood native forests, selecting a mix of species, rather than planting a monoculture, is crucial (Brancalion & Chazdon, 2017). A mixed-species forest, either with native species only or with a mix of native and non-native species, will have higher capacity to conserve biodiversity, create habitats for wildlife, and attract seed dispersers and pollinators. This forest can regenerate autonomously, especially if patches of native vegetation are maintained inside the plantation matrix as habitat islands (Horák et al., 2019). It will also be more resilient to disease, fire and extreme weather events (Florentine et al., 2016; Verheyen et al., 2016). Monoculture plantations sequester little more carbon than the degraded lands on which they are planted, especially if they are used for fuel or timber with the carbon released back into the atmosphere after about 20 years (Körner, 2017; Lewis et al., 2019b).

Including exotic species in livelihood native forests is controversial (Catterall, 2016). For example, eucalypts (*Eucalyptus* L'Hér.) may have high cash value, but eucalypt plantations support lower biodiversity than native forests (Calviño-Cancela et al., 2012), and are colonised by mainly generalist plant and animal species (Brockerhoff et al., 2008). A major concern is that exotic species often become invasive, for example *Acacia* species in South Africa (Richardson & Kluge, 2008). Invasive species rank second to habitat loss and degradation as a cause of the current global biodiversity crisis (Bellard et al., 2016). They have long-term effects on the environment, compete with native species, reduce biodiversity and often reduce water availability (Dyderski & Jagodziński, 2020; Scott & Prinsloo, 2008). Their removal, which needs to be done before restoration interventions can commence, is invariably difficult and can render restoration uneconomical. Invasive exotic species should never be planted.

However, in certain conditions, some exotic, non-invasive species can be good allies for tropical forest restoration. In a humid tropical region of Brazil, exotic eucalypts, when planted in mixed plantations with native species and selectively harvested after five years, did not slow down the regeneration of native trees and provided substantial economic support to the restoration costs (Amazonas et al., 2018; Brancalion et al., 2020). Crucially, the eucalypts did not regenerate.

Further research is required to identify more high-value native species that could be used instead of, or together with, the desired exotic species. For example, in Kenya, *Melia volkensii* Gürke is a popular native timber species and has a lower demand for water than eucalypts (Ong et al., 2006; Stewart & Blomley, 1994). The use of mainly native species in new livelihood native forests has been successful in Latin and Central America, where companies such as Symbiosis Investimentos and Sucupira Agroflorestas are developing propagation protocols for native species, promoting agroecological principles, practising sustainable forestry, and in some cases conserving and restoring natural forestland alongside the plantations.

Adaptability to GCC is a further point to consider when selecting species for both native and livelihood native forests. When GCC is proven to negatively impact native species, non-native species could be considered on the basis of preserving ecosystem functions. Such species have to be tested under a comprehensive risk assessment that includes biosecurity threats and the potential to become invasive (Ennos et al., 2019). This could form part of an assisted migration programme.

7. Use resilient plant material

Obtain seeds or seedlings with appropriate genetic variability and provenance to maximise population resilience.

To ensure the survival and resilience of a planted forest, it is vital to use material with appropriate levels of genetic diversity, consistent with local or regional genetic variation. Vegetative propagation, or using seeds with low genetic diversity, generally lowers the resilience of restored populations through reduced evolutionary potential, 'founder effects' and problems with inbreeding depression (Thomas et al., 2014). As a result, the planted forests may be disease-prone and unable to adapt to long-term environmental change. Such genetic bottlenecks can result from poor seed collection strategies, such as collecting from too few parent trees or declining source populations. Using material from well-designed seed orchards, or, in the many cases where this is not available, mixtures of seed with different provenances, will in most cases help increase the genetic diversity in planted forests (Ivetić & Devetaković, 2017). However, in exceptional ecosystems, such as Australian OCBILs, that have strong local adaptation and where genetic diversity may not be linked to evolutionary potential, (Hopper, 2009; James & Coates, 2000), highly local provenancing is required.

Best practice involves collecting seeds from many individuals across the full extent of the parent population, preferably by random sampling, in order to include the rarest alleles (Hoban, 2019; Hoban & Strand, 2015). Ivetić & Devetaković (2017) similarly identified the size of the parental population as the key determinant for the level of genetic diversity in the planted forest; they viewed provenance and seed-collecting strategies as the most important management practices in tree-planting projects. As a general rule, in order to adequately capture genetic diversity, seed should be collected from at least 30 individuals of **outcrossing species** and at least 50 individuals of **selfing species** (Pedrini et al., 2020b).

It is generally advisable to use seeds collected from a local parent population, as the individuals will be adapted to a similar climate and environment. However, more distant provenances could also be appropriate if the conditions are similar across a large part of a species' range, or if the objective is to match conditions under future GCC scenarios (**predictive provenancing**). If decisions are being made based on climate predictions, then sound science and experimental evidence of why climate-adapted genetic material is being used should be articulated (Alfaro et al., 2014). A cautionary strategy is to use the **composite provenancing** *sensu* Broadhurst et al. (2008). **Seed zone** maps can help practitioners to identify appropriate provenances of material for planting at target sites; however, such maps are rare for most forest systems, particularly for understorey species.

One of the main bottlenecks for forest restoration is frequently inadequate seed supply. Lack of seeds (Jalonen et al., 2018; León-Lobos et al., 2020) and planting stock (Bannister et al., 2018; Whittet et al., 2016) of target species from appropriate sources in the required amounts is often critically limiting. This problem is particularly acute in the tropics and for animal-dispersed, large-seeded trees species, which are of crucial importance for forest restoration (Brancalion et al., 2018). In addition, many of the seed supply sources are forestry genebanks that often have different aims, such as conserving desired traits rather than broad genetic diversity.

8. Plan ahead for infrastructure, capacity and seed supply

From seed collection to tree planting, develop the required infrastructure, capacity and seed supply system well in advance, if not available externally. Always follow seed quality standards.

For projects involving tree planting or direct seeding, it is fundamental to have the appropriate infrastructure and seed supply systems in place to support project activities. Decisions should be made at least a year in advance on whether to source seeds and produce seedlings in-house, sub-contract these tasks, or purchase plant material from an external supplier. If seeds are purchased externally, the supplier should be able to provide information on seed quality and the legality of their collection (Pedrini & Dixon, 2020). If commercial suppliers of seeds and seedlings fail to meet project requirements for species mix, quantity, genetic diversity, provenance or quality (Rule 7), many projects will need to develop their own collection, storage and propagation capacity.

Where seed is self-sourced, follow national legislation on access to biological material (UN Convention on Biological Diversity, 2011) (https://www.cbd.int/abs/) and international seed standards (e.g. ENSCONET, 2009b; Pedrini & Dixon, 2020) to ensure seeds are high quality and to avoid damaging source populations by over-collecting (no more than 20% of the available ripe seeds should be collected). Basic equipment for wild seed collecting, cleaning and storage is needed. Collecting from tall trees requires specialist equipment, including extendible pruners, throw lines, tarpaulins and tree-climbing harnesses. Seed collectors should be trained to use this equipment efficiently and safely. Training should include phenological monitoring and seed physiology, to ensure collecting trips are timed efficiently for periods of peak fruiting and that seeds are collected at the point of optimum maturity (Kallow, 2014). Involving botanists and local people in the process will enable identification of species, efficient location of trees of target species and optimum timing for collection. Data on species identification, ecological conditions and provenance should be collected simultaneously with the seeds. Alternatively, seeds can be provided by a third party, either collected directly from the wild or regenerated from wild-collected seed orchards, usually by state agencies or commercial suppliers (Pedrini et al., 2020b).

If collecting seeds, the seed storage behaviour of the target species should be checked first, so they are handled appropriately. **Orthodox seeds** can be stored in seed banks, increasing their longevity for decades and allowing their use over extended periods, which optimizes collecting efforts and reduces waste (De Vitis et al., 2020; ENSCONET, 2009a). Literature on seed storage behaviour is available for many taxa (Hong et al., 1998), and it is possible to predict (Wyse & Dickie, 2018) or test (Hong & Ellis, 1996; Mattana et al., 2019) the behaviour of understudied species. The Seed Information Database, https://data.kew.org/sid/, curated by the Royal Botanic Gardens, Kew (RBG Kew), stores information on a wide range of species.

Low-cost seed-storage facilities can be installed if seed banks are not available regionally. Further information from RBG Kew is freely available here: http://brahmsonline.kew.org/msbp/Training/Resources. Seed banking is particularly useful in arid and semi-arid biomes (León-Lobos et al., 2012), where over 97% of the species are estimated to have orthodox seeds, but it is also a valuable option for the majority of species in humid ecosystems (Wyse & Dickie, 2017).

Propagation protocols are available for many common species, but, if not, germination trials are required. Most wild species have dormant seeds (Baskin & Baskin, 2014), requiring specific conditions to germinate. These can sometimes be deduced from the seed morphology and ecology of each species (Kildisheva et al., 2020).

If direct seeding is chosen, it may be beneficial to prime the seeds for optimum germination and/or coat them with materials that provide protection against predators, drought, fungal infection and weeds (Madsen et al., 2012; Pedrini et al., 2020a; Williams et al., 2016). The number of seeds required is generally significantly greater than the target number of trees, since conversion rates of seeds to established seedlings are usually very low and are highly species dependent (James et al., 2011). However, the level of success among sites can vary significantly (Freitas et al., 2019). The development of a seeding plan that includes site preparation and seeding strategy, as well as monitoring after planting, is crucial to success (Shaw et al., 2020).

If saplings are to be planted, an in-house nursery must be built (Elliott et al., 2013) or an appropriately accredited nursery selected for the propagation. If such infrastructure and expertise are not available locally at the start of the project, it is important to include them in project planning. Local people can be an important resource of labour and expertise, and it may be possible to convert private agricultural or horticultural facilities into the resources needed for the project.

9. Learn by doing

Base restoration interventions on the best ecological evidence. Perform trials prior to applying techniques on a large scale. Monitor appropriate success indicators and use results for adaptive management.

Before commencing any forest restoration or livelihood native forest establishment, consult international standards for general guidance (e.g. Gann et al., 2019) and make use of indigenous knowledge to inform planning decisions (Wangpakapattanawong et al., 2010). Other useful information sources include Floras, previous project reports and the scientific literature, particularly functional trait data for species selection (Chazdon, 2014).

Ideally, small-scale trials should be implemented before large-scale tree planting commences, to guide species choices and test the effectiveness of proposed techniques. These may include land management interventions to overcome site specific barriers, such as degraded soils (Arroyo-Rodríguez et al., 2017; Estrada-Villegas et al., 2019), competitive weeds (FAO, 2019), fire and herbivores (Gunaratne et al., 2014; Rezende & Vieira, 2019), and the absence of mutualistic organisms in soils, such as mycorrhizal fungi (Asmelash et al., 2016; Fofana et al., 2020; Neuenkamp et al., 2019). Unfortunately, trials take years to yield results, so projects often have to be initiated through the exchange of previous knowledge. Subsequent monitoring then generates data for adaptive management, a fundamental principle of FLR since its inception (Gilmour, 2007).

For monitoring forest restoration sites, it is useful to establish permanent sample plots in: i) the restoration site (treatment); ii) a site where no interventions are implemented (control); and iii) a reference forest remnant (target). Comparing i) and ii) determines the effectiveness of restoration interventions. Comparing i) and iii) tracks the progress of restoration towards the target end-state. Data should be collected before and just after restoration interventions are initiated (baseline) and annually thereafter, at least until canopy closure.

Restoration progress is indicated by the biomass, forest structure, biodiversity and ecosystem functioning in restoration sites all trending towards those of the reference (or target) ecosystem. However, monitoring can focus on biomass and biodiversity, since the other two ecological indicators and many socio-economic benefits (Table 2) stem from them.

Biomass is estimated from stocking density and tree sizes in sample plots. Allometric equations are used to derive biomass and carbon from measurements of tree diameter and height and wood density (Chave et al., 2014). Soil samples should also be collected to determine soil carbon. Ground surveys are rapidly being replaced by aerial photogrammetry (de Almeida et al., 2020) using drones to create 3D forest models within which the heights and shapes of all trees can be measured. However, to gather species-specific data and calibrate remote sensing approaches, ground surveys remain essential.

It is impractical to monitor all species to assess biodiversity recovery, so biodiversity indicator groups are used, most commonly plants and birds. For trees and ground flora, the abundance of species in sample plots should be recorded and the data used to construct species-effort curves and calculate diversity indices (Ludwig & Reynolds, 1988). To monitor bird species richness, we recommend the Mackinnon List Technique (Herzog et al., 2002). If resources are available, more comprehensive biodiversity assessments using environmental DNA and insect traps can provide rich and cost-effective data (e.g., Ritter et al., 2019).

Monitoring should also assess progress towards project-specific goals, such as erosion control or recovery of an endangered species. Where livelihood benefits are a key objective, they may be assessed using indicators such as jobs created or changes in income, and equity in distribution at the gender, household and communal levels. Where income is to be generated from extraction of timber or NTFPs, it is vital to achieve sustainable production by ensuring that harvest rates of products do not exceed their productivity. This can be monitored through simple 'yield-per-unit-effort' techniques – recording product quantities harvested and harvesting time expended – with community-agreed reductions in harvesting intensity, if yields start to decline.

Monitoring and verification of restoration, particularly to claim income from carbon credits and other environmental services, is usually carried out by independent assessors at great expense. However, studies have shown that local people are capable of performing monitoring more cost effectively (Boissière et al., 2017; Danielsen et al., 2013), and their indigenous knowledge is of great value to the process (Wangpakapattanawong et al., 2010).

10. Make it pay

Develop diverse, sustainable income streams for diverse stakeholders, including carbon credits, non-timber forest products, ecotourism and marketable watershed services.

Income generation by selling forest products from livelihood forests is easily achieved, whereas marketing environmental services from existing and restored native forest is more difficult, particularly in protected areas. However, the sustainability of forest restoration depends on income streams generated from it exceeding those from alternative land-uses and on that income being shared fairly among all stakeholders, including the poorest (Brancalion et al., 2012).

In 2009, The Economics of Ecosystems and Biodiversity initiative estimated the value of tropical forest ecosystem services to be 6,120 USD/ha/year (USD 7,732, today, after inflation), based on data from 109 studies (TEEB, 2009). Watershed services contributed most (38.8%), followed by climate regulation (32.1%), provisioning services (21.5%) and recreation/tourism, (6.2%). All these values depend on the two fundamental indicators of restoration: biomass accumulation and biodiversity recovery (Table 2).

REDD+ has made some progress with monetizing forests as carbon sinks (Angelson et al., 2012). Forest carbon value alone often exceeds revenue from the main drivers of deforestation (e.g. oil palm (Abram et al., 2016)), but application of REDD+ to incentivize restoration has been problematic, due to issues of governance and socio-economic conditions, particularly fluctuations in carbon credit prices. To ensure revenue flows mostly into local economies, local people should have direct access to carbon markets as well as low-interest start-up loans, to fund restoration work and support their families until break-even is achieved. Furthermore, transaction costs, including monitoring, reporting and verification (MRV), should be minimized by building local capacity, to reduce dependency on paid external agents (Köhl et al., 2020).

Whilst NTFPs are usually less valuable than carbon, local people can easily monetize them, and start-up investment is minimal (de Souza et al., 2016). Furthermore, NTFPs can provide security and adaptability during periods of financial hardship (Pfund & Robinson, 2005) and their diversity buffers against fluctuating markets. If the price of one product falls, another can be substituted. Conversely, monoculture plantations leave farmers vulnerable to fluctuations in a single commodity market price. Thus, biodiversity recovery drives both ecological stability and economic security. However, to ensure sustainable production, harvesting rates must be carefully monitored (Rule 9).

Watershed services are the most difficult to monetize, since they constitute 'avoided detrimental impacts', such as flood damage or decline of agricultural productivity. The need for such services is unpredictable in time and place. They are a 'public good', rather than a readily quantifiable commodity. Consequently, government funding (via taxes or water charges) is the most appropriate monetization mechanism. Several such schemes have been well-documented in Latin America and China (Porras et al., 2008).

Ecotourism can be a lucrative source of local income that puts a direct value on biodiversity. However, its potential is often over-estimated. Substantial start-up funding is needed, particularly for accommodation construction, and the skilled labour required to meet the demands of ecotourists is often imported from outside, sidelining local people.

Innovative marketing will be essential to turn restoration values into financial incentives, since both investors and the public are unfamiliar with paying for some of the services outlined above (Brancalion et al., 2017). Comprehensive socio-economic monitoring will be needed to ensure that payments actually benefit local communities and that changes in the values of land and resources have no deleterious social consequences. Finally, if such financial incentives lead to a surge in restoration projects at the expense of agriculture, the prices of carbon credits and NTFPs could crash, and food production could decline, resulting in increased food prices and reduced food security. Models of the potential macro-economic effects of restoration financing are therefore needed, to forestall such impacts.

Conclusion and outlook

The guidelines presented here show that reforestation is more complex than is often initially thought. There is no universal, easy solution to a successful initiative. In most cases, restoration goals can only be achieved through creating a mosaic of land uses at the landscape level and by engaging with society at large (Fig. 5).

Despite the inherent complexity of tree-planting initiatives, there are successful examples to build on and develop further. Over the past 30 years, ecologists have transformed the concept of forest restoration to an attainable goal, having developed tools to overcome the technical and knowledge barriers to its implementation through robust scientific research. This means that calls by the UN and many other organizations to restore forest to hundreds of millions of hectares worldwide – inconceivable before – are becoming increasingly feasible. However, achieving such ambitious goals will only happen through careful consideration of the various aspects discussed in this review.

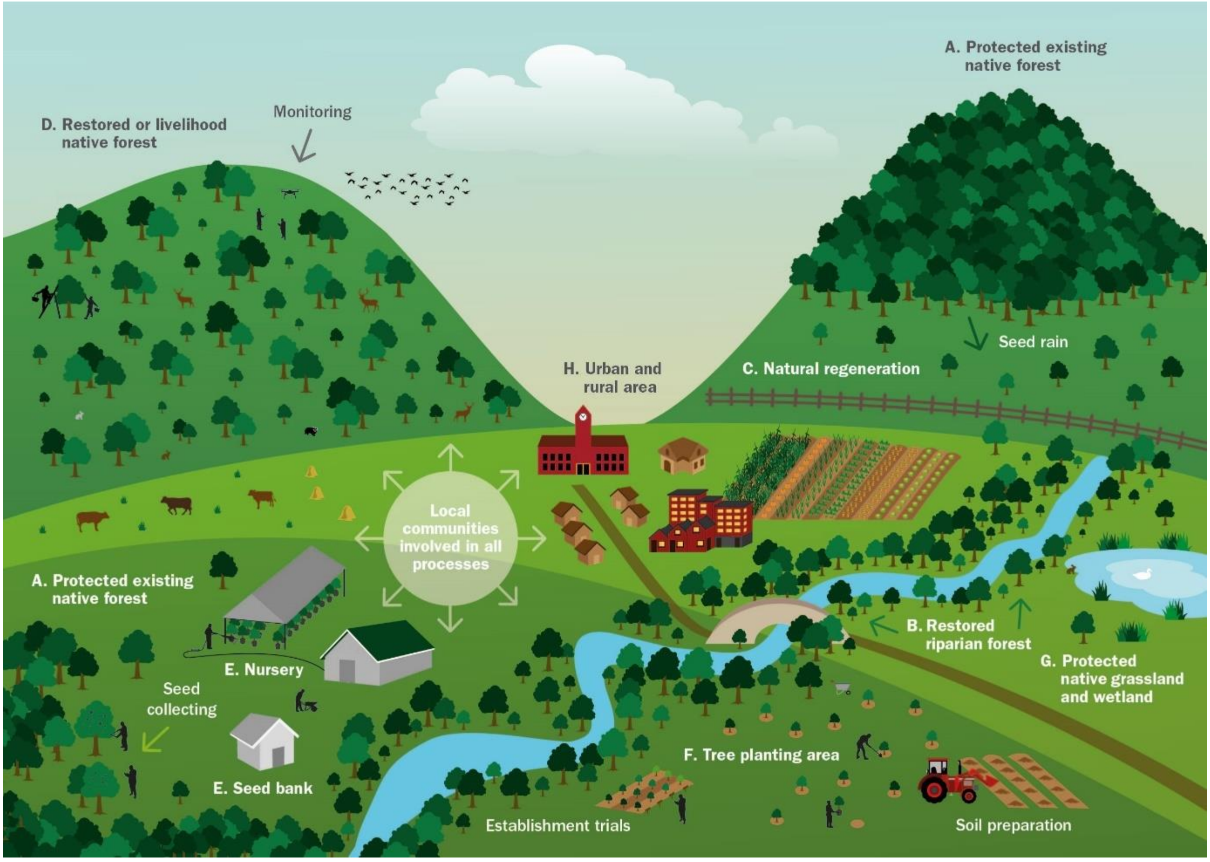


Figure 5. Schematic view of a successful reforestation programme. This landscape contains several components: A) protected existing native forests, either old- or second-growth, where native seeds are collected; B) restored riparian forest creating a biological corridor connecting remaining forest patches; C) a naturally regenerating area, adjacent to an existing native forest that provides seed rain for natural regeneration; D) restored or livelihood native forest, which might include non-invasive exotic useful species for timber and NTFPs, where people monitor biomass and biodiversity recovery; E) tree nursery and seed bank where native seeds are stored and propagated; F) tree-planting area, with a section dedicated to establishment trials; G) protected native non-forest ecosystems, such as grassland and wetland; H) urban and rural areas, with sustainable agriculture and livestock.

Partnerships involving multiple stakeholders (corporates, governments, NGOs, scientists, practitioners, landowners) are likely to yield most long-term benefits. Overcoming the socio-economic and political barriers to forest restoration will also require good governance, long-term funding mechanisms and effective communication among stakeholders at the science–policy–practice interface.

Vast tree-planting programs are now underway across the planet, and these will require monitoring so that learning opportunities are not lost. We need to rely on the best available scientific evidence and carry out carefully planned, replicated, controlled experiments at large spatial scales. This is key to objectively testing and continuously improving the effectiveness of existing socio-economic constructs, such as community forestry, REDD+, FLR, and PES. Critically, politicians and policymakers need to act now to engineer a rapid paradigm shift in the way we protect existing forests and restore new ones using native species, for benefits to people and nature. They should use innovative regulations, incentives and all the levers at their disposal. In 2021, 196 parties to the Convention on Biological Diversity are planned to gather in China to reflect on a decade in which their objective of halting the loss of biodiversity was spectacularly missed. This will provide a unique opportunity for governments to live up to their commitments and responsibilities with actions, not words.

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1404 **Table 1:** Glossary (terms highlighted in bold on first occurrence in the text)

Term	**Definition**
Adaptive management	An intentional approach to making decisions and adjustments in response to new information and changes in context
Afforestation	Creation of forest on areas not naturally forested in recent times
Agroforestry	Restoration and sustainable management of existing agricultural land through integration of trees in the agricultural landscape
Assisted (or accelerated) Natural Regeneration (ANR)	Managing the process of natural forest regeneration to achieve forest ecosystem recovery more quickly, through interventions such as fencing, weeding and enrichment plantings
Deforestation	Destruction and degradation of native forest
Composite provenancing	The use of a mix of mainly local provenance material with a small amount from distant but ecogeographically matched provenances
Existing native forest	Old-growth and second-growth forests.
Forest Landscape Restoration (FLR)	Ongoing process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes.
Forest restoration	See Restoration
Livelihood native forest	Mixed species forest with entirely or mostly native species, managed sustainably to provide local economic benefits
Natural Regeneration (NR)	The process of natural forest regrowth, which can occur spontaneously following land abandonment or be assisted by human interventions (see 'Assisted Natural Regeneration')
Non-Timber Forest Products (NTFPs)	Commodities obtained from a forest without logging, e.g. fruit, honey, mushrooms, medicinal plants
Old-growth forest	Also called primary or virgin forest. Forest that has not been recently disturbed
Orthodox seeds	Seeds that tolerate drying to 5% moisture content and freezing at -20°C (approximately 92% of all plant species), as opposed to recalcitrant seeds that do not survive such conditions and would require cryopreservation (storage at about -196°C in liquid nitrogen) or direct cultivation
Outcrossing species	Species that reproduce by fertilization between gametes produced by different individuals
Payments for Ecosystem Services (PES)	Financial incentives for managing land that provide an ecological service, e.g. watershed protection
Predictive provenancing (also called provenance transfer)	The use of distant genotypes that are experimentally determined to be adapted to projected conditions
Proforestation	Protecting existing natural forests
REDD+	Programme from the United Nations for "Reducing Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries".
Reforestation	Re-creation of forest on a previously forested area
Restoration (forest restoration)	"The process of assisting the recovery of a forest ecosystem that has been degraded, damaged, or destroyed" (Gann et al., 2019)

Restored native forest	Native forest ecosystems reinstated on degraded land
Second-growth (or secondary) forest	Forest grown after recent human disturbance
Seed zone	An area within which plant materials can be transferred with little risk of being poorly adapted to their new location
Selfing species	Species that reproduce by fertilization between gametes within the same hermaphrodite individual

Table 2. Why income-generating forest ecosystem services increase with both biomass accumulation and biodiversity recovery (both of which are higher in existing and restored native forests than in monoculture plantations). Sources: [1]Liang et al., 2015; [2]Mensah et al., 2018; [3]Martin & Thomas, 2011; [4]Steur et al., 2020; [5]Gardon et al., 2020

INCOME-GENERATING ECOSYSTEM SERVICE	Biomass accumulation	Biodiversity
Carbon Storage	About half (~47%) of all tree biomass is carbon[3]	Biodiversity increases biomass accumulation[4]
Forest Products	Biomass accumulation increases the quantity of products	Biodiversity increases the variety of products, providing economic security against fluctuating market prices
Watershed Services I: *Flow regulation (flood/drought mitigation; irrigation for agriculture)*	Biomass accumulation increases organic matter accumulation and thereby soil moisture-holding capacity	Tree species diversity increases interception, decreases runoff (flash floods) and improves infiltration[5]
Watershed Services II: *Soils (erosion landslide mitigation)*	Biomass accumulation increases below-ground root biomass and thereby reduces erosion and landslides	Different tree species root to different depths, decreasing erosion[5]
Ecotourism	Biomass accumulation increases ecosystem structure, niches and biodiversity	Biodiversity-rich native forests attract more ecotourists