Pathways for implementing forest restoration in the Amazon

Lead authors: Catarina Jakovac (UFSC), Nathália Nascimento (ESALQ-USP)

Co-authors (now in alphabetical order): André Pellicciotti -Secretaria de meio ambiente do Acre, Carolina Fernandes (USP), Daniel Vieira – Embrapa Recursos Genéticos e Biotecnologia, Danielle Celentano - Instituto Socioambiental/Aliança pela restauração na Amazônia, Silvia C. Gallegos - University of Halle, Germany & Herbario Nacional de Bolivia, Silvio Brienza Junior - Embrapa Florestas

Key messages

1. **THE AMAZON IS APPROACHING A CRITICAL TRANSITION** to degradation, posing serious local and global risks, which underscores the urgent need to halt deforestation and promote restoration. Signatory countries of the Paris Agreement have pledged to achieve zero deforestation and restore degraded areas by 2030; however, progress has been limited, highlighting the necessity for immediate action.

2. **ECOLOGICAL RESTORATION IS AN OPPORTUNITY** to foster socio-economic development and avoid the critical transition of the Amazon system if respecting social and ecological safeguards at all levels. Economic and development benefits include income from seeds and seedlings supply, jobs from implementing, maintaining, and monitoring restoration efforts, and empowerment of local communities through capacity building and education.

3. **MAIN CHALLENGES FOR ECOLOGICAL RESTORATION IN THE AMAZON** include a lack of political will to promote a forest-based socio-bioeconomy instead of the expansion of activities over the forests, of a comprehensive governance system that integrates primary forest conservation with restoration efforts, of incentives for multiple stakeholders to promote conservation and protection, of sustainable infrastructure gaps and of investments in education and awareness raising.

4. **FOUR KEY PATHWAYS FOR UPSCALING RESTORATION** are conserving mature forests, promoting natural forest regeneration, including restoration in socio-productive arrangements, and fomenting a restoration supply and value chain.

5. **LARGE-SCALE AND LONG-TERM RESTORATION REQUIRE** a variety of technical and financial strategies tailored to specific ecological, cultural and socio-economic contexts, as well as strong local engagement and multi-sector collaboration.

6. **RESTORATION STRATEGIES SHOULD BE LOCALLY DEFINED** to align with specific goals, socio-ecological opportunities, constraints, and cultural values. Utilizing natural forest regeneration is a promising way for cost-effective ecosystem recovery. In areas with low regeneration potential, productive and biocultural restoration guided by local people and indigenous knowledge and interests can enhance biodiversity and foster community engagement.

Recommendations

1. **National governments** must integrate ecological restoration across ministries and policies to enforce conservation laws, support sustainable forest management, promote natural regeneration, and subsidize restoration supply chains rooted in regional needs tailored to the multiple local actors (e.g. local communities and indigenous people, small to large farmers) and territories (e.g. protected areas, communal lands, private lands).

2. **To establish a robust supply and value chain** for restoration, it's essential to subsidize seed and seedling production, develop regulations for native species, invest in infrastructure for the flow of supplies for restoration and products from the sociobiodiversity, include restoration in transversal bioeconomy programs, and promote capacity building across the region embracing the local knowledge and cultural values in the co-development of solutions.

3. **Financing** must be flexible to support diverse restoration strategies and their varying timelines, including long-term maintenance and monitoring. Tax exemptions on supplies like seeds and seedlings, along with subsidies and payments for Environmental Services, are crucial to reduce high implementation costs.

4. **Capacity building** is essential for promoting ecological restoration principles, Amazonian biodiversity, and social justice among practitioners. It should focus on local institutions, such as rural technical assistance organizations and NGOs, to effectively disseminate knowledge and foster engagement in co-designing restoration strategies that incorporate local ecological knowledge.

1. The Amazon in the UN decade on ecosystem restoration

The Amazon system is close to facing a critical transition towards a degradation condition with local and global consequences (Flores et al 2024). Immediate action is required to stop deforestation, forest degradation and wildfires, while promoting ecosystem restoration and regulate the local and regional climates (Barlow et al., 2021). This includes conserving soils and water, protecting and recovering biodiversity, promoting connectivity, building resilience to adapt to climate changes, foster productivity and human well-being and make restoration possible.

Amazonian countries that signed the Paris Agreement and committed to achieving zero deforestation and restoring degraded and altered areas by 2030 include Brazil, Bolivia, Colombia, Ecuador, Guyana, Guiana Francesa, Peru, Suriname, and Venezuela. In the first Nationally Determined Contributions (NDC) presented in 2015 (i) Brazil proposed to restore and reforest 12 million hectares of forests by 2030, (ii) Colombia has pledged to increase the coverage of their protected areas by more than 2.5 million hectares; (iii) Ecuador planned to curb deforestation and restore 500,000 hectares by 2017 and increase this total by 100,000 hectares per year until 2025, within the National Forest Restoration Program; and (iv) Bolivia intends to increase the area of forested and reforested land by 4.5 million hectares by 2030.

With just 5 years until the agreement´s deadline, Amazonian countries have made limited progress, with an intense increase in deforestation and record fires in 2024, necessitating urgent and robust efforts to achieve conservation and restoration goals. This document builds on prior recommendations (Barlow et al, 2022) to offer guidance for implementing ecological restoration in the Amazon region. Drawing on current science and restoration practices, we suggest pathways for overcoming major challenges and implementing large-scale forest restoration in the Amazon. The focus is on non-flooded forest ecosystems, which cover the largest area. Other important Amazonian ecosystems such as savannas, wetlands, and aquatic systems are not addressed here and require specific and contextual studies.

2. Defining ecological restoration

According to the UN Decade on Ecosystem Restoration, "ecosystem restoration means assisting the recovery of ecosystems that have been degraded or destroyed, along with the conservation of ecosystems that are still intact". This includes a range of practices such as impact reduction, remediation, rehabilitation, and ecological restoration. Ecological restoration seeks to fully or partially recover ecosystem structure, composition, and functions (Gann et al 2019), directed to Amazonian forest ecosystems.

Full recovery requires restoring all key ecosystem attributes to closely resemble a mature or high-integrity reference system (Gann et al 2019; Rosenfield et al 2022). This can be achieved through various strategies including natural regeneration, planting seeds and seedlings, and successional agroforestry systems with different species and spatial arrangements (Barlow et al., 2021).

Partial ecosystem recovery focuses on restoring ecosystem functions while producing goods (productive restoration) and/or recovering cultural values (biocultural restoration). Strategies include managed natural regeneration, mixed species plantings (through seeds or seedlings), and agroforestry systems (Brienza & Yared, 2023). Under the scope of ecological restoration are excluded those land uses that do not sustain forest structure or ecosystem processes, such as monoculture plantations of exotic (e.g. eucalyptus, oil palm) or native species, which offer low conservation value and can drive deforestation (Almeida-Maués et al 2022).

Different strategies can be adopted to achieve forest restoration depending on the goals, the aimed benefits and the socio-ecological enabling conditions (Figure 1). Effective restoration strategies must be defined at the local scale to align with local ecological and socio-cultural contexts, and engage multi-sector stakeholders throughout planning, implementation, monitoring and long-term commitment to protect the area from deforestation and degradation.

3. Pathways for upscaling ecological restoration

The Amazon biome encompasses a vast diversity of socio-economic conditions and actors with unique ways of interacting with the environment and a rich cultural diversity in terms of social organization, economy, and belief systems. Large-scale restoration in the Amazon, therefore, can only be successfully achieved through multiple pathways across the basin.

Ecological contexts where restoration is needed in the Amazon range from landscapes predominantly covered by mature forests with localized small to medium-size degradation (such as illegal deforestation in protected areas and Indigenous lands) up to landscapes in old agricultural frontiers that are largely covered by extensive croplands and pastures and small and degraded forest fragments (e.g. in the Arcs of restoration) (Figure 2). Along this gradient, the degradation level and ecological limitations to restoration increase together with the demand for actively adding biodiversity, for human work and for external inputs (such as seeds, seedlings, and fertilizers).

Socioeconomic contexts can be broadly categorized according to land tenure and legal obligation, into private lands (including legal and/or mandatory restoration, in the Brazilian context), public protected areas (protected areas and Indigenous lands) (Camara et al., 2023), and undesignated public lands where deforestation pressure is highest (Nascimento & Brancalion, 2024) (Figure 2). Cultural values differ within and between such contexts that are populated by different actors such as indigenous peoples, riverine communities, migrants and their descendants, afro-descendent people, and others. Each socio-economic and cultural context brings different challenges and opportunities for restoration.

Therefore, implementing ecological restoration in the Amazon requires local scale co-planning, with local actors, to decide where and how to restore and regional-level pathways fomented by governments and institutions to promote enabling conditions. Below we describe four main pathways for the effective implementation of restoration, which require specific policies and actions and are essential for leveraging large-scale restoration in the Amazon.

3.1 Conserving standing primary forests

Primary forests are those that suffered minimum degradation in the past, holding a high ecological integrity (often named as old-growth forests). The conservation of existing primary and old-growth forests must be the top priority in restoration programs in all socio-economic contexts. Forest remnants must be conserved because (i) are irreplaceable in their biodiversity conservation value and the provision of environmental services and timber and non-timber forest products (NTFP) (Barlow et al., 2007, Gibson et al 2011, Sist et al., 2023), (ii) regulate the climate and help to avoid critical ecosystem transitions (Flores et al 2024), (iii) provide the seeds and animals necessary for ecosystem recovery (Bello et al 2024) and (iv) conserving is much easier and economically cheaper than restoring.

Deforestation and forest degradation undermine restoration efforts by causing local species extinctions, losing plant species needed for seed sources, reducing populations leading to inbreeding and reproductive declines (Chiriboga-Arroyo et al., 2021), and eliminating animal dispersers (Dirzo et al 2014). Large animals are significantly reduced in areas with less than 40% forest cover (Bello et al 2024), limiting the dispersal of large-seeded species to open areas (Galetti et al 2013). Defaunation, especially of large-bodied birds and mammals, impacts seed dispersal of late-successional species and reduces forest diversity (Gardner et al 2019), as well as biomass recovery by 38% (Bello et al 2024). Restoration methods, based on natural regeneration or tree plantings, depend on dispersal from surrounding forests to recover local biodiversity and ecosystem processes (Figure 1).

Illegal deforestation must be stopped in protected areas, undesignated lands and in private properties (Figure 2), requiring establishing and reinforcing legislation, strengthened public policies, law enforcement and solving land tenure conflicts. Land tenure regularization gaps significantly drive deforestation, particularly in undesignated public forests in the Brazilian Amazon. Collective lands, such as Indigenous territories, show the lowest deforestation rates, while private properties and rural settlements, despite having regularized tenure, contribute significantly to deforestation. Public policies of command and control and land tenure regularization programs have helped reduce deforestation in Brazil, from 28.000 Km^2/yr to 4.000 Km^2/yr between 2004 and 2012 (INPE-Prodes, 2023) and could be adopted in other countries to combat land grabbing mainly driven by illegal activities and agribusiness.

Additionally to law enforcement, it is imperative that governments prioritize bioeconomies over the expansion of commodities and large infrastructure projects (Garrett et al., 2023). Forest conservation must be fomented where deforestation pressure is largest such as in undesignated lands and in private properties in the Arcs of restoration where destructive economic models continuously expand over forests (e.g. agribusiness in Bolivia and Brazil, coca plantations in Bolivia and Colombia, and oil palm plantations mainly in Colombia, Brazil and Ecuador) (Barlow et al., 2022).

3.2 Promoting and protecting natural forest regeneration

Natural Forest Regeneration (NFR) is the spontaneous growth of forest communities in deforested areas, leading to secondary forests. If ecological conditions are adequate and there is willingness to protect it in the long-term, NFR can serve as a cost-effective strategy to upsclae restoration. High diversity and rapid recovery potential for NFR are greatest in landscapes with $\geqslant$ 40% forest cover (Bello et al 2024) and following low to mid-intensity land use (<4 fire events and <10 years of continuous use and no mechanized agriculture; Jakovac et al 2021, Heinrich et al 2021), where there is minimal competition with productive uses, and a commitment to protect the area from degradation in the long-term (e.g., fire, cattle).

Secondary forests support numerous species (Lennox et al., 2018), enhance connectivity between forest remnants (Smith et al 2023) and provide services like protecting river margins, regulating climate, and supplying goods (Chazdon et al, 2017). Secondary forests absorb carbon up to 11 times faster than old-growth forests (though they store less) (Poorter et al., 2015). After 20 years, regrowth can recover 80% of soil fertility, carbon stocks, and tree species diversity compared to old-growth forests (Poorter et al., 2021). NFR supports more species diversity at a lower cost than seed and seedlings plantings (Meli et al 2017, Jakovac et al 2023).

Secondary forests currently cover ca. 18.9 million hectares in the Amazon biome but most stands last for less than 10 years (Nunes et al 2020, Smith et al 2023). The effectiveness of NFR as a restoration strategy, therefore, depends on its long-term conservation. It is important to realize that secondary forest fallows within shifting cultivation systems are ephemeral by definition and should not be accounted for as an outcome of restoration. In Brazil fallows account for around 35% of standing secondary forests (Nunes et al 2020). The remaining 65% (ca. 12 million hectares if extrapolated to the Amazon Basin) could contribute to ecological restoration if effectively protected in the long term and monitored (Nunes et al 2020, Smith et al 2023) through awareness raising, economic incentives and public policies targeted to different actors.

Encouraging people and institutions to support NFR requires shifting perceptions through information dissemination and incentives. NFR is often seen as disorganized and less appealing than tree plantations, and neglect by farmers (except when fallow), less marketable to financing agencies, harder to set standards for compared to planted trees, and inadequately compensated by governments for illegal deforestation (Chazdon et al., 2023). Transforming these views involves recognizing NFR as a restoration strategy in the policy and practice arenas (as the Brazilian forest code does), pretecting NRF from deforestation (as the unique Pará state regulation Instrução normativa 05/2015), raising awareness among decision-makers, building capacity among practitioners, and establishing clear indicators for monitoring restoration success (REGENERA-Amazônia, 2023).

Adding value to NRF can additionally incentivize their conservation as many successional species provide useful timber and NTFP (Sist et al., 2023). The economic value and social interest of these forests can be enhanced through enrichment planting, pruning, and selective thinning, for example. For that, forest management regulations need to be expanded to cover different successional stages (Vieira et al., 2014), and knowledge on management practices and valuable species need to be disseminated.

Protecting standing secondary forests could be done in ca. 12 million ha and promoting NFR in an additional X% [to be added after analysis] of Amazonian landscapes (Figure 2). From a joint ecological and socio-economic perspective, NFR will be more effective in recently illegally deforested (public and private) lands because they still hold high resilience, in protected territories (such as indigenous lands and conservation units) where forest cover in the landscape is high, and in legally protected areas within public and private lands where it has low competition with other land use systems.

3.3 Including restoration in socioproductive arrangements

Productive restoration strategies aim to restore ecological functions and generate economic benefits helping diversify the sources of income and contribute to building an Amazonian bioeconomy (Garrett et al., 2023). For that, forest restoration must be included in developmental public policies and productive arrangements as a consumer of products (e.g. seeds, seedlings, fertilizers), supplier of products from the socio-biodiversity (e.g. NTFP, timber, food), and as a provider of environmental services (e.g. water quality, carbon sequestration and storage, climate regulation and biodiversity). Safeguards are important to be followed for avoiding biotic contamination and homogenization that can result from the cultivation of hybrids and few native species.

Productive restoration can enhance income, food sovereignty, empower local communities, and support biocultural restoration, as agroforestry systems and natural regeneration management are integral to local culture. Species typical of early successional stages with established markets, like *Bertholletia excelsa* (brazil-nut), *Carapa guianensis* (andiroba seed oil), *Euterpe* spp. (açaí), and other palm species, as well as timber from *Schizolobium parahyba* var. *amazonicum* (Paricá) and *Goupia glabra* (Cupiúba), and timber and NTFP from *Dypterix odorata* (Cumaru), can be promoted along with other native species. Combining NTFP production with PES can provide further incentives.

To foster productive restoration, it must be integrated as a crosscutting issue in federal and regional governments, extending beyond the environmental sector. Specific credit loans for ecological restoration could incentivize farmer’s adherence. In Brazil, the Acre state promotes productive restoration to comply with the National Forest code, focusing on two main strategies: (i) developing comprehensive legal norms and handbooks to ensure clarity for farmers and government agencies, and (ii) leveraging public and private investments, including climate finance, to support PES and market access for socio-biodiversity products. The approach emphasizes concentrated and contiguous restoration through agroforestry systems on groups of nearby rural properties to maximize economies of scale and foster cooperation among family farmers.

Socioproductive restoration, using strategies like managed natural regeneration, mixed native species, and agroforestry systems, could be promoted where local people can benefit more, such as in private, communal and indigenous lands (both within and beyond legal requirements). For instance, the Brazilian law permits productive restoration in legal reserves, with an estimated 9.4 million hectares needing restoration in the Brazilian Amazon (https://termometroflorestal.org.br/plataforma). Complex multi-species agroforestry systems and managed regeneration may appeal to family farmers and indigenous communities with traditional knowledge of these practices. Conversely, medium and large-scale farmers in the Arcs of Restoration might favor mixed species plantings to diversify income sources currently reliant on monoculture crops and low-productive pastures.

3.4 Structuring a restoration supply and value chain

Implementing ecological restoration at a large scale requires structuring a restoration supply and value chain that will make available seeds and seedlings for tree plantings (especially in degraded landscapes) and promote the circulation and commercialization of forest products within and beyond the Amazon region. The restoration supply chain includes seed collection, processing, quality analysis and commercialization; seedling production, transportation, and planting; area preparation, maintenance and monitoring; transportation and processing in all links of the chain, and engagement of local peoples. The restoration value chain includes timber and NTFP resulting from restoration systems.

Fomenting such, a supply and value chain will help guarantee high species diversity in mixed tree plantings and enrichment plantings while promoting bioeconomy opportunities. Currently, many restoration projects based on plantings fail to meet native species targets due to a shortage of seeds and seedlings from regional nurseries. For example, a restoration project covering 1.25 million km² would require more than twice the capacity of all mapped nurseries in the Brazilian Amazon (Nunes et al., 2020). Upscaling restoration will amplify this demand. Such expansion is also a social development opportunity with the potential to generate 34-146 million USD income to networks of seed collectors (Urzedo et al. 2020). Social co-benefits include the empowerment of indigenous people and local communities (IPLCs) and activation of local agency capacity, fostering social innovation and resilience (Padovezi et al., 2024) and potentially facilitating the trading of forest products derived from forests under restoration.

Several networks of seed collectors are running in the Amazonian countries, but most of them are outside the Amazon region (https://www.sementesflorestais.org/mapa-das-sementes.html). Expanding the offer of seeds requires the social organization of seed collectors which could be facilitated by governments and NGOs. Alongside, a great and decentralized effort is needed for the capacity building of local seed collectors and buyers following scientific guidelines and local ecological knowledge to minimize impacts on standing forests and guaranteeing to restoration sites the use of local ecotypes and high local taxonomic and genetic diversity (Urzedo et al 2020), while avoiding genetic pollution across the region (McKay et al., 2005). Regulations should guarantee seed provenance, identity, phenotypic diversity, and safe sanitary conditions (Redário, 2023).

For seeds from native forest species to reach a restoration site it involves the collection from multiple mother trees in standing forests, processing for sanitary conditions, storing until being sold and transportation and lab analysis for quality and certification. This process is expensive and needs to be time efficient, as most forest species lose their viability within a few months. To reduce seed waste and improve planting success, investments in infrastructure are needed for adequate seed storage chambers near collection sites, efficient transportation logistics, connecting seed producers and buyers and amplifying lab analysis capacity. Tax exemptions and subsidies for seeds from native forest species are imperative for the feasibility of this supply and value chain. Alongside, NTFP derived from restored areas can flow across the region and beyond helping diversify income for local communities and strengthen the bioeconomy market (Garret et al 2023).

Without sufficient and stable market demand, even a robust value chain may undermine the success of restoration efforts, limit social engagement, and reduce the anticipated ecological benefits. Establishing nurseries with continuous and biodiverse production could provide continuity to the market and accelerate high-diversity restoration. In this context, land regularization is essential to guarantee access to market and negotiation spaces. Involving IPLCs from multiple regions in seed collection and nursery establishment will enhance social inclusion, increase their economic incomes, benefit the restoration supply chain, and support the preservation of traditional ecological knowledge and cultural values.

Every Amazon location can be part of the restoration supply and value chain, though some regions are better suited for specific links. Seed collection, particularly for endemic and endangered species, is most effective in conserved mature forests, such as in conservation units for sustainable use and indigenous lands. Pioneer species, crucial for initiating tree plantings, can be collected from secondary forests close to the restoration sites. Seedling nurseries should be prioritized in the Arcs of Restoration (Figure 2), where (enrichment) planting is crucial.

4. Enabling conditions for successful restoration

4.1 Promoting knowledge dialogue

Integrating IPLCs' knowledge with scientific knowledge is crucial for co-designing restoration strategies that are resilient to the changing environmental conditions and adequate to the multiple biocultural contexts. Local peoples hold a vast knowledge of forest ecosystem dynamics and regrowth and of native species germination requirements, tolerance to soil and climatic conditions, species behavior and interactions, as well as plant uses and management requirements for harvesting of forest products (Fleuri, 2017, Eloy et al., 2021; Schmidt et al., 2021).

Knowledge dialogues must also embrace the market and technology sector for optimizing tools and technology for planning and monitoring restoration and for creating socially just and feasible opportunities to boost restoration. Such integration will contribute to engaging local peoples and optimizing existing restoration models to the Amazonian reality, possibly increasing restoration success, promoting the restoration and strengthening of cultural practices and values, empowering local peoples (Schwartzman & Zimmerman, 2005), and increasing the desired long-term permanence of restored forests.

4.2 Investing in capacity building and research

Capacity building is essential for expanding the reach and success of restoration practices through effective planning, design, and monitoring. Practitioners, technicians, consultants, and professionals involved in rural extension and restoration must be well informed about available strategies, natural regeneration potential, and ecological monitoring. Rural extensionists should be trained to raise awareness about the need and opportunities for ecological restoration across the region.

Education on plant and animal biodiversity of Amazonian ecosystems is crucial for promoting diverse restoration, proper monitoring and avoiding biotic homogenization (Holl et al 2022). Information on local species composition in successional and mature forests should be compiled and shared with stakeholders. Courses and training must be promoted on the ecology of restoration, Amazonian forest diversity, and species identification, as well as making available field guides for plant identification, seed collection, and seedling production (e.g., Ribeiro et al. 1999, Ferraz et al., 2004).

Investment should also focus on citizen science and intercultural science to enhance restoration methods and promote biocultural restoration. Research priorities must include ecology (species reproductive phenology, genetics, species physiology, biogeochemistry, and plant-fauna interactions), technology (practices for assisted natural regeneration, seed quality and seed collection, silviculture practices for timber and NTFP, mechanization and monitoring) as well as socio-bioeconomic (economics of restoration, production, markets) (Aliança pela Restauração da Amazônia, 2023). Monitoring and long-term research must be prioritized to allow the proper evaluation of restoration outcomes and increase adaptive capacity to social and ecological changes.

4.3 Financing forest restoration

Forest restoration may be expensive (Zahawi et al 2014), requiring economic incentives for both implementation and long-term maintenance. The greatest costs include land opportunity costs, protection measures (e.g., fencing and fire breaks), supplies (seeds, seedlings, soil amendments), and labor for implementation, maintenance, and monitoring. The costs of implementing restoration depends on the chosen restoration strategy and the area's level of degradation (Figure 1), ranging from 632,93 USD/ha (spontaneous NFR) to 3467,58 USD/ha (mixed species planting with high diversity) (Pará, 2023). In the Amazon, costs might further increase by long distances and lack of infrastructure.

Financing mechanisms should consider the specific needs and various stages of the restoration process, instead of focusing only on the implementation phase. Key steps include planning and engaging stakeholders, implementation, maintenance, monitoring, adaptive management and protection against degradation (e.g. cattle, fire, illegal activities). It is also important to allow flexibility in resource use and timelines, as these can vary based on regional conditions and specific strategies, and to foresee mechanisms for guaranteeing long-term protection to allow the recovery process that might take several decades.

Restoration costs can be reduced through the conservation of standing forests (because it boosts biodiversity recovery), spatial planning (to optimize restoration success and reduce risks; Strassburg et al 2020), improved infrastructure and tax exemptions along the chain. Environmental benefits of restoration should justify cost reductions through tax exemptions and incentives. Restoration reduces agricultural production costs and risks, especially in highly degraded lands such as the Arcs of deforestation. For instance, hydrological regulation from reduced deforestation could prevent USD 1 billion in agricultural losses annually in the Southern Brazilian Amazon (Leite-Filho et al., 2021).

PES including carbon and biodiversity credits, can partially cover restoration costs and incentivize efforts. Carbon investments are increasingly present in some Amazonian countries, mainly focusing on mixed species plantations and silvicultural systems with few species. To contribute to socially just and ecologically meaningful restoration, the carbon market must be regulated and safeguard social and environmental justice. The starting biodiversity credits can be an important financing pathway to help guarantee biodiversity recovery of multiple life forms and taxonomic groups.

Government programs can significantly boost restoration efforts. For example, Brazil's national development bank (BNDES) is channeling ca. 36 billion USD to restore 24 million hectares and remove 1,65 billion tons of CO_2 from the atmosphere by 2050 within the "Arc of Restoration" project. The same bank promotes credit lines for the forest sector that includes forest restoration and may have an important impact in the implementation on the ground. Also in Brazil, concessions for private companies to restore protected public areas in exchange for carbon or biodiversity credits are just starting (Lupion, 2024). Programs for family agriculture also can foster productive restoration. While program diversification is beneficial, it must ensure social justice and a focus on restoring forests with high biodiversity.

4.4 Public policies and governance

Given the numerous challenges to large-scale forest restoration in the Amazon, developing robust, inclusive, and adaptive public policies, alongside innovative financing strategies, is essential. Countries that have a robust set of public policies, though, have not yet been able to implement large-scale restoration because of lack of governance. Governance at multiple levels must integrate strict law enforcement to curb deforestation and protect forests with significant investments in deforestation command and control, research and capacity building, and the promotion of technological solutions to ensure long-term success of restoration efforts.

It is crucial that countries work towards the goals agreed upon between the Amazonian countries, which provide for partnerships in the development of technologies and mechanisms for monitoring and punishing illegal deforestation and protecting areas of forest regrowth. The Amazon Cooperation Treaty Organization (ACTO) can play a pivotal role in coordinating the exchange of deforestation monitoring technology, and forest restoration policies and governance, sharing best practices and harmonizing regulations. Regional civil organizations such as the Alliances for restoration in Brazil and in Colombia are gathering together multiple stakeholders and helping create and empower a restoration community and should be fostered. This requires capacity building for participatory leadership.

Governance structures should be inclusive and adaptive, acknowledging the diverse array of actors and the unique socio-ecological contexts that characterize the Amazon region. For that, countries must promote community engagement to support restoration projects tailored to local needs and co-designed with local stakeholders helping guarantee the long-term permanence of regenerating forests. Continuous monitoring programs for social and ecological aspects need to be put in place to allow adaptive capacity and ensure resilience to social and environmental changes.

The identification of priority areas for restoration, as Brazil and Colombia are doing, is important to channel resources and infrastructure to critical regions. A decentralized restoration support hub in priority areas could bring together agro-industries, research sites, technical assistance, training on how to access financial resources for restoration, and logistical support for local actors. In addition, empowering LPICs, including youth and women, through capacity-building programs will ensure they are equipped with the necessary skills and knowledge to engage in the decision-making processes and to build long-term sustainability into restoration strategies.

Redirecting financial flows from activities that drive deforestation to those that promote restoration, particularly through the bioeconomy, can significantly reduce restoration costs and create sustainable value chains that support low-impact forest products. The first step is to map the gaps and challenges across the various links of the restoration supply and value chain in the different regions of the Amazon. At the same time, national programs should prioritize the implementation of bioeconomy pathways that increase the value, reduce the costs and promote the flow of forest products in sustainable ways (Garrett et al., 2023). It is important that such programs are based on native species, follow ecological and social safeguards, and should involve local actors.

By fostering collaboration and creating enabling conditions through a variety of public policy tools, governments can ensure that restoration efforts across the Amazon are scalable, resilient, and effective. A national roadmap for forest restoration, aligned with international commitments, would further ensure that all sectors are working together towards achieving long-term restoration targets.

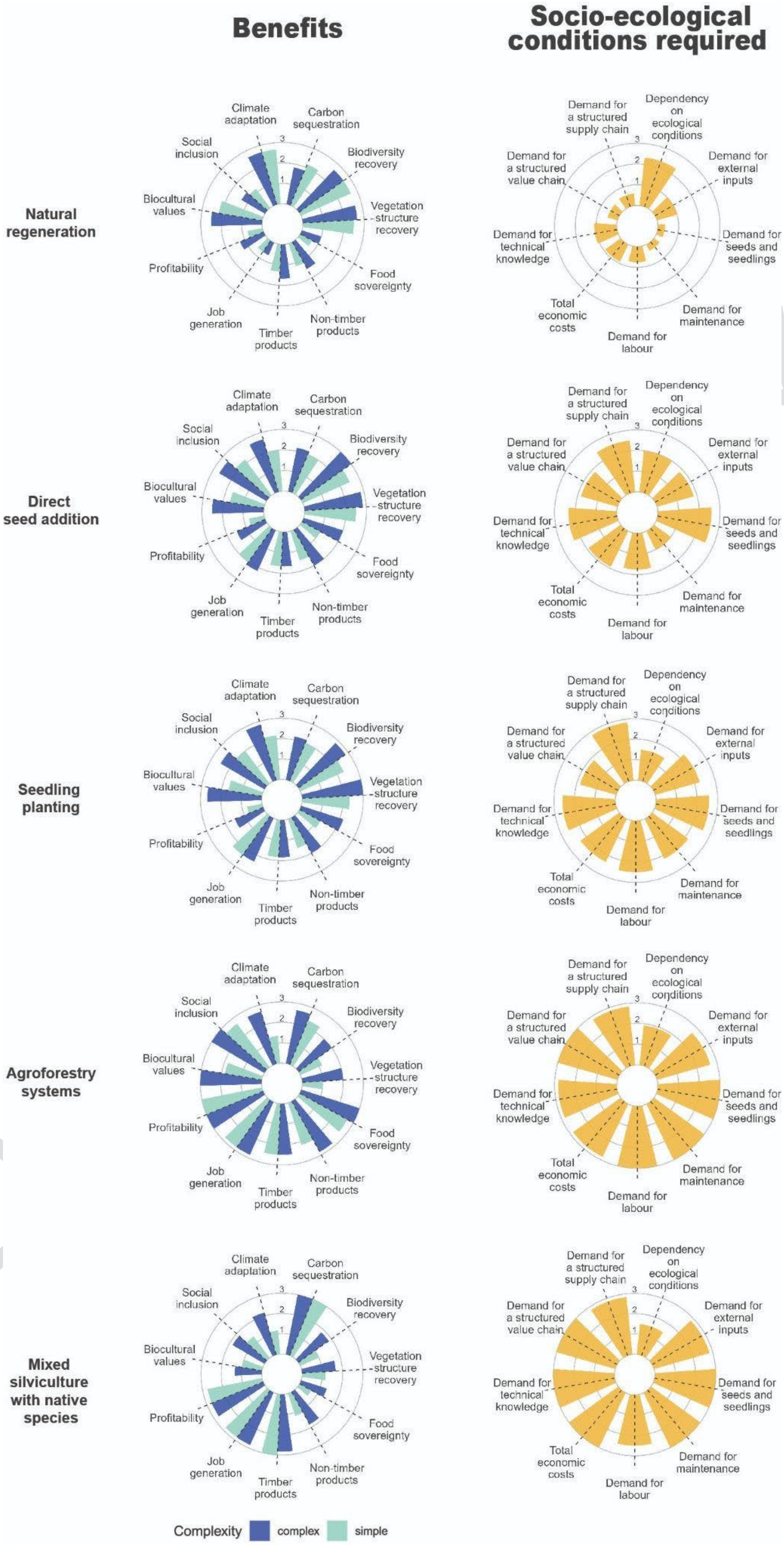
Benefits
Socio-ecological conditions required
Natural regeneration
Direct seed addition
Seedling planting
Agroforestry systems
Mixed silviculture with native species
Climate adaptation
Carbon sequestration
Biodiversity recovery
Vegetation structure recovery
Food sovereignty
Non-timber products
Timber products
Job generation
Profitability
Biocultural values
Social inclusion
Dependency on ecological conditions
Demand for external inputs
Demand for seeds and seedlings
Demand for maintenance
Demand for labour
Total economic costs
Demand for technical knowledge
Demand for a structured value chain
Demand for a structured supply chain
Complexity
complex
simple

Figure 1. Socio-ecological benefits and enabling conditions of five main ecological restoration strategies. Based on expert opinion, we attributed values from 0 to 3 (none, low, intermediate and high) for each axis in the radar plots. In the left column, the axes of the radar plots represent potential benefits of simple (few species) and complex (many species) restoration methods in terms of: Carbon sequestration, Biodiversity recovery, Vegetation structure recovery, Food sovereignty, Non-timber products, Timber products, Job generation, Profitability, Biocultural values, Social inclusion and Climate adaptation. In the right column, the axes represent the socio-ecological conditions required for each restoration method in terms of: Dependency on ecological conditions, Demand for external inputs (fertilizers, machinery, etc.), Demand for seeds and seedlings, Demand for maintenance (cutting, etc.), Demand for labour, Total economic costs, Demand for technical knowledge, Demand for structured supply chain, Demand for a structured value chain.

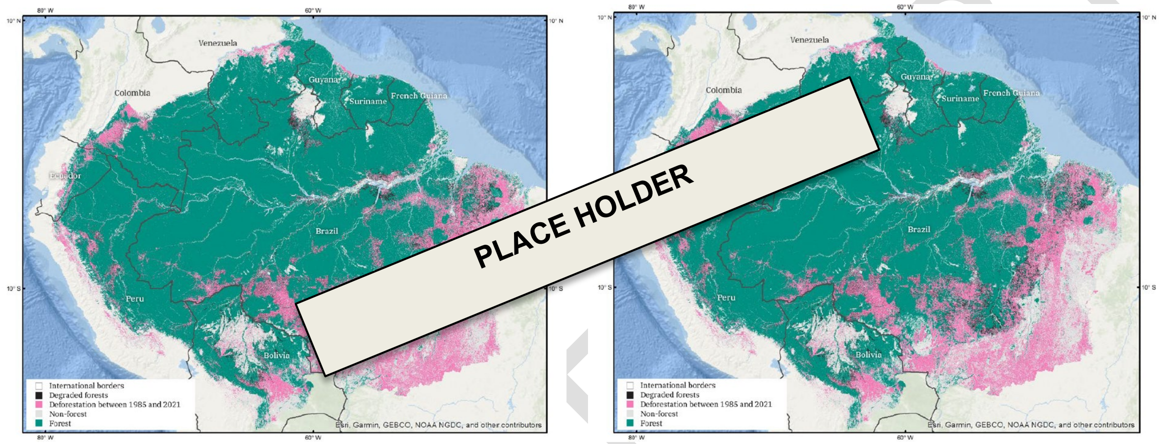

Figure 2. Standing forests, unprotected areas and potential for natural regeneration. To the left**,** map of standing primary and secondary forests to be conserved inside and outside publicly protected territories. To the right, potential for natural regeneration as a restoration strategy in watersheds Otto level 3.

7. References

Aliança pela Restauração na Amazônia, 2020. Panorama e Caminhos para a Restauração de Paisagens Florestais na Amazônia. Position paper: 16p. ISBN 978-65-00-12760-7

Aliança pela Restauração na Amazônia, 2023. Recomendações para as Agências de Fomento para Investimentos em Pesquisas sobre Restauração Ecológica na Amazônia. Aliança: Belém, 6p.Disponível em: https://aliancaamazonia.org.br/

Almeida-Maués, P. C., Bueno, A. S., Palmeirim, A. F., Peres, C. A., & Mendes-Oliveira, A. C. (2022). Assessing assemblage-wide mammal responses to different types of habitat modification in Amazonian forests. Scientific Reports, 12(1), 1797.

Barlow, J., Anderson, L., Berenguer, E., Brancalion, P., Carvalho, N., Ferreira, J., Garrett, R., Jakovac, C., Nascimento, N., Peña-Claros, M., Rodrigues, R., & Valentim, J. F. (2022). Policy Brief: Transforming the Amazon through 'Arcs of Restoration.' Science Panel for the Amazon, Sustainable Development Solutions Network (SDSN). https://doi.org/10.55161/kjcs2175

Barlow, J., Sist, P., Almeida, R., Arantes, C., Berenguer, E., Caron, P., Cuesta, F., Rodrigues da Costa Doria, C., Ferreira, J., Flecker, A., Heilpern, S., Kalamandeen, M., Lees, A. C., Nascimento, N., Peña-Claros, M., Piponiot Laroche, C., Santos Pompeu, P., Souza, C., & Valentim, J. F. (2021). Chapter 28: Restoration options for the Amazon. Amazon Assessment Report 2021. Science Panel for the Amazon, Sustainable Development Solutions Network (SDSN). https://doi.org/10.55161/ospd2912

Barlow, J., Sist, P., Almeida, R., Arantes, C., Berenguer, E., Caron, P., Cuesta, F., Rodrigues da Costa Doria, C., Ferreira, J., Flecker, A., Heilpern, S., Kalamandeen, M., Lees, A. C., Nascimento, N., Piponiot Laroche, C., Santos Pompeu, P., Souza, C., & Valentim, J. F. (2021). Chapter 29: Restoration priorities and benefits within landscapes and catchments and across the Amazon basin. Amazon Assessment Report 2021. Science Panel for the Amazon, Sustainable Development Solutions Network (SDSN). https://doi.org/10.55161/ggir9016

Barlow, J., Gardner, T. A., Araújo, I. S., Ávila-Pires, T. C., Bonaldo, A. B., Costa, J. E., ... & Peres, C. A. (2007). Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. Proceedings of the National Academy of Sciences, 104(47), 18555-18560.

Bello, C., Crowther, T. W., Ramos, D. L., Morán-López, T., Pizo, M. A., & Dent, D. H. (2024). Frugivores enhance potential carbon recovery in fragmented landscapes. Nature Climate Change, 1-8.

Brancalion, P. H. S.; et al (2022). Ecosystem restoration job creation potential in Brazil. People and Nature, 4, 1426– 1434. https://doi.org/10.1002/pan3.10370

Brienza Junior, S. & Yared, J. A. G. Silvicultura de espécies nativas para restauração socioprodutiva na Amazônia. Revista Opiniões, p. 68-70. 2024.

Camara, G., Simoes, R., Ruivo, H. M., Andrade, P. R., Soterroni, A. C., Ramos, F. M., Ramos, R. G., Scarabello, M., Almeida, C., Sanches, I., Maurano, L., Coutinho, A., Esquerdo, J., Antunes, J., Venturieri, A., & Adami, M. (2023). Impact of land tenure on deforestation control and forest restoration in Brazilian Amazonia. Environmental Research Letters, 18(6), 065005. https://doi.org/10.1088/1748-9326/acd20a

Chazdon, Robin L., Blaise Bodin, Manuel Guariguata, David Lamb, Bethanie Walder, Unna Chok-kalingam, Kenichi Shono. (2017). Partnering with nature: The case for natural regeneration in forest and landscape restoration. FERI Policy Brief. Montreal, Canada.

Chazdon, Robin L., Danielle Celentano, Patrick Durst, Mawa Karambiri, Joice Ferreira, Rowena Soriaga, Djibril Dayamba, Mariana Oliveira and Carlos A. de Mattos Scaramuzza. 2023. A status report on Assisted Natural Regeneration: What, why, who, where, and how? ANR Alliance, World Resources Institute, São Paulo, Brazil. ISBN: 978-85-61975-48-7.

Chiriboga-Arroyo, F., Jansen, M., Bardales-Lozano, R., Ismail, S. A., Thomas, E., García, M., & Kettle, C. J. (2021). Genetic threats to the Forest Giants of the Amazon: Habitat degradation effects on the socio-economically important Brazil nut tree (Bertholletia excelsa). Plants, People, Planet, 3(2), 194-210.

Dirzo, R., Young, H. S., Galetti, M., Ceballos, G., Isaac, N. J., & Collen, B. (2014). Defaunation in the Anthropocene. Science, 345(6195), 401-406.

Eloy, L., Ramos, R., Schmidt, M., y Ono, K., Steward, A., & Ferreira, J. (2021). 7.5. Manejo do fogo por povos indígenas e comunidades tradicionais no Brasil. Povos tradicionais e biodiversidade no Brasil: contribuições dos povos indígenas, quilombolas e comunidades tradicionais para a biodiversidade, políticas e ameaças/Seção 7 (org. Laure Emperaire): Gerar, cuidar e manter a diversidade biológica, 7, 72-93.

Ferraz, I. D. K., Camargo, J. L. C., Mesquita, M. R., Eicher, I., Palacios, S., Barbosa, A. S., ... & Pereira, B. T. (2004). Guia de propágulos e plântulas da Amazônia. Manaus, Projeto Dinâmica Biológica de Fragmentos Florestais-INPA.

Fleuri, R. M. (2017). Aprender com os povos indígenas. Revista de Educação Pública, 26(62/1), 277-294.

Flores, B. M., Montoya, E., Sakschewski, B., Nascimento, N., Staal, A., Betts, R. A., ... & Hirota, M. (2024). Critical transitions in the Amazon forest system. Nature, 626(7999), 555-564.

Galetti M, Guevara R, Côrtes MC, Fadini R, Von Matter S, Leite AB, Labecca F, Ribeiro T, Carvalho CS, Collevatti RG, Pires MM, Guimarães PR Jr, Brancalion PH, Ribeiro MC, Jordano P. Functional extinction of birds drives rapid evolutionary changes in seed size. Science. 2013 May 31;340(6136):1086-90. doi: 10.1126/science.1233774. Erratum in: Science. 2013 Dec 13;342(6164):1316. PMID: 23723235.

Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., ... & Dixon, K. (2019). International principles and standards for the practice of ecological restoration. Restoration ecology, 27(S1), S1-S46.

Gardner, C. J., Bicknell, J. E., Baldwin-Cantello, W., Struebig, M. J., & Davies, Z. G. (2019). Quantifying the impacts of defaunation on natural forest regeneration in a global meta-analysis. Nature communications, 10(1), 4590.

Garrett, R., Ferreira, J., Abramovay, R., Brandão, J., Brondizio, E., Euler, A., Pinedo, D., Porro, R., Cabrera Rocha, E., Sampaio, O., Schmink, M., Torres, B., & Varese, M. (2023). Supporting socio-bioeconomies of healthy standing forests and flowing rivers in the Amazon. Science Panel for the Amazon, United Nations Sustainable Development Solutions Network, New York, USA. https://doi.org/10.55161/gaxe5921

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., ... & Sodhi, N. S. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. Nature, 478(7369), 378-381.

Holl, K. D., Luong, J. C., & Brancalion, P. H. (2022). Overcoming biotic homogenization in ecological restoration. Trends in Ecology & Evolution, 37(9), 777-788.

Instituto de Pesquisas Espaciais (INPE – PRODES). Taxas de desmatamento - Amazônia Legal. Disponível em: <http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/rates>. Accessed: 10.10.23.

Ferraz, I.D.K.. (2004). Guia de propagulos & plantulas da Amazônia Local: Manaus, AM Editor: INPA/PDBFF. Paginação: 26.

Jakovac, C., Korys, K. A., Rodrigues, A. F., Ronix, A., Tubenchlak, F., Monteiro, L. M., ... & Latawiec, A. E. (2024). Meta-analysis of carbon stocks and biodiversity outcomes across Brazilian restored biomes. Science of the Total Environment, 906, 167558.

Leite-Filho, A. T., Soares-Filho, B. S., Davis, J. L., Abrahão, G. M., & Börner, J. (2021). Deforestation reduces rainfall and agricultural revenues in the Brazilian Amazon. Nature Communications, 12(1). https://doi.org/10.1038/s41467-021-22840-7

Lennox, G. D., Gardner, T. A., Thomson, J. R., Ferreira, J., Berenguer, E., Lees, A. C., Mac Nally, R., Aragão, L. E. O. C., Ferraz, S. F. B., Louzada, J., Moura, N. G., Oliveira, V. H. F., Pardini, R., Solar, R. R. C., Vaz-de Mello, F. Z., Vieira, I. C. G., & Barlow, J. (2018). Second rate or a second chance?

Assessing biomass and biodiversity recovery in regenerating Amazonian forests. Global Change Biology, 24(12), 5680–5694. Portico. https://doi.org/10.1111/gcb.14443

Lupion, C. (2024, 13 de agosto). Pela 1ª vez, Brasil vai conceder floresta para restauração. DW. Disponible: https://www.dw.com/pt-br/pela-1%C2%AA-vez-brasil-vai-conceder-floresta-para-restaura%C3%A7%C3%A3o/a-70212817. Accessed: 09/20/2024.

Mapbiomas (2023). Colección 5.0 de mapas anuales de cobertura y uso del suelo en la Amazonía entre 1985 al 2022. Available: https://amazonia.mapbiomas.org/. Accessed: 24.06.24.

Meli, P., Holl, K. D., Rey Benayas, J. M., Jones, H. P., Jones, P. C., Montoya, D., & Moreno Mateos, D. (2017). A global review of past land use, climate, and active vs. passive restoration effects on forest recovery. Plos one, 12(2), e0171368.

McKay, J. K., Christian, C. E., Harrison, S., & Rice, K. J. (2005). "How Local Is Local?"—A Review of Practical and Conceptual Issues in the Genetics of Restoration. Restoration Ecology, 13(3), 432–440. Portico. https://doi.org/10.1111/j.1526-100x.2005.00058.x.

Nascimento, N., Brancalion, P. H. S. (2024). Bioeconomia e Restauração Florestal na Amazônia. In: Marcovitch, J., & Val, A. (Eds.). (2024). Bioeconomia para quem? bases para um desenvolvimento sustentável na Amazônia. https://doi.org/10.11606/9786589321453

Nunes, S., Oliveira, L., Siqueira, J., Morton, D. C., & Souza, C. M. (2020). Unmasking secondary vegetation dynamics in the Brazilian Amazon. Environmental Research Letters, 15(3), 034057.

Padovezi, A., Adams, C., Chazdon, R. L., Mendonça, M. A., Secco, L., Campos-Filho, E. M., Sampaio, A., Damasceno, E., Albuquerque, N., Santarem, F., Camargo, M. E., & Pinã-Rodrigues, F. (2024). Native seed collector networks in Brazil: Sowing social innovations for transformative change. People and Nature. Portico. https://doi.org/10.1002/pan3.10692

Pará (2023). Secretaria de Estado de Meio Ambiente e Sustentabilidade. Plano de Recuperação da Vegetação Nativa do Estado do Pará (PRVN-PA). – Belém : SEMAS. 258 p.: il., color.

Poorter, L., Bongers, F., Aide, T. M., Almeyda Zambrano, A. M., Balvanera, P., Becknell, J. M., Boukili, V., Brancalion, P. H. S., Broadbent, E. N., Chazdon, R. L., Craven, D., de Almeida-Cortez, J. S., Cabral, G. A. L., de Jong, B. H. J., Denslow, J. S., Dent, D. H., DeWalt, S. J., Dupuy, J. M., Durán, S. M., … Rozendaal, D. M. A. (2016). Biomass resilience of Neotropical secondary forests. Nature, 530(7589), 211–214. https://doi.org/10.1038/nature16512.

Poorter, L., Craven, D., Jakovac, C. C., Van Der Sande, M. T., Amissah, L., Bongers, F., ... & Hérault, B. (2021). Multidimensional tropical forest recovery. Science, 374(6573), 1370-1376.

Pereira, C. A., Tabarelli, M., Barros, M. F., & Vieira, I. C. G. (2023). Restoring fire-degraded social forests via biocultural approaches: a key strategy to safeguard the Amazon legacy. Restoration Ecology, 31(8), e13976.

REGENERA-Amazônia, 2023. Recomendações para o monitoramento da regeneração natural na amazônia. Manaus, 24p. Disponível em: http://regeneraamaz.pdbff.org.br/publicacoes/ . DOI: 10.5281/zenodo.8347140

Redário e Comitê Técnico de Sementes Florestais.(2023). Desafios e oportunidades para o desenvolvimento da cadeia produtiva de sementes nativas para a restauração de ecossistemas no Brasil. Nota Técnica. 18p.

Ribeiro, J. E. L. S., Hopkins, M. J. G., Vicentini, A., Sothers, C. A., Costa, M. A. S., Brito, J. M., Souza, M.A.D., Martins, L.H.,Lohmann, L. G.,Assunção, P.A., Pereira,E. C., Silva, C. F., Mesquita, M. R. & Procópio, L. C. 1999. Flora da Reserva Ducke. Guia de identificação das plantas vasculares de uma floresta de terra firme na Amazônia Central. INPA-DFID, Manaus, 800 p.

Rosenfield, M. F., Jakovac, C. C., Vieira, D. L. M., Poorter, L., Brancalion, P. H. S., Vieira, I. C. G., de Almeida, D. R. A., Massoca, P., Schietti, J., Albernaz, A. L. M., Ferreira, M. J., & Mesquita, R. C. G. (2022). Ecological integrity of tropical secondary forests: concepts and indicators. Biological Reviews, 98(2), 662–676. https://doi.org/10.1111/brv.12924

Sist, P., Peña-Claros, M., Baldiviezo Calles, J. P., Derroire, G., Kanashiro, M., Mendoza Ortega, K., Piponiot, C., Roopsind, A., Veríssimo, A., Vidal, E., Wortel, V., & Putz, F. E. (2023). Forest management for timber production and forest landscape restoration in the Amazon: The way towards sustainability. Science Panel for the Amazon, United Nations Sustainable Development Solutions Network, New York, USA. https://doi.org/10.55161/wxnq3205

Schmidt, M. V. C., Ikpeng, Y. U., Kayabi, T., Sanches, R. A., Ono, K. Y., & Adams, C. (2021). Indigenous knowledge and forest succession management in the Brazilian Amazon: Contributions to reforestation of degraded areas. Frontiers in Forests and Global Change, 4, 605925.

Smith, C. C., Barlow, J., Healey, J. R., de Sousa Miranda, L., Young, P. J., & Schwartz, N. B. (2023). Amazonian secondary forests are greatly reducing fragmentation and edge exposure in old-growth forests. Environmental Research Letters, 18(12), 124016. https://doi.org/10.1088/1748-9326/ad039e

Schwartzman, S., & Zimmerman, B. (2005). Conservation alliances with indigenous peoples of the Amazon. Conservation Biology, 19(3), 721-727.

Urzedo, D. I. D., Piña-Rodrigues, F. C., Feltran-Barbieri, R., Junqueira, R. G., & Fisher, R. (2020). Seed networks for upscaling forest landscape restoration: Is it possible to expand native plant sources in Brazil?. Forests, 11(3), 259. https://doi.org/10.3390/f11030259

Vieira, I., Gardner, T., Ferreira, J., Lees, A., & Barlow, J. (2014). Challenges of Governing Second-Growth Forests: A Case Study from the Brazilian Amazonian State of Pará. Forests, 5(7), 1737–1752. https://doi.org/10.3390/f5071737.

Zahawi, R. A., Reid, J. L., & Holl, K. D. (2014). Hidden costs of passive restoration. Restoration Ecology, 22(3), 284-287.

Strassburg, B. B., Iribarrem, A., Beyer, H. L., Cordeiro, C. L., Crouzeilles, R., Jakovac, C. C., ... & Visconti, P. (2020). Global priority areas for ecosystem restoration. Nature, 586(7831), 724-729.