

# Establishing mixed-species planted forests for restoration and production in Brazil

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Figure 1 | An experimental mixed plantation of eucalypts and native species (right) contrasting with a monoculture eucalypt plantation (left, mature trees on top left of the picture and a recently planted stand on the bottom left of the picture)



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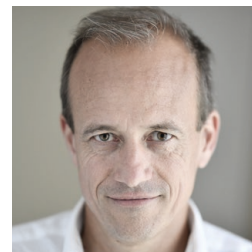
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## Highlights

- Mixed-species planted forests have considerable untapped potential in Brazil for the restoration of degraded conservation areas and legal reserves and in agroforestry.
- Although increased management complexity might limit the adoption of mixed-species configurations in industrial plantations, clone mixtures might be viable.
- Various economic, ecological and legal constraints must be overcome to upscale deployment of mixed-species planted forests in Brazil.

## Introduction

Tree plantations have considerable importance for the Brazilian forest sector today. Brazil harbours the largest area of forest plantations in Latin America. Most of these plantations are industrial monospecific tree plantations with short rotations (6–8 years). They cover about 9.93 million hectares (ha), of which 7.53 million ha are planted with eucalypt (representing about 30 percent of the global area of eucalypt plantations), 1.93 million ha with pine and 0.475 million ha with other species (mostly rubber, acacia, teak and parica). Wood consumption from forest plantations in Brazil was 273 million cubic metres (m<sup>3</sup>) in 2021, and it is steadily growing, mirroring the global trend (IBÁ, 2022). Current evidence suggests that sustainable management of natural tropical forests will not meet this increasing timber demand, which indicates that plantations and other tree-based systems, such as agroforestry, will be increasingly important in the future. Moreover, the current international momentum towards forest restoration has resulted in very ambitious targets for reforestation and restoration in various biomes of Brazil, which often involve tree planting in all or part of the areas concerned.

As described in other chapters of this issue, mixed-species forestry is a promising alternative to monocultures for both production and conservation

purposes, as monocultures have a lower capacity to provide diverse ecosystem goods and services than multispecies (mixed) plantations. Yet, this potential remains overlooked in Brazil. On the other hand, very few native tropical tree species are used in commercial plantations, which means that the potential represented by the wealth of Brazilian tropical tree species is not being exploited for production. The reason for this is twofold. Rapidly growing, homogeneous plantations dominate supply for industrial uses while illegal logging in forest remnants in the Amazon supplies the market with hardwood. The increasing frequency and intensity of disturbances associated with climate change, and the growing demand for wood and timber may result in wider adoption of mixed plantation systems in the future.

This article describes some important types of mixed-species plantations currently found in Brazil and their potential to contribute to restoration goals as well as production needs. Using Brazil as a case study, we show how mixed plantations can be used in permanent conservation areas and legal reserves, for forest restoration, agroforestry systems and industrial tree plantations.

## Regulatory frameworks and mixed tree plantations

The main piece of legislation guiding forest conservation, restoration and production in Brazil is the Native Vegetation Protection Law, also known as the new Forest Code, which was adopted in 2012. This law established three main land-use classes in private landholdings: (i) permanent preservation areas (APPs), which are established on farms and other areas to protect vulnerable ecosystems, such as riparian buffers, springs, steep slopes and mountain tops (e.g. within a 50 m radius for riparian buffers, 30 m wide riparian buffers along water courses less than 10 m wide, and all areas with a slope greater than 45 degrees); (ii) legal reserves (LRs) established to safeguard a minimum cover and the sustainable use of native ecosystems within farms, on areas ranging from

80 percent of the farm area in the Amazon to 20 percent in other regions of Brazil; and (iii) production areas, which represent the areas not covered by APPs or LRs, where alternative land uses (e.g. cropland, pastureland, infrastructure) are allowed (for more details on APP and LR regulations, see Brancalion *et al.* [2016]). Understanding this regulatory framework is critical for planning forest plantations. In APPs, only mixed plantations of several native species are allowed, as the forests established in these areas cannot be commercially exploited and must be exclusively used for restoring native ecosystems. In LRs, mixed plantations of native and exotic species are allowed, as forest plantations in these areas combine promoting the recovery of native ecosystems with commercial forest use. However, to be legally accepted, mixed plantations in LRs must have no more than half of the area covered in exotic trees and cannot be clearfelled; both exotic and native trees can be harvested and replanted for further exploitation. Similarly, agroforestry systems, which are land-use systems that integrate woody perennial species with agricultural crops or livestock, or both, in spatial and temporal arrangements (IBGE, 2019), are permitted in LRs. In production areas, all types of forest plantations are allowed, including industrial monoculture plantations.

## Mixed tree plantations for the restoration of legal reserves

Brazilian LRs can be restored and exploited using both natural regeneration and tree planting. Tree plantations are usually managed with strips of two to four contiguous rows of valuable, slow-growing native species, interspersed with the same number of strips planted with fast-growing pioneer species (Figure 1). Fast-growing exotic species have been preferred as pioneers, as this may help offset restoration costs and provide an income and wood for farmers while initiating regeneration processes (Brancalion *et al.*, 2020). Eucalypt has been the commercial pioneer species most used because of its versatility (e.g. for

cellulose, coal, fuelwood, mooring and construction) and rapid growth, resistance to pests and diseases, ability to adapt to different site conditions and good economic returns. Amazonas *et al.* (2018) examined three main experiments in the south of the State of Bahia and northern Espírito Santo to evaluate the development of stands planted in strips with a high diversity of forest species (23–30 species) native to the Atlantic Forest, interspersed with eucalypt strips. The mixed plantations were beneficial to the growth of the eucalypts, which produced almost 75 percent of the basal area of monocultures from only 50 percent of the trees. Although the eucalypts slowed the growth of the native species, this effect was not strong enough to jeopardize their survival. The slower growth of the native species was not considered a major concern in the short term because after the eucalypt harvest, the native species were able to make up for lost growth. According to these authors, the mixed planting of native species with eucalypt is technically and economically viable, and represents an important alternative for establishing multipurpose plantations, especially in the context of forest and landscape restoration (Brançalion *et al.*, 2020). Moreover, small and medium-sized producers have shown interest in mixed plantations for obtaining multiple forest products and increasing ecosystem services on their landholdings. Tree species of the Fabaceae, Myrtaceae, Arecaceae and Lecythydaceae families appear to be the most promising for use in mixed plantations for wood production and as a food source for fauna (Paula *et al.*, 2020). Science-based silvicultural guidelines for this type of plantation are lacking and should be developed in the future, as these mixed plantations are emerging as an important option for meeting the combined goals of livelihoods, production and environmental protection, both within and outside LRs.

### Mixed tree plantations in agroforestry systems

Agroforestry systems (AFS) are usually associated with a high diversity of tree

species, in most cases not arranged in rows. Agroforestry systems are mostly used in small and medium-sized landholdings, with low to medium intensification. In 2006, 8.3 million ha managed in agroforestry were classified on 306 000 farms. Of late, this cultivation system has benefited from public policies supporting environmental protection, food security and climate mitigation. For example, AFS were included as one of the proposed technologies of the Brazilian Programme for Low Greenhouse Gas Emissions in Agriculture (ABC Programme), ratified under the Paris Agreement. Agroforestry systems have commonly been used as an alternative for agricultural and forest cultivation to increase crop resilience in regions with a humid tropical climate, such as the Amazon Forest region, or a subhumid tropical climate, such as the Atlantic Forest region, where the risk of pests and diseases is high. Agroforestry systems are considered to be more resistant to these disturbances than monocultures, and thus have expanded over the last decades.

For example, the Mixed Agricultural Cooperative of Tomé-Açu, formed by Japanese immigrants in the State of Pará in the Amazon after a period of prosperity and decline of black pepper (*Piper nigrum* L.) monocultures, began agroforestry in the 1970s, intercropping forest species typical of the region with cocoa, black pepper and other species that provide noble vegetable oils and pulp from 15 tropical fruits. They were motivated by the success in pest and disease control achieved by small landowners on the banks of Amazon River tributaries. Currently, approximately 17 000 ha are managed by 172 cooperative members and 1 800 farmer suppliers, directly and indirectly supporting 10 000 jobs in the region (CAMTA, n.d.). The southern State of Bahia has the largest cocoa plantation area in Brazil over 700 000 ha in the central corridor of the Atlantic Forest. There are two typical cocoa production systems used both by smallholders (5–8 ha) and larger farmers (approximately 300 ha). In the traditional cultivation system known as *cabruca*, cocoa plantations are established under native forest

cover. The total area is approximately 400 000 ha, with a stocking of 600 cocoa trees/ha (Fontes *et al.*, 2014). In the other system, all native forest is removed, and cocoa plantations are established with a stocking of 1 100 cocoa trees/ha shaded with banana and *Erythrina glauca*, a nitrogen-fixing tree (Müller and Gama-Rodrigues, 2012). These cacao agroforestry systems generally accumulate large amounts of soil organic carbon (Monroe *et al.*, 2016).

### Industrial mixed tree plantations

Most of the mixed tree plantations managed for industrial production that were studied in Brazil combined nitrogen-fixing and other species. In particular, mixtures of fast-growing *Eucalyptus* with *Acacia mangium* received considerable attention (Figure 2). Eucalypt-acacia mixtures can offer a wider range of products from the same plot compared to monoculture stands. They also maximize the provision of ecosystem services, for example by reducing surface runoff, and increasing carbon sequestration and biological nitrogen fixation (Paula *et al.*, 2020). In the last two decades, Brazil has developed a network of experimentation sites mixing *Eucalyptus* with *A. mangium*. A body of evidence suggests that there are gains of biomass to be had in mixed plantations compared to eucalyptus monocultures under favourable climatic conditions (i.e. hot and humid) for the development of *A. mangium*, as well as low soil fertility and reduced water availability. Such plantations can be more productive than monospecific plantations when established at sites with low productive capacity. Positive interactions are expected to prevail at poor sites (Marron and Epron, 2019), whereas intraspecific competition among fast-growing species dominates over facilitative interactions at more productive sites (Bouillet *et al.*, 2013; Forrester *et al.*, 2006). Zoning the productive capacity of the managed forest area is therefore a prerequisite for identifying sites where mixed plantations should be implemented.



**Figure 2.** An experimental mixed plantation of *Eucalyptus grandis* and *Acacia mangium* in Itatinga in São Paulo State, southern Brazil

Note: The two species are planted in alternating rows. In this picture, eucalypts largely dominate an understory of acacia, resulting in strong crown complementarity in canopy space.

However, management of mixed plantations, including eucalypt for commercial purposes in Brazil faces strong technical and economic limitations, which preclude their adoption on a large scale. The main silvicultural limitation stems from mechanization and automation of field operations and practices. Because each species planted in a mixture requires specific management in the establishment and maintenance phases, mixed plantations often have lower operational yield and increased production costs. In addition, harvesting and wood transport are more complex. In the wood processing phase, either for pulp, steel (charcoal) or panel production, there are similar limitations, as standardized, high-quality raw materials are required to optimize industrial processes. In addition, the invasive potential of acacia species may

restrict their use in mixed plantations in climatic regions where this species thrives.

Another option towards increased diversity in industrial plantations that is currently being explored in Brazil is the mixture of eucalyptus clones (Rezende *et al.*, 2019). Results suggest that clone mixtures exhibit better growth stability (i.e. yield predictability) than monocultures and lower vulnerability to biotic or abiotic damage agents while being more compatible with industrial plantation management. Whether clone mixtures are economically viable (i.e. with stable production costs) and can provide a wider array of ecosystem services and greater biodiversity than monocultures deserves further scrutiny.

## Conclusion

By reviewing current practices and successful examples of mixed plantations as well as economical and legal barriers to their adoption in Brazil, we hope to increase the current momentum towards adaptation of forest plantations to climate change. Our review suggests that the greatest potential for mixed-species plantations in Brazil is in agroforestry and restoration areas. In productive plantations, especially when the objective is production of a very calibrated product such as cellulose from monoclonal eucalyptus stands, increased management complexity remains a challenge for large adoption of mixed-species guidelines. Intermediate systems with mixed eucalyptus clones or where eucalyptus is mixed with native species are an interesting way forward. Future efforts should be directed towards the

development of science-based silvicultural guidelines for mixed plantations in the different Brazilian biomes, using species of commercial interest and which are resilient to biotic and abiotic stress. Large field trials will help demonstrate the benefits of this new silviculture and prove its relevance for large-scale management. In addition, silviculture of native tree species – from breeding programmes to nursery techniques to field management – needs to be further developed to better exploit the huge potential of Brazilian trees for the supply of wood and other products and services under climate change.

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