PERSPECTIVES

ECOLOGY

# Tree planting is not a simple solution

## Tree planting must be carefully planned and implemented to achieve desired outcomes

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This mixed-species tree-planting project is part of a larger-scale initiative to restore 15 million hectares of Brazil's Atlantic Forest.

PHOTO: HOLL *ET AL.*

A plethora of articles suggest that tree planting can overcome a host of environmental problems, including climate change, water shortages, and the sixth mass extinction (*1*–*3*). Business leaders and politicians have jumped on the tree-planting bandwagon, and numerous nonprofit organizations and governments worldwide have started initiatives to plant billions or even trillions of trees for a host of social, ecological, and aesthetic reasons. Well-planned tree-planting projects are an important component of global efforts to improve ecological and human well-being. But tree planting becomes problematic when it is promoted as a simple, silver bullet solution and overshadows other actions that have greater potential for addressing the drivers of specific environmental problems, such as taking bold and rapid steps to reduce deforestation and greenhouse gas emissions.

These ambitious tree-planting efforts (examples in supplementary table S1) are mostly well intentioned and have numerous potential benefits, such as conserving biodiversity, improving water quality, providing shade in urban areas, and sequestering carbon (*1*, *3*). Nonetheless, the widespread obsession over planting trees can lead to negative consequences, which depend strongly on both how and where trees are planted (see the table). For example, whereas tree planting often enhances floral and faunal diversity, planting trees in historic grasslands and savannas can harm native ecosystems and species (*4*). Likewise, trees are often suggested as an important income source for small landholders but may increase social inequity and dispossess local people from land if tree-planting programs are imposed by governments and external investors without stakeholder engagement (*5*). Repeatedly, top-down reforestation projects have failed because the planted trees are not maintained, farmers use the land for livestock grazing, or the land is recleared.

The massive Chinese government Grain-for-Green tree-planting program, which cost an estimated $66 billion, illustrates a number of these trade-offs. The program is credited with increasing tree cover by 32% and reducing soil erosion by 45% in southwestern China over a 10- to 15-year period (*6*). But like many large-scale reforestation programs, most new tree cover is composed of one or a few non-native species that have much lower biodiversity than native forests (*6*). Moreover, large-scale tree planting in the semiarid Loess Plateau in central China has reduced river runoff and in turn the amount of water available for human activities, owing to the large amount of water transpired by rapidly growing trees (*7*). Most of the trees for this program were planted in former agricultural land, resulting in a 24% decrease in cropland. During the same time period, native forest cover decreased by 7% (*6*). This illustrates a major overarching concern about tree planting, which is the displacement of agriculture from the land being reforested to areas occupied by native forests, thus resulting in further deforestation (*8*).

Reforestation projects can be an important component of ensuring the well-being of the planet in coming decades, but only if they are tailored to the local socioecological context and consider potential trade-offs. To achieve the desired outcomes, tree-planting efforts must be integrated as one piece of a multifaceted approach to address complex environmental problems; be carefully planned to consider where and how to most effectively realize specific project goals; and include a long-term commitment to land protection, management, and funding.

The first priority to increase the overall number of trees on the planet must be to reduce the current rapid rate of forest clearing and degradation in many areas of the world. The immediate response of the G7 nations to the 2019 Amazon fires was to offer funding to reforest these areas, rather than to address the core issues of enforcing laws, protecting lands of indigenous people,

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and providing incentives to landowners to maintain forest cover. The simplistic assumption that tree planting can immediately compensate for clearing intact forest is not uncommon. Nonetheless, a large body of literature shows that even the best-planned restoration projects rarely fully recover the biodiversity of intact forest, owing to a lack of sources of forest-dependent flora and fauna in deforested landscapes, as well as degraded abiotic conditions resulting from anthropogenic activities (*9*).

Tree planting is not a substitute for taking rapid and drastic actions to reduce greenhouse gas emissions. Certainly, planting trees in formerly forested lands is one of the best options to offset a portion of anthropogenic carbon emissions, but increasing global tree cover will only constitute a fraction of the carbon reductions needed to keep temperature increases below 1.5° to 2°C (*4*). Potential carbon sequestration estimates of increasing tree cover range more than 10-fold, depending on assumptions about the rate of carbon uptake, the amount of land considered appropriate for reforestation, and how long those trees remain on the land (*2*, *3*, *10*). Moreover, much uncertainty remains about how much carbon trees will sequester in the future, given that increasing drought and temperatures from climate change can lead to substantial tree mortality either directly or indirectly through feedback loops involving fire and insect outbreaks (*11*). Conversely, some high-latitude areas that were unsuitable for trees may become favorable in the future.

Maximizing the benefits of tree planting requires balancing multiple ecological and social goals to prioritize where to increase tree cover regionally and globally. Some global maps estimate potential land area for reforestation without factoring in that people need places to live, produce food, and extract natural resources (*12*). Large-scale reforestation may be feasible in some areas, particularly those in public ownership, but reforestation will mostly occur in multiuse landscapes. Several recent studies suggest that prioritizing forest restoration on the basis of criteria, such as past land use, potential for natural regrowth of forest, conservation value, and opportunity cost from other land uses, can increase feasibility and improve reforestation success (*13*). For example, choosing appropriate locations for tree planting in the Brazilian Atlantic Forest biome can triple conservation gains and halve costs (*14*). Large-scale planning is more likely to result in successful reforestation projects over the long term and prevent deforestation elsewhere. But recognizing competing land uses means that the actual land area feasible for reforestation is much lower than the amount proposed by some ambitious global reforestation maps and national commitments (*12*).

## Contrasting tree-planting outcomes

Tree-planting efforts can have both negative and positive ecological and social outcomes depending on whether the location-specific pros and cons of different alternatives are rigorously evaluated, and projects are comprehensively planned in consultation with all stakeholders.

**Unintended negative effects**

- Reduced water supply
- Destruction of native grasslands and spread of invasive tree species
- Increased social inequity
- Displacement of farmland
- Increased deforestation

**Potential beneficial outcomes**

- Greater carbon and water storage
- Reduced soil erosion
- Increased landscape connectivity and native biodiversity
- Provision of food, wood, and shade
- Income generation

Successful tree planting requires careful planning at the project level, which starts by working with all stakeholders to clearly identify project goals. People plant trees for many different reasons, such as restoring forest, sequestering carbon, providing income from timber harvesting, or improving water quality. A single tree-planting project may achieve multiple goals, but it is rarely possible to simultaneously maximize them all, because goals often conflict, and prioritizing one goal may result in other undesirable outcomes. Clear goals are key to being able to evaluate whether the project was successful and to selecting the most cost-effective way to increase the number of trees. For example, if a primary project goal is to restore historically forested habitat, simply allowing the forest to regrow naturally often results in the establishment of more trees at a much lower cost than actively planting trees, particularly in locations with nearby seed sources and less-intensive previous land use. By contrast, if the goal is to provide landowners with fruit trees or species with valuable timber, then plantations of non-native species may be the most suitable approach. Many additional questions must be addressed prior to project implementation, such as potential unintended consequences of tree planting, which species to plant, how landowners will be compensated for lost income, and who is responsible for maintaining trees over the long term.

Most projects set targets of how many trees to plant (table S1), rather than how many survive over time or, more importantly, whether the desired benefits are achieved. By contrast, most tree-planting goals, such as carbon sequestration and providing timber and nontimber forest products to landowners, require decades to achieve. This short-term view has resulted in large expenditures on tree-planting efforts that have failed. For example, approximately $13 million were spent to plant mangrove trees in Sri Lanka following the Indian Ocean tsunami in 2004, yet monitoring of 23 restoration planting sites five or more years later found that more than 75% of the sites had <10% tree survival because of poor project planning and lack of seedling maintenance (*15*).

Hence, successful tree-planting projects require a multiyear commitment to maintaining trees, monitoring whether project goals have been achieved, and providing funding for corrective actions if they are not. Using this adaptive management approach will certainly increase the price tag of tree planting, but it is money better spent than simply planting trees that mostly do not survive.

To realize the potential benefits of increasing tree cover, it is essential that tree-planting projects include thorough goal setting, community involvement, planning, and implementation, and that the time scale for maintenance and monitoring is sufficient. Otherwise the extensive human energy and financial resources invested in tree planting are likely to be wasted and have undesirable consequences, thus undermining the potential of this activity to deliver the expected environmental benefits that are critically needed for humans and nature in this time of rapid global change. ■

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### SUPPLEMENTARY MATERIALS

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