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People today who plant trees successfully do it for livelihoods and income not for biodiversity or climate mitigation

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Recently, many studies have touted the idea of planting trees as a natural means of climate mitigation (Bastin et al., 2019). Initial estimates were strongly criticized for their false assumptions about the technical capacity and open space available for such large-scale plantings (Veldman et al., 2019), but many of the critiques also failed to acknowledge that at least a century of work has documented successful tree planting (Holl and Brancalion, 2020). Responses had largely been written by ecologists, not by practitioners who plant trees for a living or silviculturists, social scientists, and others who conduct research on how, when, and where to plant trees and why landowners plant trees. Tree planting can be successful and very effective in the right circumstances, and there is an enormous technical literature under the applied ecological discipline of silviculture that has been ignored and should be recognized (Ashton and Kelty, 2018).

On the other side of the reforestation debate are studies touting the abilities of naturally regenerated forests to come back on "abandoned" lands on their own with little assistance from humans (Chazdon and Guariguata, 2016; Cook-Patton et al., 2020). No planting necessary. Such evaluations have been published as global or regional analyses of potential lands that can naturally revegetate; but again, these analyses have largely come from researchers who used a biological lens and evaluated possibilities remotely and through secondary literature. Natural forest regeneration certainly has occurred on some abandoned land, but analyses advocating this phenomenon assume that all open land identified via remote sensing is abandoned and available regardless of location (Griscom et al., 2017; Gvein et al., 2023; Zheng et al., 2023) and that the socio-economic context can be planned and promoted to provide the right conditions for facilitating successional regrowth (Chazdon et al., 2020). In most circumstances these assumptions are wrong: land that is perceived as abandoned is often in fallow and will be cultivated again; and when sustained natural regrowth does occur, it is often due to unplanned local conditions and driven by external factors such as conflict, economic transition, and population migration (Holl et al., 2022; Sloan, 2022). On some apparently abandoned lands, regrowth has not come back because the site and soil cannot sustain tree survival (e.g., arid lands) or the site is unable to self-propagate for any number of reasons related to failure of seed to disseminate or germinate (e.g., Crouzeilles et al., 2019; Timsina et al., 2022).

As with most resource issues concerning trees and forests, everything about planting as a solution is nuanced and based on the science of place. Success depends upon social, economic, and biophysical circumstance, and therefore the truth about tree planting as a climate solution falls somewhere in the middle of the "everywhere or nowhere" planting debate. Possibilities exist, but planting trees is not a panacea. Yet when done correctly and in an appropriate circumstance, with thought and careful planning, it can be very effective and bring multiple benefits that range from poverty alleviation (Afonso and Miller, 2021) to improved water quality (Keller and Fox, 2019). Lessons learned from years of experience and documented in textbooks (e.g., Ashton and Kelty, 2018) present four conditions which generally should be met:

1. Trees can only be planted successfully where there is technical knowledge on how to plant the right tree in the right place. Many people who plant trees lack this knowledge (species autecology) (e.g., Burns and Honkala, 1990). Many regions, particularly the tropics, lack the research capacity to develop it.
2. Tree planting requires specialized infrastructure (propagation, seed collection, provenance, nurseries and nursery stock) and human capacity (logistics, extension) (Haase and Davis, 2017; Jalonen et al., 2018).
3. Successful tree planting also requires future continued long-term care and protection for seedling survival and growth. This means secure tenure over trees and land and supportive and predictable governance structures (regulation and enforcement) (Ota et al., 2020).
4. Finally, tree planting must generate an acceptable return to landowners or others who invest in it. In most circumstances, households, communities, governments, and private institutions plant trees for their utility or livelihood benefit (Miller et al., 2017; Martin et al., 2021). To date, low carbon prices have made tree planting for climate mitigation insufficiently economic on a large scale compared to growing trees for wood production (Philipson et al., 2020; Vincent et al., 2021). In the tropics, cropland and pastureland account for most of the land where tree growing offers relatively low-cost carbon sequestration (Shyamsundar et al., 2022), and farmers require a financial incentive to switch to growing trees. Although current climate policies do not offer this incentive at scale, tree planting does offer carbon sequestration as a societal co-benefit when it occurs (Bukoski et al., 2022).

There are exceptions to planting for utility. Examples exist of successful tree planting for ecosystem service values such as restoration of biodiversity on public wildlands or the creation of greenspace within cities (Doroski et al., 2020; Eisenman et al., 2021), but only where governments and citizens have the institutional capacity, knowledge and security and financial resources to meet the conditions listed above.

There are plenty of examples of where planting trees at scale has been very successful, but again these occur under specific circumstances, and there are no broad top-down dictums that can guarantee such success. Here are some well-known examples:

A. *Planting at scale by large organizations and ownerships*: The best examples of planting at scale have been done by private landowners and industry (North America, Scandinavia) and strong central governments (China). In all cases these parties have the capital, land and social security, management infrastructure, technical knowledge, and financial rewards to carry out such operations. Markets are a key ingredient for tree planting at scale. Planted forests represent only 7% of global forestland, with intensively managed plantations accounting for about half of that amount (FAO, 2020), but they produce nearly half of the world's industrial roundwood (Payn et al., 2015). When evaluating the entire life cycle, wood is also a uniquely sustainable construction material compared to other options (Woodard and Milner, 2016; Mishra et al., 2022).

   1. The U.S. South holds 71% of planted timberland and produces 60% of timber harvests in the U.S. (Coulston et al., 2023). Most of this land is plantations of loblolly and other native pine species on former marginal agricultural lands (Fox et al., 2007). These plantations generate employment and income, support retirement and insurance systems (Binkley et al., 2021) and can be very compatible with other values when regulations require or provide incentives for management for endangered species (Miller et al., 2009), riparian and watershed protection (Aust and Blinn, 2004), hunting and recreation (Macaulay, 2016).
   2. More recently, intensive plantation management has been adopted in countries with developing economies by industrial and private landowners who have again planted on marginal agricultural lands (e.g., SE/coastal Brazil, Vietnam). One difference is greater use of non-native trees, especially Eucalyptus and Acacia from Australia (Turnbull, 1999) and conifers from North America (Simberloff et al., 2010). While some of the same climate and watershed protection co-benefits mentioned for the U.S. can apply here, impacts of planting on the conservation of native forests can be more complicated and varied. For example, Brazilian law requires farmers to set aside 20%–80% of their land for native forest restoration, but similar laws are rare in other countries. More controversial in our mind is the clearance of native forests for industrial plantations of non-native species in regions such as Indonesia often under the premise that the cutover native forest is degraded (Brockerhoff et al., 2008).

Large-scale planting enterprises have been criticized by those who argue that single-species plantations have negative impacts on the ecology of the region (Lewis et al., 2019). It is also true that these plantation systems can exclude other values that trees and land can provide and thus potentially disadvantage local communities (Malkamäki et al., 2018; Erbaugh et al., 2020). Yet, the high productivity of planted forests cited above—<10% of global forest area but nearly 50% of global timber supply—implies that they have spared a large area of natural forest from timber harvesting pressures (see also Meli et al., 2019).

B. *Planting at scale on smallholder land*: The planting alternative to single-species plantations are the diverse tree systems often chosen by private smallholders and communities, especially in the tropics and subtropics. Here, management regimes and planting are more eclectic and nuanced to the values of the landowner, especially where livelihoods are dependent upon income in regional markets and a variety of food, wood products, and medicines from trees. These systems can involve both native and non-native trees, with the latter often emphasized when income is the goal. Timber harvests are generally only one objective, with many tree species planted together for their fruits, sap, and fodder.

1. Tree gardens/home gardens are widely distributed across the tropics and subtropics (Kumar and Nair, 2004). They are usually privately cultivated by small landowners for a range of foods, medicines, wood products, and ornamentals for home use and some subsistence income in local markets. Although individually small, they can represent a significant component of forest cover, standing carbon, and climate mitigation, particularly in some of the more densely populated countries of south and Southeast Asia (Kumar, 2006).
2. Commercial smallholder plantations that are the chief source of income utilize simpler, more uniformly grown mixtures of trees. Such plantings tend to be more singular in management focus with one commercially valuable tree crop (e.g, timber, rubber, coffee, cacao). They are especially common in wet tropical and subtropical regions of Latin America, West Africa, and Asia (Miller et al., 2017). Scale can be gained by aggregating smallholders through market-driven schemes to connect with domestic and international buyers (Vincent et al., 2021).
3. Governments with sufficient budgets can achieve large-scale smallholder tree planting by paying smallholders to plant ("payments for ecosystem services") (Vincent et al., 2021). The best example is China's Sloping Lands Conversion Program, which paid US$69 billion to 32 million smallholders to grow trees on 15 Mha of upland farmland during 1999–2015 (Jin et al., 2017).

Take home message: Widespread examples of successful tree planting exist. They are place-based and adhere to biophysical and knowledge constraints, specific economic incentives and social security conditions. People and organizations plant trees for many reasons, primarily utilitarian. Society can gain multiple co-benefits from such activities, carbon sequestration being one. Ecosystem service values such as climate mitigation and biodiversity conservation will continue to be co-benefits, secondary to utilitarian goals, until landholders receive larger economic incentives to supply them.

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