Received: 29 April 2020 | Accepted: 10 July 2020

DOI: 10.1111/1365-2664.13725

Journal of Applied Ecology

MANAGING FOREST REGENERATION AND EXPANSION AT A TIME OF UNPRECEDENTED GLOBAL CHANGE

Review

Guidance for successful tree planting initiatives

Pedro H. S. Brancalion[1] | Karen D. Holl[2]

[1]Department of Forest Sciences, "Luiz de Queiroz" College of Agriculture, University of São Paulo, Piracicaba, Brazil

[2]Environmental Studies Department, University of California, Santa Cruz, CA, USA

Correspondence
Pedro H. S. Brancalion
Email: pedrob@usp.br

Funding information
Fundação de Amparo à Pesquisa do Estado de São Paulo, Grant/Award Number: 2018/18416-2

Handling Editor: Cristina Garcia

Abstract

1. A growing number of initiatives at global, regional and national scales propose to plant millions, billions or even trillions of trees as a simple solution to resolve complex environmental problems. However, tree planting is much more complicated than it seems.
2. We summarize the multifaceted decision-making process needed and offer guidelines to increase the success of the proposed ambitious efforts to increase tree cover world-wide.
3. Given the varied definitions of and motivations for tree planting, it is critical that stakeholders work together to clearly define the biophysical and socio-economic goals of each project. Then a series of questions must be addressed about where and how (e.g. planting trees vs. allowing for natural forest re-growth) to most effectively achieve these goals and minimize unintended negative consequences, as well as how, when and by whom success of efforts will be evaluated.
4. Key guidelines to successfully increase tree cover include: (a) first addressing the underlying drivers of deforestation; (b) integrating decision-making across scales from local to global; (c) tailoring tree planting strategies to clearly stated project goals and planning, adaptively managing and evaluating success over a sufficiently long timeframe; (d) focusing on the forest ecosystem as a whole, and not just the trees; (e) coordinating different land uses and (f) involving stakeholders at all stages of the planning process.
5. *Synthesis and applications*. Tree planting, along with other strategies to increase tree cover in appropriate locations and contexts, can make a valuable contribution to ensuring the ecological and social well-being of our planet in coming decades, but only if these efforts are considered as one component of multifaceted solutions to complex environmental problems and are carefully planned, implemented and monitored over a sufficiently long time-scale with stakeholder engagement and broader consideration of socio-ecological complexities.

KEYWORDS

afforestation, carbon stock, climate change mitigation, ecosystem services, forest landscape restoration, forest restoration, forestry, reforestation

1 | INTRODUCTION

Tree planting has a storied and passionate place in the psyche of many human cultures. A well-known proverb advises that 'The best time to plant a tree was 20 years ago. The second best time is now'. In 2004, Wangari Maathai was awarded the Nobel Peace Prize for leading the Greenbelt Movement to plant trees across Africa, and in July 2019, the Ethiopian government garnered extensive publicity when thousands of volunteers planted a record 350 million trees in 1 day. Countless tree planting programmes have been established in the past decade as part of a growing global movement that has promoted tree planting as a panacea for myriad social and environmental problems (Holl & Brancalion, 2020). Currently, there are at least three initiatives to promote one trillion trees on the planet (e.g. 1t.org—World Economic Forum; Trillion Trees—BirdLife International, Wildlife Conservation Society, and World Wide Fund for Nature; Trillion Trees Campaign—Plant for the Planet and United Nations Environmental Program). Reforestation is also a central component of the national commitments to the Paris Climate Agreement and of the United Nations' Sustainable Development Goals and Decade on Ecosystem Restoration (2021–2030). There is no doubt that tree planting will receive unprecedented financial, political and societal support in the next decade. A critical issue is how to make it work.

Well-planned tree planting projects can be a valuable intervention to address some of the most critical challenges of our time, such as mitigating climate change, conserving biodiversity and providing food, wood and income to small landowners (Holl & Brancalion, 2020), but the number of trees planted should not be seen as an end goal. Rather, tree planting is a means to achieve clearly specified goals and should be considered as part of a multidisciplinary decision-making process that thoroughly evaluates trade-offs and uncertainties (Chazdon & Brancalion, 2019). Tree planting is often viewed as the simple act of digging a hole, putting a tree seedling there and filling the hole with soil. But, this short-term, naïve view has resulted in large quantities of money being spent on tree planting efforts that have failed almost entirely (Kodikara, Mukherjee, Jayatissa, Dahdouh-Guebas, & Koedam, 2017). In contrast, a well-planned, multi-year commitment is required to restore a forest, sequester carbon or provide timber.

Previously we succinctly outlined both the potential benefits and unintended negative consequences of tree planting to make the point that tree planting is not a panacea to complex environmental problems (Holl & Brancalion, 2020). Here we draw on a broader literature review to provide detailed, forward-thinking guidance on how to address tree planting complexities to achieve more successful outcomes. We begin by unpacking the varied definitions of, and motivations for, tree planting. We describe the complicated decision-making process required to plan, implement, maintain and monitor projects. We then offer guidelines on how to thoughtfully design projects going forward to enhance their success in increasing tree cover and achieving other project goals.

2 | PEOPLE PLANT TREES FOR MANY DIFFERENT REASONS

Tree planting is an action, not an endpoint. Peoples' motivations for planting trees are varied (Table 1) and often vague, yet have marked consequences for achieving tree planting *success* (i.e. achieving pre-set objectives). Common motivations for tree planting include *restoration* to a semblance of the historical habitat (Table 2) to conserve biodiversity in highly deforested and fragmented *forest* ecosystems (Banks-Leite et al., 2014). In urban areas, dispersed trees provide shade, improve air quality and improve aesthetics (Mullaney, Lucke, & Trueman, 2015). Tree planting is often economically motivated to provide timber and/or non-timber forest products (Table 1);

TABLE 1 Varied motivations for tree planting. Modified from Holl (2020)

Category	Motivation	Examples
Improving environmental conditions	Conserving biodiversity	Species and habitat types
	Enhancing ecosystem processes	Primary production, nutrient and water cycling
	Counteracting climate change	Carbon storage, coastal erosion
Economic	Regulating ecosystem services	Water purification, water supply, air quality, moderation of climate extremes
	Provisioning income and goods	Agroforestry and silvopastoral systems, food, timber and non-timber forest products
	Providing employment	Nursery and tree planting workers, ecotourism
	Improving public environmental image	Companies aiming to market themselves as 'green' businesses
Cultural/ spiritual	Reconnecting with nature and experiential education	Local adopt-an-ecosystem forest restoration projects, community green spaces in cities, enhanced recreational opportunities
	Conserving cultural values	Planting species important to cultural heritage
	Atoning for past damages	Personal renewal through participating in volunteer tree planting projects
	Celebrating and honouring	Commemorating births, deaths or other life events
Legislative	Complying with legislation	Various laws require reforestation (e.g. Brazilian forest code, mine reclamation legislation in various countries, tree planting requirements following timber harvest)

TABLE 2 Commonly used terms in the tree planting and forest restoration literature

Afforestation—Planting or seeding trees on land that was not previously forested (FAO, 2012)
Agroforestry—Trees are planted and/or regenerated in association with agricultural crops and pastures on the same land and at the same time (Liu et al., 2018)
Assisted regeneration—A restoration approach that focuses on actively harnessing any natural forest regrowth capacity of biota remaining on site or nearby (Gann et al., 2019)
Degradation—A level of deleterious human impact to ecosystems that results in the loss of biodiversity and simplification or disruption in their composition, structure and functioning, and generally leads to a reduction in the flow of ecosystem services (Gann et al., 2019)
Forest—An ecosystem dominated by trees, in which tree composition and structure drive most of the functioning of the ecosystem. A widely used operational definition of forest considers it as land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds in situ (FAO, 2012), but the minimum tree cover threshold for an ecosystem to comprise a 'forest' is highly debated
Forest and landscape restoration—A planned process that aims to regain ecological functionality and enhance human well-being in deforested or degraded landscapes (Gann et al., 2019)
Mixed-species plantations—Planting two or more tree species across a targeted area. It can include many tree species (e.g. restoration plantations in high-diversity forest ecosystems) or only two species (e.g. many mixed plantations for productive purposes; Liu et al., 2018)
Monocultures—Planting a single tree species, and often a single clone, across a targeted area. Monocultures have usually been established to supply industrial demands of forest products (Liu et al., 2018)
Natural forest regrowth (also referred to as passive restoration or natural regeneration) —An approach to restoration that relies on spontaneous increases in biota without direct reintroduction after the removal of degrading factors alone (Gann et al., 2019)
Reforestation—Planting or seeding trees on land that was previously forested (Gann et al., 2019). The species used may or may not be native. This intervention may be undertaken as part of forest restoration or for specific uses such as timber production, carbon storage or agroforestry
Restoration—The process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (Gann et al., 2019). The target is usually a reference model informed by the historic ecosystem
Tree planting—The action of establishing trees in a targeted area, which is usually achieved by introducing nursery-grown seedlings, yet other planting stocks such as seeds or cuttings can also be used
Success—Achieving pre-set goals and quantifiable objectives for tree planting projects. Tree planting success is then a context-dependent, value-laden term, that will be determined by the association of stakeholder's expectations with project performance evaluated by assessing whether pre-defined, quantifiable objectives have been achieved

these projects usually consist of intensively managed *monocultures* to maximize production (Liu, Kuchma, & Krutovsky, 2018). Planted forests covered 280 million hectares globally in 2015, representing only 7% of the global forest area (Keenan et al., 2015), but plantations supply a third of the global industrial demand for roundwood with projections to achieve 50% by 2040 (Jürgensen, Kollert, & Lebedys, 2014). Increasingly, tree plantings have been established to provide ecosystem services (Lamb, 2018) and have employed *mixed-species plantations* and *agroforestry* (Liu et al., 2018). Many recent tree planting efforts are part of national commitments to *forest and landscape restoration*, which combine protective and productive *reforestation* schemes for increasing tree cover across heterogeneous, multipurpose landscapes (Table 2; Chazdon, Gutierrez, Brancalion, Laestadius, & Guariguata, 2020).

The reasons for planting trees vary among stakeholder groups and harmonizing these different expectations is often challenging. For instance, a global corporation aims to offset its greenhouse gases emissions and provides funding for a conservation organization to plant trees with the priority of maximizing habitat availability for threatened species. The conservation organization does not own land, so it uses the money to plant trees on farmers' land. Most farmers, in turn, will only plant trees in areas with lower agricultural productivity and of species that provide direct benefits (e.g. fruit crops, erosion control along waterways), which may result in planting trees in areas or with species that provide sub-optimal outcomes for both carbon stocking and biodiversity conservation. Although tree planting may contribute to achieving many goals, it is impossible to simultaneously maximize them all, as evidenced by the abundant literature on ecosystem services trade-offs (Turkelboom et al., 2018; Wang et al., 2019) and discussed in the next section.

3 | TREE PLANTING IS MORE COMPLICATED THAN IT SEEMS

3.1 | Tree planting has complex outcomes and can have unintended negative consequences at multiple scales

Many tree planting efforts are motivated by the general 'tree planting is good' mentality, but widespread tree planting has much more complex effects on carbon and hydrological cycles, local and global temperature, biodiversity and social issues than most people recognize (Bonnesoeur et al., 2019; Luyssaert et al., 2018; Temperton et al., 2019) and may actually result in ecosystem 'disservices' (Shackleton et al., 2016). The balance of positive and negative effects depends strongly on where and how tree planting is done (Figure 1). For instance, increasing cover of a diversity of tree species can benefit forest-adapted birds, mammals, insects, plants and other species (Crouzeilles et al., 2016). But, a large number of tree planting initiatives are based on industrial monocultures of exotic trees, mostly pines and eucalypts (Lewis, Wheeler, Mitchard, & Koch, 2019), which may result in marked trade-offs between timber production and biodiversity. Moreover, in more arid ecosystems, extensive tree planting may increase the risks of massive fires (Bowman et al., 2019) that can destroy forest remnants and decimate vulnerable native species.

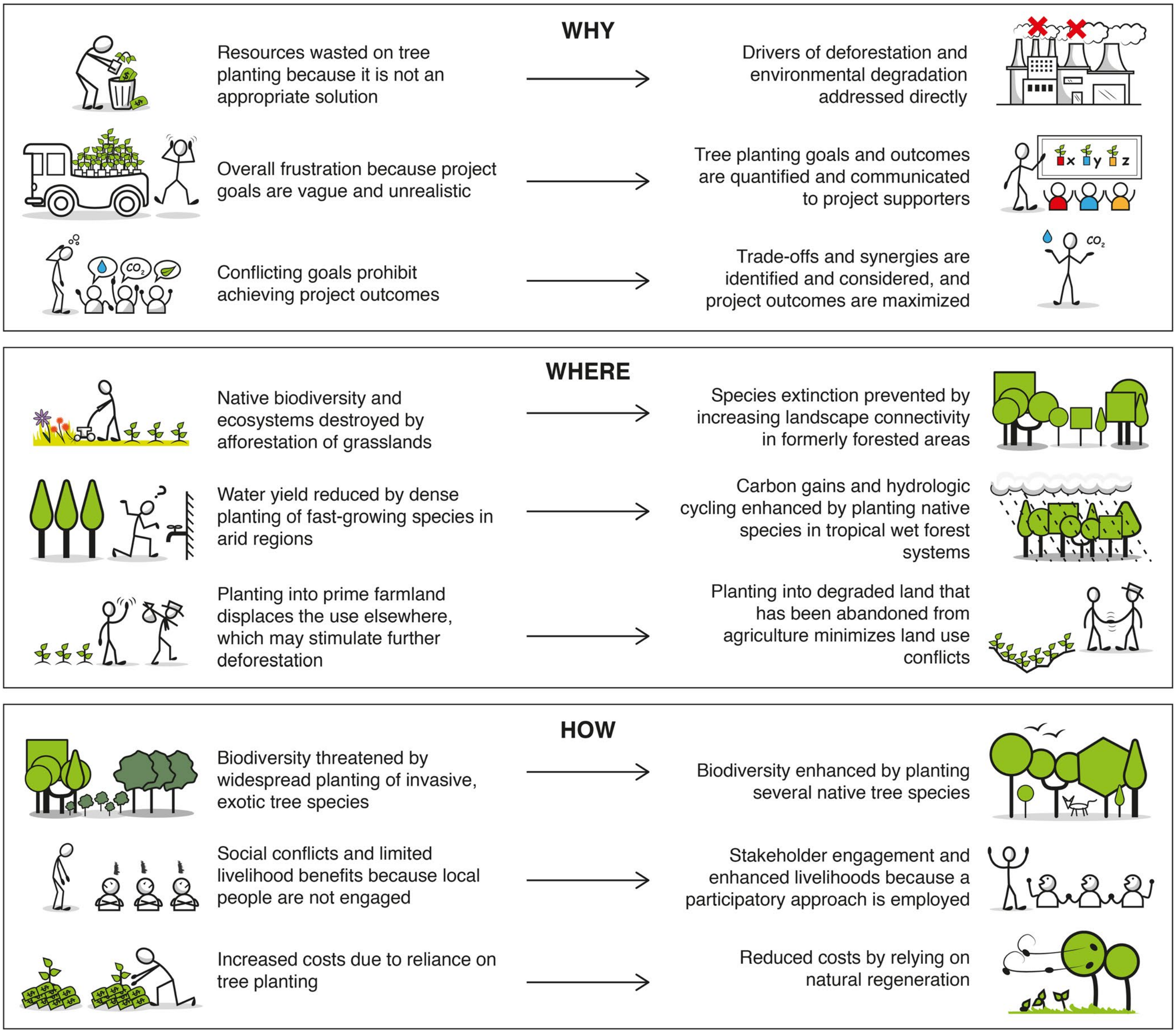

FIGURE 1 Outcomes depend on why, where and how tree planting is done

Tree planting can be especially problematic in native non-forest ecosystems (Veldman et al., 2015), which are often overlooked by restoration and conservation policies. Tree planting can destroy the rich and unique biodiversity of ancient grasslands and savannas, in which many herbs and grasses are shade-intolerant and adapted to disturbances such as grazing and fires (Bond, 2016). Therefore, defining whether a target area was historically covered by forests is not a mere detail, but is one of the most important steps of a reforestation initiative (Figure 2).

Changes to the water cycle provide a good example of the complex effects of tree planting. At the catchment scale, increasing tree cover often reduces local water yield due to increased evapotranspiration (Filoso, Bezerra, Weiss, & Palmer, 2017), particularly in more arid regions (Farley, Jobbagy, & Jackson, 2005). At the regional scale, the added evapotranspiration of planted trees contributes to moisture redistribution (Ellison et al., 2017) and cloud formation through the emission of volatile organic compounds that serve as moisture condensation nuclei (Spracklen, Bonn, & Carslaw, 2008). However, the additional rain may fall on areas far beyond the project boundaries. For instance, an important share of the rainfall that sustains agriculture in Brazil results from the moisture produced in the Amazon (Lovejoy & Nobre, 2018). The impacts of tree planting on climate are even more uncertain. Global estimates of the carbon sequestration potential of forest regrowth vary more than 10-fold (Fuss et al., 2018), and there are multiple feedback loops with albedo, carbon dioxide concentration in the atmosphere, emissions by trees of volatile organic compounds that are potent greenhouse gases and changes in rainfall patterns that complicate the assessment of the overall climatic impacts of tree planting (Lewis, Mitchard, Prentice, Maslin, & Poulter, 2019; Swingland et al., 2002). Quantifying the final balance of the multiple hydrological processes and climatic feedback is a major research challenge (Ellison et al., 2017). Moreover, the high

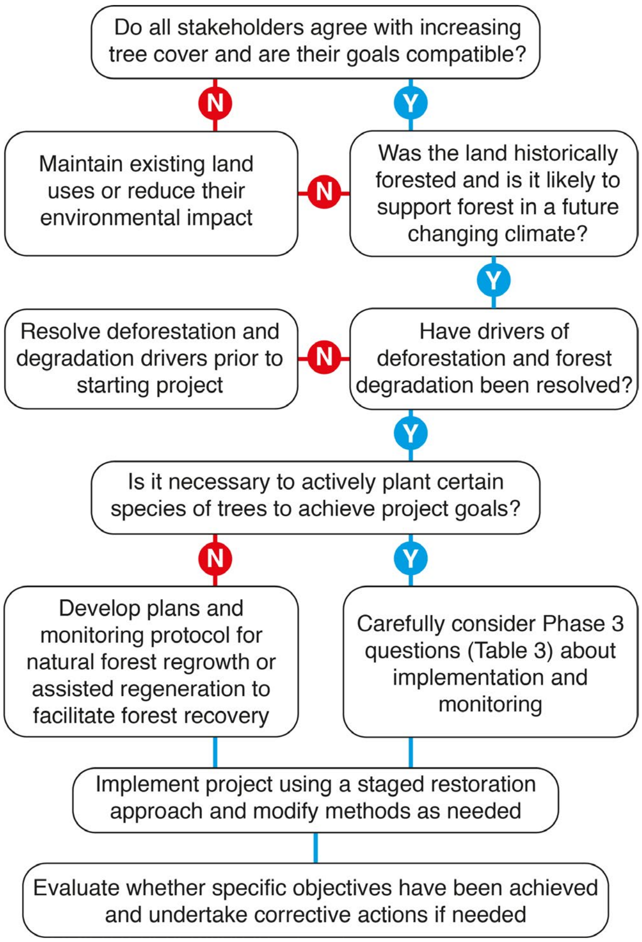

FIGURE 2 Key decisions in planning for projects to increase tree cover. More detailed questions to be addressed at each stage are discussed in Table 3. This figure was based on Crouzeilles, Alexandre, et al. (2019)

level of uncertainty regarding whether locations that are currently climatically suitable for forests will remain so in the future is a major concern (Anderegg et al., 2020).

Tree planting has equally complex effects on social systems (Figure 1). Tree planting is commonly promoted to provide a range of social benefits, such as increasing shade and encouraging physical activity in urban areas (Mullaney et al., 2015) and providing income to landowners from selective harvesting of timber and non-timber products in rural areas (Baral, Guariguata, & Keenan, 2016). At the same time, external investments to promote forestry and carbon farming have dispossessed local people from land in several developing countries (Borras, Franco, Gómez, Kay, & Spoor, 2012; Scheidel & Work, 2018), thus leading to appropriation of their land and resources for environmental ends (Fairhead, Leach, & Scoones, 2012). In other cases, reforestation has displaced agricultural land uses and caused degradation elsewhere (Meyfroidt, Rudel, & Lambin, 2010). Many of these problems can be minimized if tree planting follows the guidelines discussed below. Moreover, some software and modelling approaches may help to evaluate and balance these trade-offs in reforestation planning (Strassburg et al., 2019).

3.2 | Planting trees is not always the best solution to increase tree cover

The most appropriate strategy to increase tree cover depends on the project goals, rate of natural recovery, resources available, legal and normative frameworks and specific local constraints (Chazdon, Lindenmayer, et al., 2020; Holl & Aide, 2011), which should all be considered before deciding to plant trees in a site. Actively planting trees is the most efficient way to establish trees in urban areas and to provide timber and/or non-timber forest products, as it allows better control of plantation composition, spacing, silvicultural treatments and harvesting. Conversely, the most cost-effective way to increase tree cover to obtain environmental benefits is not necessarily by planting trees, but by allowing them to regenerate naturally, particularly in sites with nearby seed sources and less intensive past land uses (Chazdon, Lindenmayer, et al., 2020). *Natural forest regrowth* (Table 2) has been the main driver of forest cover increases throughout the Americas and Europe over the last decade and has the benefit of relying less on costly, labour-intensive human interventions and resulting in more favourable ecological outcomes than tree planting (Chazdon, Lindenmayer, et al., 2020).

A broad suite of management actions can *assist regeneration* (Table 2) of naturally recruiting trees and reduce the need for costly tree plantings, such as site protection through fencing and firebreaks, weeding competitive grasses and ferns and controlling climbers (Holl & Aide, 2011). In lands where natural forest regrowth is slower than desired, small patches or strips of trees may be planted throughout the site, rather than planting the entire area, to improve regeneration conditions while reducing planting and maintenance costs and increasing habitat heterogeneity (Holl et al., 2020). At sites where early successional species resprout or colonize quickly, but large-seeded species are dispersal limited, enrichment seeding or planting of later successional species can be a cost-effective strategy to enhance tree diversity and introduce desired species.

3.3 | Successful tree planting efforts require a multifaceted decision-making process

A host of challenging questions have to be answered about why, where and how to plant trees (Figure 2; Table 3). Key questions to address at the outset include identifying the goals of different stakeholders and determining whether they are compatible (Guideline 2), identifying the most promising sites to achieve these goals while ensuring that the site was historically forested and is likely to support forest in the future and resolving the drivers of deforestation (Guideline 1). The second phase of planning must consider what reforestation strategy is most appropriate to achieve project goals and how landowners and local communities will be engaged in the project. Then a host of decisions must be made about implementation and monitoring (Table 3: Phase 3), many of which do not have a single right answer, Even the question of 'which species to plant'? is not a mere detail, as there may be hundreds of native and commercially

TABLE 3 Key questions to address as part of projects to increase tree cover. Goal setting and general planning questions need to be coordinated across organizational scales. Planning for implementation and monitoring will mostly be done at the local scale but will be informed by expertise, experience and oversight at the regional scale. Monitoring will be conducted at the local scale but should be informed by regional monitoring plans to enable comparisons of outcomes, as well accountability of programmes. Phases 1–3 should be completed prior to implementing projects

Phase 1: Goal setting and determining project suitability
What is/are the biophysical and/or socioeconomic goal(s) of the stakeholders involved in funding or implementation? Have stakeholders at all scales been involved in discussions and differences in goals among scales been resolved?
Where can the goals best be achieved and negative consequences minimized? Is it feasible to achieve the desired goals in the selected locations?
Was the area forested historically and, if so, what was the natural density of tree cover?
Based on available models is the area likely to support trees over the next several decades?
Have the drivers of deforestation and human disturbances that affect tree planting and forest recovery in the region and at the project site been identified and controlled as much as possible prior to project implementation?
Phase 2: General project planning
What is the most cost-effective way to achieve the agreed upon project goals? Is it necessary to plant trees to achieve the goals?
What are potential unintended consequences of tree planting at the project location?
What regulations, if any, affect tree planting?
How much will it cost and who will pay for the cost to fence the land; plant, care for and monitor trees; undertake other forest restoration strategies; and protect the site from human degradation?
Who will grow the seedlings and plant, care for and monitor the trees or implement other restoration strategies?
Is land tenure secure and how will landowners be compensated for lost income?
How will local people be engaged in these activities?
Have gender considerations been assessed in the context of tree planting and tending?
Phase 3a: Planning for implementation
What existing sources of information are available to inform reforestation efforts, such as regional manuals, forestry departments or academic institutions?
Which and how many species will be planted, and how will those species be distributed over the planting area? At what density will seedlings be planted?
What will be the source of the genetic material used and have guidelines been established for ensuring sufficient genetic diversity? Is there enough planting material?
Are the species and genetic material selected appropriate for current and future abiotic conditions?
During which period of the year are climatic conditions most favourable to plant or seed trees?
What specific site preparation (e.g. soil preparation, weed control, fencing), tree planting (e.g. mechanical planting vs. hand planting or seeding) and maintenance methods (e.g. irrigation, weed control, fertilization) will be used? Will herbicides be used?
How will planters be trained on the correct planting methodology and appropriate safety measures to minimize labour accidents?
How will specific methods be tested as part of staged-restoration prior to scaling up?
Phase 3b: Planning for monitoring
What quantifiable objectives that correspond to project goals will be used to evaluate project success?
Which variables will be monitored to evaluate whether objectives have been achieved?
How often, for how long and at what time of the year will these variables be measured?
Who will do the monitoring and be responsible for quality control?
How will the monitoring data be used and by whom?
Are there trigger points to initiate follow-up management actions if objectives are not achieved?
How will monitoring data be aggregated and analysed across multiple sites?
Phase 4: Monitoring and adaptive management
What are the survival and growth rates of trees, as well as amount of natural recruits?
Are the goals and objectives of tree planting being achieved and, if not, that corrective action will be taken to improve performance?
Are unintended consequences of tree planting being observed and, if so, what corrective actions will be taken?
Were relevant drivers of deforestation and human disturbances effectively controlled and, if not, what actions will be taken?

valuable exotic species to choose from, each with specific characteristics that affect tree planting outcomes (Brancalion et al., 2018; Kettle et al., 2010), such as growth rate, life span, conservation value, genetic diversity and provenance of seeds and economic and cultural use. The potential advantages and disadvantages of different species need to be weighed carefully to match the project goals.

The multidisciplinary knowledge, data and tools needed to deal with such complex decisions, including developing and implementing monitoring protocols, may not be available, especially in tropical developing countries, which comprise 140 out of the 170 million hectares already committed to the Bonn Challenge (Brancalion, Niamir, et al., 2019). For example, tree planting requires extensive knowledge of seed collection and propagation methods, as well as nursery facilities, which often are not available. Large-scale reforestation initiatives increasingly utilize remote sensing and mapping of soils, topography, tree and forest cover and other biophysical variables to prioritize and choose species for specific planting locations, but have usually ignored livelihood issues (Boillat et al., 2017). Large-scale social surveys are critically needed to assess people's perceptions, expectations and financial constraints in relation to large-scale reforestation. Hence, scaling up efforts to increase forest cover will require extensive multi-disciplinary capacity building in many regions (Bloomfield et al., 2019).

4 | GUIDELINES FOR IMPROVING TREE PLANTING OUTCOMES

We advocate that thoughtful, well-planned tree planting, along with allowing for natural regrowth and protecting existing forest, are important components of ensuring the ecological and social well-being of our planet in the coming decades. To that end, we provide guidelines for better integrating tree planting into overall landscape management and offer a list of questions that need to be addressed (Table 3). These guidelines are explicitly or implicitly considered amongst the principles of other organizations focused on ecological restoration (Gann et al., 2019), forest landscape restoration (Besseau, Graham, & Christophersen, 2018) and forest management (FSC, 2015), which have helped to inform the recommendations for tree planting programmes associated with the UN Decade on Ecosystem Restoration (UN, 2020) and the World Economic Forum 1t.org Initiative. Here we succinctly synthesize and explain these key guidelines to facilitate their incorporation into tree planting projects.

4.1 | Guideline 1: Address the underlying drivers of environmental degradation

It is essential to address the drivers of forest degradation and destruction, as it is impossible to increase net tree cover if these drivers are still operating. A recent study of 11 tropical countries shows that the area of natural forests cleared between 1990 and 2010 outpaced gains in planted tree cover by 1.5–2.3 times (Sloan, Meyfroidt, Rudel, Bongers, & Chazdon, 2019). Preventing forest clearing, better managing existing forests and allowing for natural forest regrowth are more cost-effective natural climate solutions than planting trees (Chazdon, Lindenmayer, et al., 2020; Houghton, Byers, & Nassikas, 2015). Most meta-analyses suggest that recovering forests provide less carbon storage, nutrient cycling and biodiversity conservation values than intact ecosystems (Crouzeilles et al., 2016; Jones et al., 2018). Moreover, if forests do recover the desired characteristics, it takes at minimum a few decades and often much longer, during which these ecosystem services are lost (Moreno-Mateos et al., 2017).

Hence, the highest priority should be to identify and address the most important drivers of forest loss and degradation and integrate protective measures as part of tree planting initiatives. To this end, the 1t.org and trilliontrees.org initiatives explicitly include ending deforestation and protecting forests from degradation as part of their ‘tree planting’ scope. It is important to recognize that the primary drivers of forest loss and likewise the obstacles to reforestation success vary greatly depending on the ecological and social context. For example, anthropogenic fires and livestock grazing often cause substantial mortality to tropical wet forest seedlings, but can be an integral part of restoring forests that have evolved with and are adapted to lightning-caused fire or large ungulate grazing (Holl, 2020).

4.2 | Guideline 2: Integrate decision-making across scales

The innumerable tree planting initiatives range from those committed to planting a few trees in a school backyard to a trillion trees across the planet. Although most of these initiatives are launched independently from each other, they necessarily require some co-ordination, as there is not enough land available for all of them and often trees are counted by initiatives at multiple scales. The complex hierarchy of initiatives is illustrated using the Brazilian Atlantic Forest as an example (Figure 3). Dialogue among tree planting initiatives within and among multiple scales is critical to allocate resources, optimize site selection and balance land uses that minimize ecological and social trade-offs, and coordinate goals among, and maximize benefits to multiple stakeholders (Table 3). This dialogue is especially important because the reforestation goals are determined based on organizational or policy decisions, without necessarily considering the feasibility of these goals (Fagan, Reid, Holland, Drew, & Zahawi, 2020) or their appropriateness for achieving expected outcomes (Brancalion, Niamir, et al., 2019). Usually, there is a communication gap between global programmes and local organizations which impedes the flow of investment and technical support.

A number of tree planting initiatives and conservation organizations strive to coordinate tree planting efforts at the global scale, which is important to mobilize collaboration among countries and funding from large investors, non-profit organizations and corporations; but it is impossible for international actors to negotiate directly with the tens of thousands of tree planting projects world-wide and each of their many stakeholders. This necessitates ‘regional’ organizations, the focal area of which ranges from several thousand square kilometres to the continental scale, and they may be organized around political or biome boundaries (Figure 3). Regardless, these organizations serve to interface between global initiatives and farmers and local organizations to provide funding and capacitation, and ensure that local projects are being well planned, maintained and monitored (Table 3).

For example, the multistakeholder coalition Atlantic Forest Restoration Pact in Brazil has not planted a single tree, but it has markedly contributed to the recovery of ~700,000 ha of native forests from 2011 to 2015 by supporting restoration activities of other organizations, by providing trainings for landowners, lobbying the government for policy changes, encouraging researchers to develop innovative restoration schemes, channelling international funding and developing standardized monitoring protocol and data repository (Crouzeilles, Santiami, et al., 2019). A challenge to this hierarchical integration will be identifying or developing regional coordination groups that have sufficient expertise and leadership, but do

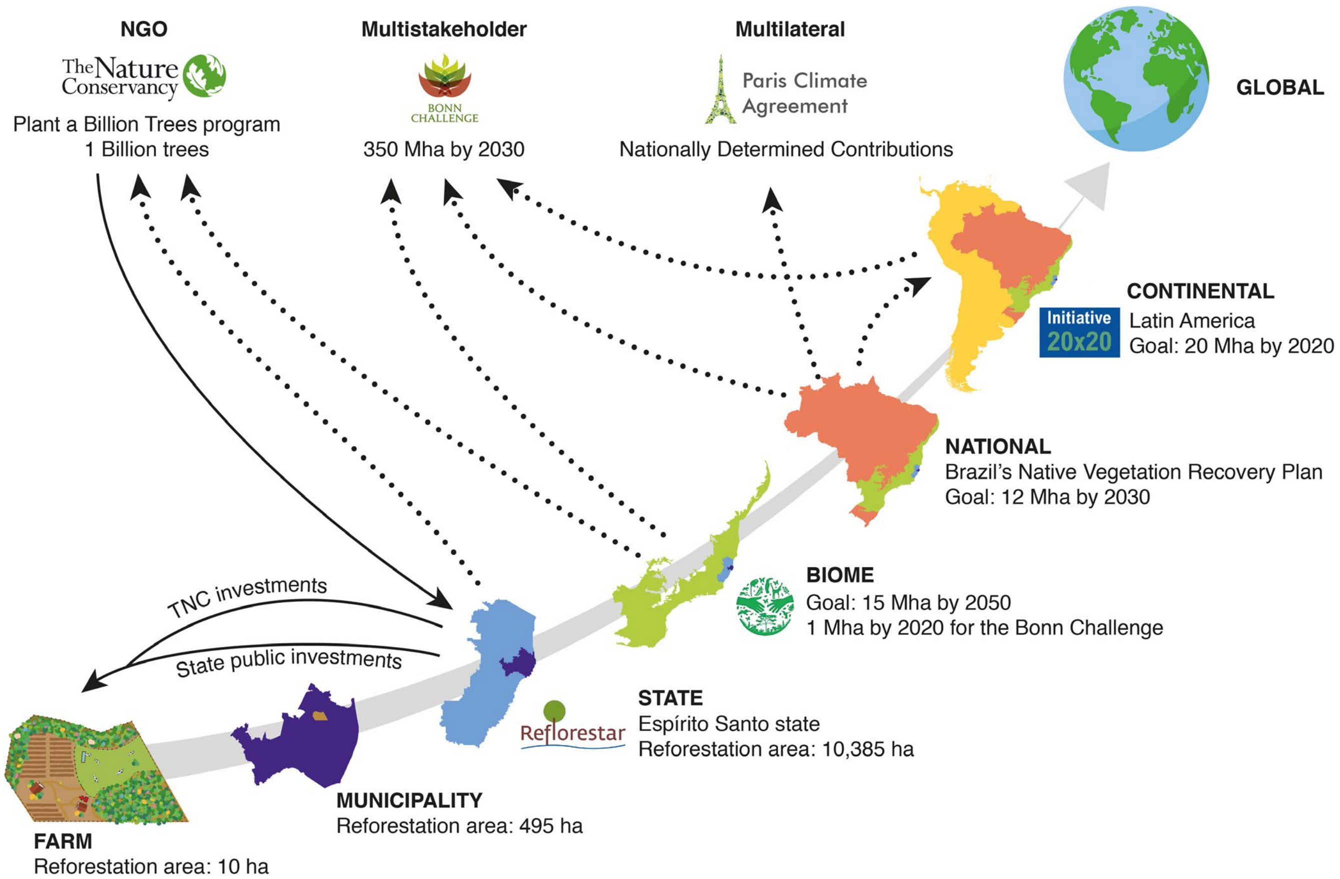

FIGURE 3 Brazilian Atlantic Forest as an example of the hierarchy of tree planting scales and accounting. The international environmental organization The Nature Conservancy (TNC) has obtained financial support from donations and partnerships to support their Plant a Billion Trees program (TNC, 2020, https://www.nature.org/en-us/get-involved/how-to-help/plant-a-billion/). The funding and technical support provided by the state government and this TNC program (solid lines) is being used to plant trees and support natural forest regrowth on farms, as part of municipal and state reforestation programmes. The new trees and area of land planted and regenerated are counted as part of the Plant a Billion program, as well as the Atlantic Forest Restoration Pact (dotted lines), as TNC is a member of this coalition. Likewise, these trees and land area, along with others, will be counted by Brazil, as part of their commitment to the Latin American 20 × 20 Initiative and separate global commitments to the Bonn Challenge and the Paris Climate Agreement (dotted lines). The areas of land planted are actual examples from a specific farm up to the global scale

not undermine tree planting efforts by spending funds to other ends, as corruption is an ongoing problem in many local and regional tree planting programmes (Afroz, Cramb, & Grünbühel, 2016).

4.3 | Guideline 3: Tailor tree planting strategies to clearly stated project goals and plan, adaptively manage and evaluate success over a sufficiently long timeframe

As discussed previously, it is important to clearly define and align the goal(s) of the multiple stakeholders involved in projects at the outset and then select the most cost-effective strategy to achieve those goals given local site conditions. The comprehensive planning process necessary to answer the many questions in Table 3 is time-consuming but is critical to being able to achieve and evaluate long-term outcomes. Many recent large-scale tree planting efforts set targets of how many trees are planted, rather than tree survival over time or, more importantly, whether the desired biophysical and socioeconomic benefits from plantings were achieved (Holl & Brancalion, 2020). In contrast, most tree planting goals require many years to centuries to achieve. Substantial evidence suggests that failure of tree planting efforts is common (Brancalion et al., 2016; Kodikara et al., 2017) and that recovering forests often are recleared within a few decades (Reid, Fagan, Lucas, Slaughter, & Zahawi, 2018; Sloan et al., 2019). Ensuring the survival and growth of trees will be even more challenging in the future with increased temperatures and climate-induced changes to disturbance regimes, such as drought, fire, hurricanes, biotic outbreaks and their interactions (Anderegg et al., 2020).

For tree planting to succeed in achieving the desired endpoints requires a longer planning and management timeframe and sufficient financial support that extends well beyond the short-term funding usually allocated for tree planting (Brancalion, Meli, et al., 2019). It also necessitates a detailed adaptive management plan and sufficient funding for monitoring to ensure that the objectives are met (Gann et al., 2019; Holl, 2020). For instance, forest restoration projects that are established to comply with laws or receive public funding in the state of São Paulo, Brazil, are required to monitor specific vegetation parameters after 3, 5, 10, 15 and 20 years to determine whether the specified values have been achieved or whether corrective actions are required (Chaves, Durigan, Brancalion, & Aronson, 2015). Long-term success of tree planting will be increased by carefully selecting species and genotypes that are adapted to local abiotic conditions and enlisting rapidly improving ecophysiological models and remote sensing data to predict which species are most likely to survive under future conditions (Anderegg et al., 2020). Moreover, staged-scale restoration will enhance the success of large-scale reforestation efforts; this approach starts with pilot studies and progressive evaluation of restoration schemes that employ the same operational procedures and equipment to be used at on-the-ground projects, followed by the application at scale of the most successful schemes tested (Bakker, Delvin, & Dunwiddie, 2018). Regardless of the amount of prior planning, adaptive management of tree planting efforts is crucial to address unpredictable socio-ecological factors, such as biological invasions, natural and human-induced disturbances and natural resources extraction. Finally, long-term research and monitoring of the efficacy of tree planting and other forest restoration strategies to achieve biodiversity and carbon sequestration gains is needed, since most studies to date have only focused on the first few years post planting (Holl, 2017b).

4.4 | Guideline 4: Focus on the forest, not the trees

Tree planting efforts that aim to restore forest habitat need to explicitly recognize that forests are not comprised of trees alone, and to set and evaluate goals accordingly. Tree planting in some cases facilitates forest recovery, but tree planting and forest restoration are not synonyms (Table 2). In fact, trees represent less than a third of the plant species across a range of forest types (Spicer, Mellor, & Carson, 2020). Forests host a diverse suite of plants (e.g. lianas, epiphytes, herbs), animals, fungi and microbes that form various mutualistic relationships that are critical to forest recovery (e.g. seed dispersal and pollination by fauna, symbiotic microbe–plant interactions). It is often assumed that all these other species will colonize spontaneously, but rarely does this occur (Bullock, Aronson, Newton, Pywell, & Rey-Benayas, 2011; Garcia, et al., 2016; Oliveira, Oliveira, Suganuma, & Durigan, 2019). A large proportion of tree planting efforts to date consists of large-scale, industrial plantations of one or a few exotic species (Payn et al., 2015) which meet the goal of providing pulpwood, but have a much more homogeneous vegetation structure and composition than a naturally recovering forest (Almeida et al., 2019; Zahawi et al., 2015). Tree planting initiatives that aim to restore forest need to set objectives beyond the typical seedling survival and growth, consider strategies for facilitating the recolonization of non-tree species, and utilize a multifaceted monitoring approach. For instance, jarrah forest restoration efforts on formerly mined land in western Australia use a range of different methods (e.g. topsoil transfer, direct seeding, vegetative propagation) to restore the full suite of plant species and growth forms (Koch, 2007). The Brazilian nonprofit Institute for Ecological Research (IPE) monitors faunal biodiversity in reforested ecological corridors using GPS tracking collars in large mammals, sound recorders, camera trapping and environmental DNA.

4.5 | Guideline 5: Coordinate different land uses across the landscape

Many proposed reforestation maps estimate the maximum area of land that could be reforested without factoring ongoing human land uses into the equation (Grainger, Iverson, Marland, & Prasad, 2019). At least for the foreseeable future, human population and consumption patterns will continue to increase, which will require that humans use a substantial proportion of land for people to live, produce food and extract natural resources. Large-scale tree planting may be feasible in some areas, particularly those in public ownership. For the most part, however, reforestation will occur in multi-use landscapes. As a result the land area available for tree planting in some countries is much lower than reforestation commitments (Fagan et al., 2020), and more realistic goals have to be set to balance multiple ecological and social needs (Le, Smith, Herbohn, & Harrison, 2012). It will be most cost effective to use highly productive lands for agriculture and plan ecologically sensitive and/or marginally productive lands that were previously occupied by native forests for tree planting or natural forest regrowth (Doelman et al., 2020; Latawiec, Strassburg, Brancalion, Rodrigues, & Gardner, 2015). For example, riparian forest restoration along the Sacramento River, the largest river in California, focuses on restoring the most flood-prone lands where fruit and nut orchard production is less profitable due to frequent losses to flooding (Golet et al., 2006). Several recent studies suggest that prioritizing forest restoration spatially based on various criteria, such as potential for natural forest regrowth, conservation value, past land use and opportunity cost from other land uses, can increase restoration feasibility and improve restoration success (Brancalion, Niamir, et al., 2019), while also minimizing unintended negative consequences, such as increasing forest clearing elsewhere (Meyfroidt et al., 2010). A high priority for future research is to test the actual predictive capacity of these models when applied to specific projects.

4.6 | Guideline 6: Involve all stakeholders throughout the process

Many national governments have made ambitious forest and landscape restoration commitments (Fagan et al., 2020) but successful implementation of restoration depends critically on involving stakeholders at all stages of forest restoration (Holl, 2017a; Mansourian & Vallauri, 2014). Time and time again top-down projects have failed because the planted trees are not maintained, farmers utilize the land for livestock grazing, the land is recleared for agricultural purposes, or less frequently the plantings are actively destroyed because people feel they were not involved in the decision-making process (Brown, Fadillah, Nurdin, Soulsby, & Ahmad, 2014). Early in the planning process it is important to clarify land tenure issues, as well as who is likely to use the land for other resources either legally or illegally (Chang & Andersson, 2019; Guariguata & Brancalion, 2014). Those people should be involved in the planning process in order to understand and address their needs and concerns (Schirmer & Bull, 2014), as well to monitor the direct benefits they obtain, such as local employment opportunities and provisioning of food and fibre (Le et al., 2012). For example, Gregorio and Herbohn (2018) describe a people-based reforestation programme established as part of the Philippines National Greening Program, in which they emphasize the importance of capacitating local communities to plan, implement and monitor tree plantings as a way to reduce their dependency from external aid, ensure long-term engagement and provide livelihoods benefits. Participatory monitoring should be emphasized as a way to encourage social learning and promote adaptive management (Evans, Guariguata, & Brancalion, 2018).

5 | CONCLUSIONS

We close by reiterating that there are many potential benefits of tree planting and we applaud the enthusiasm of those who undertake these efforts. However, these efforts must be viewed as one component of multi-faceted solutions to complex environmental problems that must start by reducing the drivers of habitat destruction and degradation in the first place. Even if the best science and technology available are employed to determine where and how to plant trees, goals may conflict, trade-offs emerge and undesirable outcomes happen (Temperton et al., 2019). However, we can substantially improve the success of tree planting efforts by clearly stating the goals of different projects, coordinating the efforts and interest of stakeholders both within and among spatial scales and taking a sufficiently long view of tree planting success. The challenge will be to put these guidelines into practice in an effort to scale up tree planting and forest landscape restoration commitments to the scale needed to provide both biophysical and socioeconomic benefits proposed. Fortunately, there are some past successes, as well as many failures, which together can help to guide the way.

ACKNOWLEDGEMENTS

We thank R. Chazdon, C. Garcia, M. Guariguata, A. Kulikowski, F. Joyce, J. Lesage, M. Loik, C. Philipson, J. L. Reid and K. Ross for helpful comments. P.H.S.B. thanks the São Paulo Research Foundation for financial support (FAPESP, grant #2018/18416-2).

AUTHORS' CONTRIBUTIONS

P.H.S.B. and K.D.H. jointly conceived the idea of this work, wrote and revised the manuscript, and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data have not been archived because this article does not use data.

ORCID

Pedro H. S. Brancalion https://orcid.org/0000-0001-8245-4062
Karen D. Holl https://orcid.org/0000-0003-2893-6161

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How to cite this article: Brancalion PHS, Holl KD. Guidance for successful tree planting initiatives. *J Appl Ecol*. 2020;57:2349–2361. https://doi.org/10.1111/1365-2664.13725