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Opinion

Nine actions to successfully restore tropical agroecosystems

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Well-designed approaches to ecological restoration can benefit nature and society. This is particularly the case in tropical agroecosystems, where restoration can provide substantial socioecological benefits at relatively low costs. To successfully restore tropical agroecosystems and maximise benefits, initiatives must begin by considering 'who' should be involved in and benefit from restoration, and 'what', 'where', and 'how' restoration should occur. Based on collective experience of restoring tropical agroecosystems worldwide, we present nine actions to guide future restoration of these systems, supported by case studies that demonstrate our actions being used successfully in practice and highlighting cases where poorly designed restoration has been damaging. We call for increased restoration activity in tropical agroecosystems during the current UN Decade on Ecosystem Restoration.

Highlights

Ecological restoration can enhance the complexity and functioning of degraded ecosystems and deliver socioeconomic benefits.

Restoring agroecosystems in the tropics has an especially high likelihood of yielding ecological, social, and economic benefits, but only if restoration approaches are well designed.

Evidence-based strategies that demonstrate how to restore tropical agroecosystems successfully and tractably are needed urgently to capitalise on the opportunities afforded by the UN Decade on Ecosystem Restoration (2021–2030).

We provide nine actions to guide future restoration of tropical agroecosystems and case studies that demonstrate our actions being applied successfully.

The promise of ecological restoration

Human activity has degraded most terrestrial ecosystems worldwide [1]. Protecting existing pristine areas alone will not achieve conservation and ecosystem service delivery goals; pervasive human impacts on ecosystems must also be halted and reversed [2,3]. Ecological restoration has great potential to reverse the detrimental effects of ecosystem degradation, by enhancing habitat structural complexity [4], benefitting biodiversity [5–9], improving levels of ecosystem functioning and delivery of ecosystem services [5,8–11], and mitigating the effects of climate change [12], while also improving socioeconomic conditions and well-being [13]. Well-designed restoration approaches can deliver multiple ecological and socioeconomic benefits synergistically [12,14,15]. Owing to this, the UN has declared 2021–2030 the Decade on Ecosystem Restoration: a rallying call to heal our planet (https://www.decadeonrestoration.org).

However, restoration does not guarantee benefits to nature or society [16–18], and poorly designed approaches can be damaging. For instance, large-scale tree planting has resulted in few benefits to forest cover or livelihoods in northern India [18]. Mangrove restoration projects in Thailand and the Philippines saw, on average, 80% of planted propagules dying [19]. Using fire to restore native grasses in the Brazilian Cerrado could inadvertently promote fire-tolerant invasive grass species [20]. These studies and others (e.g., [16,21]) show that various contextual factors including, but not limited to, biome and other climatic conditions [22], land-use history [23], stability of government [24], and local community involvement [24] affect whether different stakeholders judge restoration projects as being successful. Therefore, restoration initiatives must start by considering key questions relating to 'who' should be involved in, and benefit from, restoration, and 'what', 'where', 'when', and 'how' to restore.

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Why focus on restoring tropical agroecosystems?

Agriculture is expanding most rapidly in the tropics [25]. Although agricultural production is essential to maintaining food security and improving livelihoods [26], it is also a principal driver of ecological degradation [25] and can contribute to socioeconomic inequity, social conflict, and declines in human well-being [25]. Restoration may have the potential to reduce or reverse many of the negative ecological and social impacts of increased production [8,15].

Strategies for restoring tropical agroecosystems can range from on-farm **ecological intensification** (see Glossary) (e.g., planting of wildflower strips [27]) to removing land completely from cultivation and transforming it to more natural habitat (e.g., re-wetting abandoned croplands in tropical peatlands [28]).

There are high chances that restoring tropical agroecosystems will bring ecological success because, compared with temperate areas, plant growth rates in the tropics are fast, allowing relatively rapid recovery of floral structural complexity and diversity [7]. Also, in many tropical regions, large areas of intact natural habitat remain [29], possibly accelerating the recovery of agroecosystems through spillover of species and ecosystem services [30]. Further, '**Green Revolution**' approaches to intensifying agriculture have been implemented only relatively recently and variably across the tropics [25], potentially making it easier to reverse their impacts [31].

There are also high chances that restoration of tropical agroecosystems will bring social and economic benefits, when strategies are profitable and can be upscaled across large areas of land [15]. Many tropical countries are lower-income and lower-middle-income economies that are heavily reliant on agricultural production [32]. There is therefore potential for large local uptake of restoration strategies that diversify agricultural practices and implement more-sustainable management, which can improve livelihoods by increasing or stabilising per-area yields. However, it is noteworthy that substantial challenges to restoration exist in some regions, such as political regimes that do not support restoration [24].

Nine actions to restore tropical agroecosystems

Despite the high chances of success and benefits that restoration of tropical agroecosystems offers, there is currently a lack of guidance on how best to achieve this, and target objectives are not always reached [33]. Based on our collective experience of restoring tropical agroecosystems worldwide, we present nine actions to improve understanding of the 'who', 'what', 'where', and 'how' to restore these systems (Figure 1). We do not address 'when' to restore, as restoration is clearly needed urgently. Our nine actions identify key areas where improved understanding could increase the success of tropical agroecosystem restoration, and provide tractable steps to help guide future restoration of these systems. Our actions are ordered and somewhat sequential but do not form a mechanistic roadmap, and may need to be used in tandem, in a different order, or perhaps selectively. When actions are relevant to restoration more generally, we provide examples of their use in a tropical agriculture context. We write primarily from an ecological perspective, but consider social, economic, and political factors that may impact ecological restoration. Our actions are as follows.

(1) Involve a diverse network of stakeholders at all stages and in all parts of restoration initiatives

When restoring tropical agroecosystems, projects should involve a wide range of the numerous potential stakeholders, including farmers, land owners, local communities, activists, nongovernmental organisations, members of agricultural industries, **sustainability certification organisations**, academics, consumers of agricultural goods, funders, and policymakers [34–36]. Projects should engage stakeholders from the start, to increase the views that are

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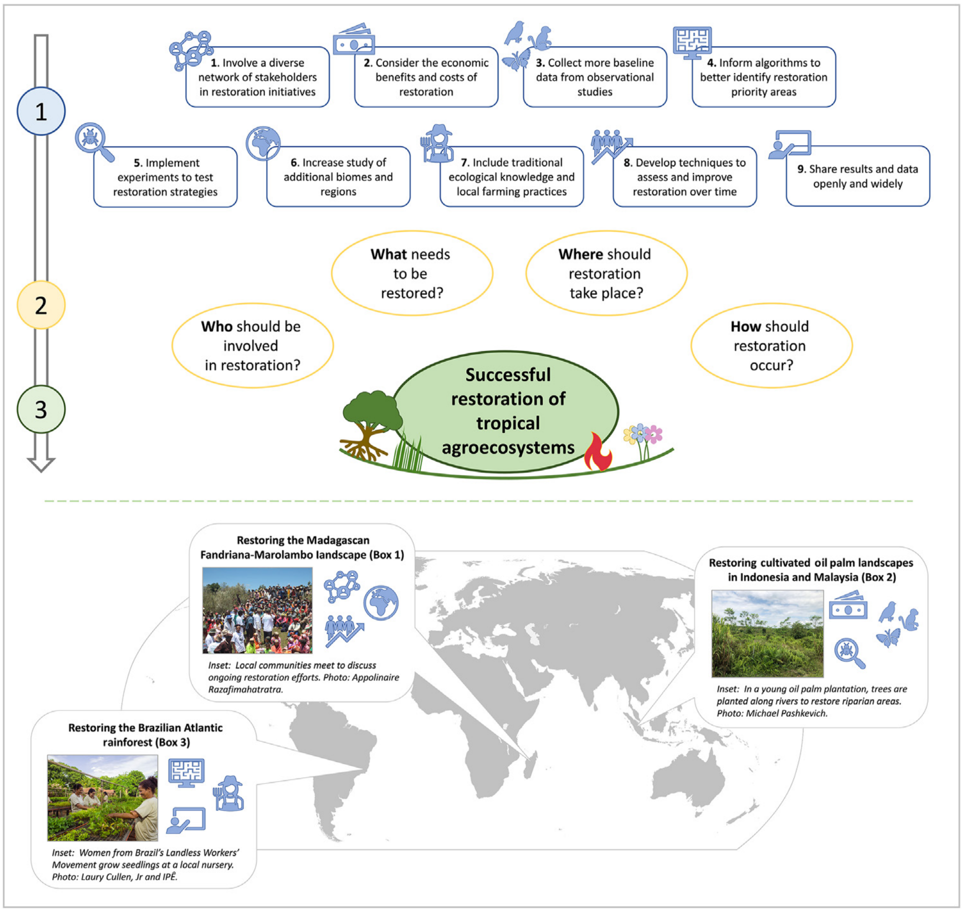

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Figure 1. Nine actions to restore tropical agroecosystems. Top: We provide nine actions (top, blue) that will help to answer key questions (middle, yellow) regarding 'who' should be involved in, and benefit from, the restoration of tropical agroecosystems and 'what', 'where', and 'how' restoration should occur. We do not consider 'when' to restore, as restoration is needed urgently. Answering these key questions will help to increase future successful restoration action in tropical agroecosystems (bottom, green) during the current UN Decade on Ecosystem Restoration. We depict four of the many strategies that may be used when restoring tropical agroecosystems: growing trees, planting native grasses, using prescribed fires, and sowing wildflower strips. The downwards-pointing arrow on the far left indicates the linear relationship between our actions (blue circle, '1'); addressing key questions regarding the 'who', 'what', 'where', and 'how' to restore tropical agroecosystems (yellow circle, '2'); and successful restoration of tropical agroecosystems (green circle, '3'). When discussing our actions (see main text), we also provide tractable steps and success stories to help guide future restoration of tropical agroecosystems. Bottom: Drawing on our experience of restoring tropical agroecosystems globally, we provide three case studies (Boxes 1–3) that show our nine actions being used successfully. We highlight three actions (blue symbols, which match their respective actions at the top of the figure) in each study that are particularly demonstrated on the ground and are referenced in their corresponding sections in the main text, although we note that all case studies use the nine actions to some extent.

considered in decision-making and therefore the likely long-term appropriateness of target objectives, methodologies, and chances of achieving direct benefits for nature and society [37]. Involving local stakeholders is essential to decolonise restoration initiatives that are established or managed by outsiders (e.g., researchers from Europe and the USA), support capacity building, and ensure local ownership over restoration [32]. It is especially important that local farmers and members of agricultural industries are engaged, as they ultimately decide whether to initiate restoration strategies on the ground. For instance, in Ghana, an agroforestry initiative

Glossary

Ecological intensification: agricultural management wherein yields are boosted by enhancing biodiversity and associated ecosystem services in agricultural landscapes.

Green Revolution: period of agricultural history since the 1960s when production was increased dramatically by harnessing new technologies and chemical-based growing methods, but which resulted in habitat degradation, partly owing to overuse of chemical fertilisers and pesticides.

Restoration priority areas: regions where restoration action has maximum ecological and socioeconomic benefits relative to the costs of implementation.

Socioecological data: information relating to the social, economic, and ecological components of a system.

Sustainability certification organisations: organisations that oversee schemes promoting more sustainable production practices by farmers, in return for farmers receiving a price premium for goods. Participation is often voluntary and funded by consumers who are willing to pay more for increased sustainability.

Transdisciplinary: research that addresses societal problems by integrating findings from across the sciences, humanities, and non-research contexts, allowing a system to be viewed as a whole rather than a sum of parts.

obtained long-term support for restoration by consulting with local communities from the outset to determine its project aims [38]. A long-term restoration project in Madagascar involved government forest administration officials and nongovernmental organisations including the World Wide Fund for Nature (WWF), Madagascar National Parks, and the Durrell Wildlife Conservation Trust as well as local farmers, mayors, village chiefs, community elders, and business leaders (Figure 1 and Box 1).

(2) Consider the economic benefits and costs of restoration

Although restoration usually results in higher net economic benefits over time [14], economic benefits are not guaranteed, may not be immediately obvious, and may not sustain local livelihoods in the long term [21]. Therefore, the financial trade-offs of restoration should be assessed and conveyed clearly to all stakeholders. We recommend that practitioners emphasise (and eventually quantify) both direct and indirect economic benefits when restoring tropical agroecosystems. For instance, working pantropically, Garibaldi *et al.* [27] showed that restoring on-farm pollinator communities could directly close yield gaps in small-scale farmlands by 24%. Restoring riparian buffers in tropical agroecosystems has been shown to improve water quality, potentially indirectly improving health and livelihoods for downstream communities [39]. Restoring tropical montane cloud forests in formerly farmed areas led to higher water yields [40], potentially improving local livelihoods by increasing access to water supplies. While all restoration will incur at least some costs, projects should ensure that these do not fall disproportionately on local communities and that, after projects are complete, there are ways that livelihoods can be sustained in the long term [15]. Sustainability certification organisations [e.g., Roundtable on Sustainable Palm Oil (https://rspo.org) (Figure 1 and Box 2), Cotton made in Africa (https://cottonmadeinafrica.org/), Rainforest Alliance (https://www.rainforest-alliance.org)] are particularly promising for offsetting local costs of restoration, since they provide direct financial benefits to farmers [41].

(3) Collect more baseline data from observational studies

Successful restoration of tropical agroecosystems will require increased collection of empirical baseline data as, across the tropics, **socioecological data** are lacking [42]. We need data from reference areas (i.e., regions that are relatively free from human activities or more structurally and ecologically complex than farmlands) to improve understanding of undisturbed ecological networks and to help inform restoration target objectives when restoring abandoned farmland to natural habitat. We also need data from tropical agricultural landscapes that receive business-as-usual management, to assess the extent to which these systems are degraded ecologically, determine how production affects local communities, and provide a reference with which agricultural areas receiving alternative management can be compared [43,44]. We suggest harnessing new technologies to help collect, and process, baseline ecological data more rapidly across spatial and temporal scales, in terms of both resolution and extent. For instance, when testing strategies to restore oil palm agroecosystems (Figure 1 and Box 2), terrestrial laser scanners have been used to measure changes in vegetation growth and structural complexity [4]. Coupling such on-the-ground methods with aerial-borne remote sensing technology offers the possibility to accurately measure restoration progress even in remote areas of the tropics, almost in real time [45,46]. Advances in technology can also help to collect georeferenced socioeconomic data. For instance, in Brazil, farmers submit information on farm ownership, management, and landscape context (e.g., percentage cover of cultivated and natural habitat, including environmentally sensitive areas such as riparian zones) to an online georeferenced database [47]. These data can be coupled with demographic data from government censuses, providing a highly valuable socioecological dataset that restoration scientists can use (Figure 1 and Box 3).

Box 1. Restoring the Madagascan Fandriana-Marolambo landscape

The Fandriana-Marolambo landscape is an area of tropical humid forest in the central eastern region of Madagascar. Although Fandriana-Marolambo has both ecological and sociocultural value, it has been degraded by slash-and-burn cultivation of rice (*Oryza sativa*), which is grown for local consumption, and sugarcane (*Saccharum officinarum*), which is used to produce rum [83]. In 2005, the WWF launched the Fandriana-Marolambo Forest Landscape Restoration Project to counteract the effects of regional agricultural production. The project aims to conserve existing biodiversity, increase the delivery of ecosystem services that are linked to the forest, and improve the well-being of local communities. From its start, the project has involved a diverse network of stakeholders to achieve its goals. These include forest administration officials from the Madagascan government and nongovernmental organisations including the WWF, Madagascar National Parks, and the Durrell Wildlife Conservation Trust, and mayors, village chiefs, community elders, and business leaders [83]. The project was initially managed through a top-down approach (led by the WWF and the Madagascan forest service), but local communities have been consulted throughout the project's duration, allowing community-driven assessment of all restoration activity. These feedback sessions were conducted in the *kabary* (a traditional Malagasy communication style that is often led by community elders and through which important, community-wide decisions are made) and started prior to the implementation of any restoration actions. The WWF and the Madagascan forest department respected all decisions made during the *kabary*, leading to development of trust between stakeholders and paving the way for long-term restoration action [84]. In 2013, more than 95 000 ha of land were protected to form the Marolambo National Park and an additional ~6800 ha were designated for passive or active restoration. The project has provided multiple benefits to local communities, such as diversifying local income sources through altered management of community forests and funding functional literacy courses to help community leaders, especially women, learn skillsets that help in everyday life (e.g., determining prices for goods sold at market). In 2015, management of restoration across the Fandriana-Marolambo landscape was gradually turned over to local stakeholders (Figure I), with the WWF withdrawing entirely from the project in 2018 [83]. Although restoration initiatives remain intact, they have been challenged in recent years by a growing local population, some of whom want agricultural expansion. Restoration advocates are currently in conversation with local communities to ensure that restoration is maintained and expanded upon over the coming years. Restoration of the Fandriana-Marolambo landscape therefore showcases how collaborative action between stakeholders can simultaneously provide ecological and socioeconomic improvements in degraded tropical agroecosystems, and highlights the challenges of maintaining restoration initiatives over the long term.

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Figure I. Rasolo, a local man, who has been commissioned by the community to produce seedlings (*Ocotea* sp. shown) at a local nursery and ensure the continuation of restoration efforts. Photograph: Appolinaire Razafimahatratra.

Box 2. Restoring cultivated oil palm landscapes in Indonesia and Malaysia

Oil palm (*Elaeis guineensis*) is a tropical crop that yields palm oil, the most-produced vegetable oil worldwide [85]. Many oil palm plantations have been established on lands that were previously rainforest, causing severe ecological damage [86,87]. Restoration in oil palm-dominated landscapes can help to reverse these patterns and – in still-productive areas – potentially also improve palm oil yields by increasing the delivery of ecosystem services. As oil palm is a widely grown (>21 Mha [88]) and long-lived crop (its commercial life is 20–30 years [89]), collaborative restoration in plantations can provide benefits across vast spatial and temporal scales. Recognising this opportunity, academics and members of the Indonesian and Malaysian palm oil industries have established restoration experiments in cultivated oil palm landscapes. Importantly, some of these experiments have been co-developed with farmers or land managers, to ensure that findings address questions that are of interest to growers and therefore more likely to result in changes to oil palm management. Several experiments (e.g., [43]) feature a 'business-as-usual' treatment to collect baseline ecological data from oil palm systems undergoing standard management practices and to provide a control against which experimental treatments can be compared. So far, experiments have included passive and active restoration of riparian buffers [43], planting of diverse tree islands (Figure I) (e.g., [4,90,91]), reducing fertiliser use to help mitigate run-off of nutrients into local waterways [92], manipulating the application of herbicides to increase understory vegetation complexity (e.g., [43,92–95]), and intercropping oil palms with other cash crops (e.g., [96–98]). These experiments have been made possible by building local capacity – for instance, by training research assistants to collect and identify specimens, by international collaborations and knowledge exchange between scientists from both industry and academia, and by working with both smallholder and industrial farmers. As a result, these large-scale, long-term experiments have shown that restoration of oil palm agroecosystems is feasible and can benefit a wide range of taxa [4,43,90,92–98], ecosystem functions [92,99], and crop yields [91]. Associated socioeconomic studies help to show how to promote restoration practices in land holdings owned by local communities [100,101]. Findings from experiments have been disseminated to the wider palm oil industry through widely attended industry conferences [e.g., the International Conference of Oil Palm and the Environment (https://icope-series.com/ICOPE/)] and industry publications (e.g., *The Planter* [102]). Furthermore, results are being communicated to sustainability certification organisations, regional certification boards, and members of the public [92,100].

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Figure I. Aerial photograph from EFForTS-BEE, which tests how planting of diverse tree islands affects oil palm ecosystems. Photograph: Watit Khokthong.

Box 3. Restoring the Brazilian Atlantic rainforest

Brazil's Atlantic rainforest is ecologically invaluable and is a global biodiversity hotspot [103]. Additionally, the region has high cultural and socioeconomic value, as it is inhabited by ~130 million people and hosts large- and small-scale agro-industries that are vital to global food security [104]. However, agricultural production has also led to substantial degradation of the Atlantic rainforest [104]. In recent years, efforts to reverse these losses have resulted in some of the most ambitious and large-scale restoration projects globally (Figure I). Restoration has been supported in two main ways: first, by a strong legal framework, for which the cornerstone is the Native Vegetation Protection Law (NVPL) (passed in 2012) [105]. The NVPL states that 20% of all private lands in the Atlantic rainforest must be preserved as conservation set-asides or, if lands are already developed, farmers must restore natural vegetation within their properties or pay to conserve or restore comparable land elsewhere [105]. Underpinning these initiatives is a publicly accessible digital database [called the Environmental Rural Registry, or *Cadastro Ambiental Rural* (CAR) in Portuguese] that contains georeferenced data on farm boundaries, including lands designated for conservation and restoration [106], and can help to determine whether private land owners are compliant with the NVPL. Restoring the Atlantic rainforest is also supported by strong civic engagement. Notably, in 2009 a coalition of government agencies, nongovernmental organisations, private companies, universities, and landowners formed the Atlantic Forest Restoration Pact (AFRP) [107], which aims to restore 15 Mha of degraded forest by 2050. The AFRP has already achieved successful restoration outcomes. For example, the *Instituto de Pesquisas Ecológicas* (IPÊ), a nongovernmental organisation and affiliate of the AFRP, uses the CAR to identify large-scale farms that lack NVPL-mandated set-asides and offers technical support, labourers, and access to agroforestry community-based plant nurseries to farmers who pledge to restore their lands. Many of these cooperative farmers are members of the marginalised Rural Landless Workers' Movement ['Movimento Sem Terra' (MST)], who, compared with industrial-scale farmers, champion local farming practices that maintain relatively high levels of biodiversity, including rare species like the black lion tamarin (*Leontopithecus chrysopygus*) [65]. These efforts have led to the restoration of 1800 ha of forest, and IPÊ-affiliated nurseries have generated ~US$367 000 of income (2016–2019) for the 23 families that manage them [65]. Restoration in the Atlantic rainforest has become a model example of how collaboration between private and public stakeholders can lead to large-scale restoration of tropical agroecosystems, with benefits to both nature and society [108].

Figure I. A riparian corridor in pastured areas in the Atlantic rainforest. Fencing and restoration of forested habitat has helped to improve landscape connectivity. Photograph: Laury Cullen, Jr and *Instituto de Pesquisas Ecológicas* (IPÊ).

(4) Inform algorithms to better identify restoration priority areas

In recent years, algorithms informed by existing data on biodiversity, ecosystem services, and socioeconomic conditions have allowed the identification of **restoration priority areas**. These algorithms have great potential to combine multiple lines of evidence into tractable recommendations for restoration policy. For instance, at a regional scale, the Brazilian Ministry of Environment is using restoration prioritisation algorithms to develop a strategic plan to restore agricultural land in the Atlantic rainforest (Figure 1 and Box 3) [12]. At a global scale, these algorithms have identified where current croplands could be relocated, to mitigate the environmental costs of agricultural production and promote recovery of formerly farmed land [48]. However, algorithms will be more useful to local decision-making if they consider the agricultural potential of landscapes (e.g., prioritising restoration of low-yield areas [15]) and are informed by standardised data from a larger number of regions, biomes, sociopolitical contexts (e.g., 'who owns the land and are they supportive of restoration?'), and farm systems (e.g., industrial vs. smallholder farmlands).

(5) Implement large-scale, long-term experiments to test restoration strategies

Experimental approaches are the gold standard for evaluating the merits of any conservation practice [49]. However, field experiments that test strategies to restore tropical agroecosystems are scarce [50–52]. Experiments should be long term, as, for instance, a restoration project in formerly farmed areas in Costa Rica found dramatic changes in recovery patterns over a 15-year period [53]. We have found before–after control–impact (BACI) experimental designs especially helpful when disentangling restoration effects from natural fluctuations in ecosystem dynamics (Figure 1 and Box 2). In addition, experiments should always consider including natural regeneration (passive restoration) as an experimental treatment, to determine whether more costly active approaches to restoration, such as soil inoculations or tree plantings, are needed [7,54]. Co-designing restoration experiments with industry can form the basis for longer-term partnerships that allow exchange of knowledge and expertise, improve access to facilities and equipment (e.g., [43]), and provide long-term industry funding (e.g., [43]) beyond the lifetime of many research grants [55].

(6) Increase study of additional biomes and regions

Restoration of tropical agroecosystems has, to date, focussed mostly on specific biomes and geographic regions. For instance, with regard to biomes, Buisson *et al.* [20] found that restoration studies in tropical and subtropical forests were more than seven times commoner than similar studies in grasslands and savannahs, and Silveira *et al.* [56] found that leading restoration practitioners tweeted nearly ten times more about forest restoration than grassland and savannah restoration. With regard to geographic regions, global assessments of tropical restoration activity indicate that studies in the Americas and Asia are about 2.5–4.3 times commoner than those in Africa [7,10]. We must increase the study of non-forest biomes and additional regions since agricultural production is often high or increasing in these areas. For instance, the Brazilian Cerrado is a hotspot of pastureland and farmland [57], and agriculture is expected to expand rapidly in sub-Saharan Africa over coming decades, matching population increases [58]. Further, we must broaden our focus of study, as successful restoration approaches are rarely one size fits all, and therefore, successful restoration practices may not be applicable in other areas. For example, although it is beneficial in a degraded forest context [54], it is now well known that planting trees in open ecosystems can threaten native grass and shrub species [20,56]. It is likely that successful restoration initiatives in tropical Africa (Figure 1 and Box 1) will need to place more emphasis on providing direct economic benefits to farmers and local communities, owing to lower incomes in the Afrotropics relative to other tropical regions [32] and greater regional activity of smallholder, rather than industrial, farming [59].

(7) Include traditional ecological knowledge and local farming practices in restoration initiatives

Over millennia, local farmers have developed close relationships with natural systems to protect and improve their livelihoods [60], resulting in a wealth of traditional ecological knowledge that can support productive and resilient agroecosystems [61]. Restoration practitioners should work more closely with members of local communities to include traditional ecological knowledge and local farming practices as experimental treatments when testing restoration strategies, helping to make restoration more **transdisciplinary** in the process [62]. For instance, traditional agroforests of the Lacandon Maya people in Mexico [61] and traditional home gardens in Indonesia [63] and Ethiopia [64] are important habitats that represent a means of restoring local bird biodiversity in agricultural areas. In Brazil, restoration researchers have worked with the marginalised Rural Landless Workers' Movement [*Movimento Sem Terra* (MST)] to champion farming practices that are alternatives to widespread industrial farm management and, by comparison, maintain higher levels of biodiversity (Figure 1 and Box 3) [65]. Including traditional ecological knowledge and local farming practices in restoration planning can also help to ensure that restoration management represents realistic practices that can be adopted by local communities, emphasises the importance of local people when restoring agroecosystems, and preserves aspects of indigenous culture.

(8) Develop techniques to assess and improve restoration over time

When restoring tropical agroecosystems, projects should be assessed regularly and empirically to determine that ecological and socioeconomic target objectives are being reached or whether changes in management are needed. However, it is currently unclear when and how assessment should occur [66]. We recommend that assessment begins before restoration, establishing valuable baseline data. Continued assessment is also needed at key time points in the restoration process. For instance, when using prescribed fire to restore tropical savannahs, assessment should occur soon after burning to assess whether the seeds of pyrophytic species have germinated and several years after re-establishment to assess long-term success [20]. When restoring still-cultivated landscapes, assessments should determine whether restoration is affecting yields and profitability [44]. For example, assessments in Madagascan vanilla agroforests showed that maintaining shade trees increased plot-level biodiversity but had no effects on yield [67]. Involving local communities in assessment can help to ensure that the social and livelihood impacts of restoration are assessed, in addition to ecological impacts. When restoring forests in Madagascar, practitioners have engaged local communities in assessment by respecting their traditional communication styles (Figure 1 and Box 1). To help evaluate restoration success, indicator taxa have been identified in many tropical ecosystems (e.g., [68–72]), alongside more widely applicable measures of ecosystem health, such as water quality and vegetation structural complexity [73], and socioeconomic indicators, such as changes in household income. Recently, a comprehensive set of 61 monitoring indicators was published to help assess the ecological and socioeconomic progress of restoration initiatives (https://globalrestorationobservatory.com/restoration-project-information-sharing-framework/). Individual monitoring indicators can be assessed comparatively (e.g., [74]) or combined into integrated indices (e.g., ecosystem multifunctionality) to showcase how restoration affects a range of different stakeholder interests [75].

(9) Share results and data openly and widely

Methodologies and findings of restoration initiatives must be communicated, to engage stakeholders and increase uptake. Results and data (including contextual data to facilitate comparisons across studies) from individual restoration experiments should be made accessible through online databases and shared with restoration syntheses [e.g., Restor (https://restor.eco/), Global Restore Project (https://www.globalrestoreproject.com), Global Restoration Observatory (https://www.globalrestorationobservatory.com)] to broaden their impact and global relevance [76]. For real change on the ground, it is critical that findings from restoration projects are communicated in a form that allows long-term engagement and education. In Brazil, demonstration field sites have been used to teach both local and outside communities successfully about restoration initiatives (Figure 1 and Box 3) [65]. Blog posts and social media can help to communicate findings to members of the public and inspire them to contribute actively to restoration [56]. Agricultural land managers can be engaged using initiatives such as Conservation Evidence [77], the Cool Farm Tool (https://coolfarmtool.org/), and PARTNERS (https://partners-rcn.org), which provide free online and print summaries of scientific evidence for management actions that can support conservation and methods to assess current practices. Engaging with policymakers and sustainability certification organisations can ensure that restoration findings are incorporated into legal frameworks and payment schemes [41,78], therefore increasing the scope and uptake of restoration efforts.

Concluding remarks: now is the time to develop solutions

The past decades have seen the increased creation of international [e.g., the Bonn Challenge (https://www.bonnchallenge.org/), the New York Declaration on Forests (https://forestdeclaration.org/)] and regional (e.g., the Atlantic Forest Restoration Pact [36], the African Union's 'Great Green Wall' [21]) agreements, global conferences [e.g., the Conference of the Parties to the Convention on Biological Diversity (https://www.cbd.int/cop/), the 26th UN Climate Change Conference (https://ukcop26.org)], and recommendations from academia (e.g., [79]) to protect and restore tropical landscapes. However, increased uptake of restoration efforts is still urgently needed worldwide [2,3]. The current UN Decade on Ecosystem Restoration offers unprecedented attention, research funding, and capacity to support restoration initiatives, aiming to inspire a large-scale, cross-cultural movement for global ecological restoration. Restoring tropical agroecosystems offers particularly promising socioecological benefits relative to the costs of restoration implementation. We must take advantage of these opportunities to improve understanding of the 'who', 'what', 'where', and 'how' of restoring tropical agroecosystems. We emphasise that the actions we have presented are only a starting point for change and acknowledge that there are unique and substantial challenges to restoring tropical agroecosystems, such as land use conflicts [80] and lack of education and awareness on how restoration can benefit biodiversity and livelihoods [81]. Further, it is likely that there will be serious challenges when applying individual restoration strategies across different regions, climatic conditions, surrounding landscape contexts, land-use histories, and crop systems [5,8,9,23,82]. Upscaling restoration can be further complicated when long-term financial support is lacking or when restoration initiatives cross borders [21]. To avoid poorly designed restoration approaches, additional questions on how ecological, social, political, and economic structures affect the success of individual restoration strategies and how to incentivise restoration uptake across the tropics must therefore still be addressed (see Outstanding questions). Despite these challenges, the promising rewards of restoring tropical agroecosystems make it clear that the time to commit to restoration action in tropical agroecosystems – and indeed all global systems – is now.

Outstanding questions

To what extent are individual restoration strategies applicable and effective across regions, biomes, and farm (e.g., industrial vs. smallholder farmlands) and crop systems?

To what extent is the success of individual restoration strategies influenced by social, political, and economic contexts? This commentary has been written from an ecological perspective, with consideration of social, political, and economic factors that may impact ecological restoration. To complement this, further work from a socioeconomic and political perspective would be highly valuable.

What outcomes do local communities want from restoration of tropical agroecosystems and how are these outcomes best investigated and provided?

What are the most effective strategies for minimising cost–benefit trade-offs when restoring tropical agroecosystems?

How can we better incentivise the uptake of restoration strategies across tropical agroecosystems?

Author contributions

M.D.P. led the writing of the manuscript (assisted by S.H.L. and E.C.T.) and figure making (assisted by S.H.L.). S.H.L., D.C.Z., E.C.T., and M.D.P. helped to design the original framework for the manuscript. A.R. led writing of the case study 'Restoring the Madagascan Fandriana-Marolambo landscape'; M.D.P., A.A.K.A., D.B., J-P.C., P.H., H.K., M.N., E.C.T., D.C.Z., and S.H.L. led writing of the case study 'Restoring cultivated oil palm landscapes in Indonesia and Malaysia'; and F.A. and A.D.G.C. led writing of the case study 'Restoring the Brazilian Atlantic rainforest'. All authors provided feedback on drafts of the manuscript and approved the manuscript.

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Declaration of interests

Authors are affiliated with the restoration projects that are outlined in the case studies in this manuscript: A.R. (Restoring the Madagascan Fandriana-Marolambo landscape); M.D.P., A.A.K.A., D.B., J.-P.C., P.H., H.K., M.N., E.C.T., D.C.Z., and S.H.L. (Restoring cultivated oil palm landscapes in Indonesia and Malaysia); F.A. and A.D.G.C. (Restoring the Brazilian Atlantic rainforest).

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