

Supplementary Information

This Supplementary Information has not been peer reviewed.

Title: Stakeholders' perspectives on barriers and pathways toward the diversification of planted forests

Table S1: More detailed information on each one of the pathways toward diversification

Barrier type	Barrier description	Pathways toward diversification	Geographic applicability	Description
Management	Operational complexity and an intimate mixture of species with contrasting growth	Establish clonal composites (Rezende et al. 2019)	Context-specific / Regional	This approach is well-suited for large-scale industrial pulp production, which relies on cellulose derived from processing wood, primarily from <i>Eucalyptus</i> clonal species commonly cultivated in forestry operations in Brazil and Portugal (Brazilian Institute of Geography and Statistics 2021). Multi-clonal stands, which involve planting at least two different clones, reduce the risk in case of pests or diseases affecting a stand, as well as the expansion of monocultures to novel areas, where there is limited knowledge on the suitability of genetic materials to local conditions. Some clones may be more susceptible/adapted than others, helping to mitigate the overall impact compared to clonal monocultures. It may also optimize wood usage by segregating it based on the specific characteristics of each clone (Rezende et al. 2019). While multi-clonal stands offer lower operational constraints compared to MFP, they are also likely to be associated with reduced functional diversity, which, in turn, lowers their potential ecological benefits.

		Plant each tree species in patches	Global	Tree species in patches enhance landscape-level diversity. When cultivating mosaics, we have different species in different biotopes or plots within a stand. This method allows people to adapt varied species to their optimal niches in the landscape. By edges, we mean to plant one or two alternative species around the monoculture stand. This also prevents tree windfalls, and depending on the species grown, can function as physical protection.
		Manage monocultures through assisted natural regeneration	Global	Monocultures with managed regeneration are initially established through planting of a single target species, while the natural or assisted regeneration of additional tree species is deliberately promoted and managed over time. In Sweden, for example, clearcut forest land is often rapidly colonized by fast-growing pioneer broadleaves such as <i>Betula pendula</i> , <i>Betula pubescens</i> or <i>Populus tremula</i> . These species can act as nurse trees, facilitating the establishment and growth of slower-growing, planted conifers such as <i>Picea abies</i> beneath their canopy by improving microclimatic and soil conditions. To facilitate the establishment of target <i>Picea</i> or <i>Pinus</i> , majority of stems of pioneer broadleaves are, however, removed during cleaning or thinning operations. Similarly, in Portugal, <i>Eucalyptus</i> plantations may promote the natural regeneration of <i>Quercus suber</i> in the understory when appropriate management practices are applied.
		Implement enrichment planting	Global	This strategy aims to achieve mixed stands through enrichment rather than conventional/specific plantings. For example, in a double-aged, two-layer monoculture, coppice is used for short-rotation pulpwood, while standard trees are grown for high-quality roundwood(Ferraz Filho et al. 2014). Similarly, chestnut (<i>Castanea sativa</i>) coppices are an opportunity for enrichment and mixing in France. Another approach involves agroforestry systems, which integrate annual crops or fruit trees into forestry plantations. Examples include combining banana or coffee cultivation with different mahogany species (<i>Khaya sp.</i>) plantations in northern Brazil and other tropical regions.

		Mix two long rotational softwood species in equal proportions (50% each)	Context-specific / Regional	It has been a growing practice in temperate or boreal forests, such as in Europe, to reduce the risk of damage caused by the bark beetle (<i>Ips typographus</i>), which mainly affects spruce (<i>Picea abies</i>). An example of this is the combined planting of <i>Pinus sylvestris</i> and <i>Picea abies</i> in Sweden and Douglas fir (<i>Pseudotsuga menziesii</i>) with <i>Picea</i> or <i>Larix</i> species in France. In Brazil his approach can also be applied to the cultivation of two species of the same genus, such as <i>Pinus elliottii</i> and <i>Pinus taeda</i> .
		Combine hardwood and softwood species	Context-specific / Regional	Even when hardwood species are not the primary focus, they add intrinsic wood value and contribute to overall diversity. This strategy is particularly effective in temperate and boreal forests, where softwood dominates the commercial stands. Including hardwoods can be crucial as they are likely to better withstand the warmer temperatures expected in the future due to climate change (Maule et al. 2017). Yet, shade-intolerance of some hardwood species can pose a management challenge. In Portugal, for example, the mixture of <i>Quercus suber</i> (which produces cork) and <i>Pinus pinea</i> (which produces cones with edible seeds) allows a combination of non-wood forest products income without cutting the trees, which can be productive for several decades.
	Ungulates' damage	Preserve RASO species, fencing, and natural repellent (Gaudin 2014)	Context-specific / Regional	One of the alternatives to reduce these problems is having wild fodder/deciduous trees in the system to put less pressure on the main species. RASO is the abbreviation in English for four of these species: rowan (<i>Sorbus aucuparia</i>), aspen (<i>Populus tremula</i>), sallow (<i>Salix caprea</i>), oak (<i>Quercus robur</i>), or RASE in Swedish: rönn, asp, sälg, ek. Not removing these naturally regenerated native species mitigates the ungulate damage in planted forests in Sweden. There are effective but expensive strategies as fencing (mesh made of metal wire) or using biological protection, for example, a natural repellent based on sheep fat (Gaudin 2014), that is increasingly used. Other respondents mentioned planting spruce to reduce pressure on pine and thinning stems to decrease canopy density, allowing light to reach the

				forest floor. This facilitates the growth of ground vegetation, which in turn serves as pasture for animals(Juvany et al. 2023).
	Adaptation to the site (local soil conditions and water regime) -	Add about 20% of deciduous trees to conifer stands	Context-specific / Regional	According to the respondents, an example is the combination of <i>Pinus pinaster</i> with <i>Quercus</i> species in France. And <i>Pinus pinea</i> with <i>Quercus suber</i> , in Portugal (southern open woodlands “montados”).
	Availability of planting material	Strengthen research centers and initiatives; establish seed nurseries in each country	Global	The establishment of a center of excellence – “Trees for Me” – between academia and forest entrepreneurs in Sweden was a solution to increase the share of fast-growing birch in Swedish forests. One of their goals is to identify the bottlenecks in the supply of birch seedlings from tree seedling nurseries in Sweden (<i>Trees For Me - Annual Report 2023</i>). Other alternatives: the government subsidizes the creation of seed orchards and nurseries in the country that could produce seedlings of native species; using natural regeneration plots; and companies to produce their own seeds/seedlings to reduce costs and ensure the availability of desired plants.
	Genetic issues	Develop breeding programs and promote collaboration between companies, universities, and research centers	Global	To address issues related to wild and unselected genetic materials, as well as the limited availability of planting materials for alternative species to dominant monocultures, investments in breeding programs and cloning technologies are essential. Collaboration between companies, universities, and research centers is recommended to merge practical field knowledge with scientific advances. Such partnerships can generate updated and actionable data, which is critical for reducing uncertainties associated with mixed planted forests in the countries studied, an example is the Research and Development program in Silviculture of Native Species from the organization called Coalition - Climate, Forests and Agriculture - which has the general objective of promoting the technological development necessary to establish silviculture of native species in Brazil on a scale comparable to that of the main agro-industrial sectors in the country(Coalizão Brasil 2021). This approach

				enables decision-makers to test mixtures on a small scale initially, fostering confidence and facilitating the expansion of mixtures if trials prove successful.
Economics	Higher costs, market trends, and less volume per species	Diversify production	Global	Diversifying production by incorporating more commercial species into the system generates a greater variety of forest products for sale. This increases the range of possibilities and can be particularly relevant given the uncertainties regarding the resistance of species to climate change and their future profitability in the market. To reduce the high costs of MPF, sustainable development strategies in the forestry sector can increase productivity by establishing partnerships between companies, such as offering areas within legal reserves of pulp industry companies in Brazil to partners who are interested in producing high-quality timber for sawmills in mixed systems, with shared income.
Economics	Lack of investment/financing	Promote public incentive policies; Carbon Credits funds	Global	The Verena Project (Batista et al. 2017), for instance, has worked to demystify the view of agroforestry systems, integrated crop/livestock/forest systems, and native tree silviculture, aiming to expand rural credit not only for conventional agriculture but also for long-term projects, as native species' silviculture projects. The Verified Carbon Standard Program (Verra 2025) has created an international voluntary carbon market to enhance afforestation, boosting carbon accumulation compared to previous land use.
Governance	Lack of knowledge/uncertainty	Implement public education policies	Global	Foresters require clear, concise, and accurate information. This can be provided through state-issued leaflets, forums, workshops, lectures, and training sessions that explain the feasibility of MPF and their legal frameworks. In all countries studied, consultants and cooperatives significantly influence landowners' decision-making. This occurs for distinct reasons, including landowners' engagement in other professions, inherited forests with limited direct involvement, or uncertainties in management. Given their indirect role in shaping decisions, training these professionals on MPF is essential. Also in the universities, training future forestry engineers and technicians, so that they are academically prepared during their education about MPFs. An example in this direction is "TreeDivNet," a network

				of scientific experiments that aims to demonstrate the feasibility and benefits of certain species mixtures (TreeDivNet 2026)
Governance	Well-consolidated monoculture practices	Promote certification of MPF, Payments for Environmental Services (PES), and carbon credits schemes	Global	Incentive policies would be useful i) to add value to products through certification of mixed stands, carbon offset initiatives, and low-carbon economies, which can increase the demand for forest products, benefiting both forestry companies and consumers; ii) to financially reward people who develop MPF through Payments for Environmental Services (PES) that could foster the adoption of mixed species stands. For instance, public notices in Brazil encourage transitioning from conventional agriculture to agroforestry systems, as well to restore degraded pastures, and similar initiatives could support mixed over monocultural stands; iii) Carbon payments, like through the Improved Forest Management framework of carbon credits, and cost-sharing by third parties have also been proposed as financial mechanisms to support biodiversity in forestry (Sinacore et al. 2023).

Table S2: Results of Binomial Generalized Linear Models: Coefficient, Standard error, and p value of each tested variable: operational, economic barriers, and motivations. OB= Operational barrier; EB= Economic barrier; M= Motivation. Signif. codes: 0 ‘***’; 0.001 ‘**’; 0.01 ‘*’; 0.05 ‘.’; 0.1 ‘ ’

<i>OB: Different Growth Rates</i>			
Variable	Coefficient	Std. Error	P value
France	0,6931	0,6355	0,2
Portugal	-0,4055	0,6570	0,5
Sweden	0,6931	0,6067	0,2
Company	1,4840	0.6304	0,01*
Private owner	0,6678	0.5693	0,24
Large scale	1,6740	1,364	0,17
Medium scale	2,4204	1,884	0,059 .
Small scale	0,7191	0,595	0,55
<i>OB: Operational Complexity</i>			
France	-0,09	0,8339	0,9
Portugal	0,16	0,9340	0,8
Sweden	0,08	0,8272	0,9
Company	0,59	0,8280	0,4
Private owner	0,27	0,7379	0,7
Large scale	1,3437	0,981	0,3
Medium scale	0,5754	0,438	0,6
Small scale	0,3677	0,296	0,7
<i>OB: Ungulates' herbivory</i>			
France	20,52	2109.0400	0,9
Portugal	18,18	2109.0400	0,9
Sweden	20,73	2109.0400	0,9
Company	-0,513	0,6304	0,4
Private owner	0,546	0,5685	0,3
Large scale	15,99	1199,77	0,9
Medium scale	15,79	1199,77	0,9
Small scale	16,69	1199,77	0,9
<i>OB: Soil adaptation</i>			
France	20,02	2109.0400	0,9
Portugal	17,69	2109.0400	0,9
Sweden	18,65	2109.0400	0,9
Company	-0,30	0,6401	0,6
Private owner	-1,02	0,6708	0,1
Large scale	17,16	1978,08	0,9
Medium scale	15,89	1978,08	0,9
Small scale	16,10	1978,08	0,9

<i>OB: Material Availability</i>			
France	0,636	0,62	0,31
Portugal	-0,3756	0,71	0,599
Sweden	-1,1558	0,74	0,122
Company	-0,5406	0,60	0,36
Private owner	-1,4087	0,62	0,02*
Large scale	1,0186	1,22	0,4
Medium scale	-0,5754	1,31	0,6
Small scale	0,1603	1,21	0,8
<i>EB: More expensive implementation</i>			
France	1,9253	0,84	0,02
Portugal	1,7177	0,85	0,04
Sweden	0,3314	0,59	0,57
Company	1,0116	0,71	0,1
Private owner	-0,2624	0,58	0,6
Large scale	0,8938	1,30	0,4
Medium scale	-0,7802	1,24	0,5
Small scale	-0,5878	1,21	0,6
<i>EB: Lack of genetic improvement</i>			
France	-18,93	2534,74	0,99
Portugal	-0,75	0,76	0,32
Sweden	-18,93	2346,71	0,99
Company	1,997	1,11	0,07.
Private owner	1,015	1,15	0,37
Large scale	16,62	1987,09	0,9
Medium scale	15,89	1987,09	0,9
Small scale	14,86	1987,09	0,9
<i>EB: Market trends</i>			
France	0,64536	0,65	0,32
Portugal	-0,71562	0,65	0,27
Sweden	-0,02247	0,59	0,97
Company	0,54	0,60	0,3
Private owner	0,08	0,55	0,8
Large scale	2.412e-01	1.078e+00	0,8
Medium scale	7.732e-01	1.115e+00	0,4
Small scale	1.252e-01	1.061e+00	0,9
<i>EP: Less volume per species</i>			
France	0,45	0,78	0,56
Portugal	-16,86	1684,13	0,99
Sweden	1,21	0,70	0,05*
Company	1,79	1,12	0,11
Private owner	2,01	1,09	0,06.

Large scale	15,91	1978,09	0,9
Medium scale	16,79	1978,09	0,9
Small scale	16,10	1978,09	0,9
<i>M: Resilience to CC</i>			
France	-0,77	0,81	0,3
Portugal	-0,55	0,87	0,5
Sweden	-1,36	0,78	0,08.
Company	-1,09	0,90	0,2
Private owner	-0,81	0,85	0,3
Large scale	-0,24	1,31	0,8
Medium scale	0,26	1,33	0,8
Small scale	0,05	1,28	0,9
<i>M: Improvement of soil conditions</i>			
France	-1,35	0,8	0,09.
Portugal	-0,66	0,77	0,39
Sweden	-1,07	0,75	0,15
Company	1,68	1,14	0,14
Private owner	1,34	1,11	0,22
Large scale	15,61	1385.38	0,98
Medium scale	15,61	1385.38	0,98
Small scale	15,65	1385.38	0,98
<i>M: Forest restoration</i>			
France	-20,31	4179,08	0,9
Portugal	-20,31	4738,64	0,9
Sweden	-20,31	4067,62	0,9
Company	-3,12	1,19	0,008**
Private owner	-20,74	29550,06	0,9
Large scale	5.216e-09	6.709e+03	1,00
Medium scale	1.673e+01	6.209e+03	0,9
Small scale	1.827e+01	6.209e+03	0,9
<i>M: Recreational services</i>			
France	2,25	1,14	0,04*
Portugal	0,14	1,46	0,92
Sweden	1,38	1,17	0,23
Company	15,62	1966,65	0,9
Private owner	17,87	1966,65	0,9
Large scale	17,73	2284,10	0,9
Medium scale	16,61	2284,10	0,9
Small scale	16,47	2284,10	0,9
<i>M: Diversify production and income</i>			
France	0,70	0,68	0,3
Portugal	0,25	0,73	0,7

Sweden	-0,52	0,70	0,4
Company	0,38	0,75	0,6
Private owner	-0,15	0,69	0,8
Large scale	-1.883e-1	1.323e+00	1,00
Medium scale	-6.931e-01	1.313e+00	0,5
Miniature scale	-1.609e+00	1.293e+00	0,2
<i>M: Biodiversity conservation</i>			
France	-0,02	0,69	0,9
Portugal	-0,53	0,73	0,4
Sweden	0,06	0,68	0,9
Company	-0,76	0,77	0,3
Private owner	-0,33	0,71	0,6
Large scale	-1.386e+00	1.323e+00	0,2
Medium scale	-1.924e-15	1.323e+00	1,00
Small scale	-4.055e-01	1.283e+00	0,7

Some details of each country's forestry sector

Brazil

Forest area. Brazil has the largest tropical forest area in the world and is one of the five biggest countries in the world. Brazil has approximately 60 % of its territory covered by native forests (with about 50 % of this area covered by the Amazon forest – 255.3 Mha). These forests are at risk of deforestation (Ruggiero et al. 2021), according to the National Institute for Space Research (Brazilian National Institute for Space Research 2020), mainly because of agricultural expansion and a lack of effective action to combat deforestation (Busch and Ferretti-Gallon 2017). Brazil has 9.7 Mha of planted forests, mainly concentrated in the southeast region (Souza et al. 2020; Vinicius Britto 2024).

Ownership. Most planted forests are under the control of private companies and landowners, while the direct participation of the State in the ownership of these areas is minimal (Embrapa and Ministry of Agriculture 2018).

Relevance to the national economy. The Brazilian Forestry industry has a strong economic impact, generating about 1.3 and 3.75 million direct and indirect jobs, respectively, across multiple tree-based economic activities (pulp, paper, sawmills, furniture, chemicals) (Brazilian Tree Industry 2024). The gross value of production in the cultivated tree sector reached 34 billion euros in 2023, and it is considered an important activity for the national Gross Domestic Product (GDP) (Brazilian Tree Industry 2024).

Legislation and main purpose. In Brazil, the regulation of land use for productive activities such as forestry is governed by the Forest Code (Law No. 12,651/2012) (Feistauer et al. 2014). This legislation establishes two primary categories of protected areas on private lands: Permanent Preservation Areas (PPA), which are zones designated for strict protection due to their high environmental significance (Sparovek et al. 2011). These areas include zones along watercourses, on steep slopes, hilltops, and other sensitive ecosystems. This is important to safeguard water resources, prevent soil erosion, and maintain biodiversity. Legal Reserves (LR) refer to areas of rural properties that must be maintained with native vegetation, with permission for sustainable use. The required percentage of land designated as LR is at least 20% but varies by region (Delalibera et al. 2008).

Most of the Brazilian forestry area is designated for large-scale industrial pulp production, with 80 % of the forestry composed of *Eucalyptus* plantations, which are made up of only a few clones focused on the industrial production of pulp and paper (Brazilian Institute of Geography and Statistics 2021).

The MPFs that exist in Brazil are mostly for forest restoration purposes, with little commercial interest or timber exploitation, making this format still very separate from the reality of the country's forestry (Paquette and Messier 2010). For this reason, many foresters believe that MPFs do not bring financial benefits and are implemented mainly to meet legal requirements, typically in areas where it is not permitted to practice agriculture or *Eucalyptus* or *Pinus* in monoculture, which is the ideal forestry standard.

Sweden

Forest area. Sweden's forests belong to temperate, boreal and subalpine biomes (Teuvo Ahti 1968), covering 27.9 Mha, which is 68 % of Sweden's land area (Teuvo Ahti 1968). Of this, 23.5 Mha (58 % of total land area and 84 % of total forest land) consist of productive forest lands. The southern part of the country is in the temperate vegetation zone, which includes hemiboreal and nemoral forests. The nemoral forests are rich in European beech (*Fagus sylvatica*). The hemi-boreal forests are dominated by Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*), with birch species (*Betula pendula* and *B. pubescens*) and European aspen (*Populus tremula*) also present. The northern half of the country lies within the boreal forest zone, where Norway spruce and Scots pine dominate. Subalpine mountain birch (*Betula pubescens ssp. czerepanovii*) forests and peatlands with Scots pine form extensive areas of virgin forest in the most northern parts of Sweden. The growing stock by tree species comprises 40 % of *Picea abies*, 39 % of

Pinus sylvestris, 13 % of *Betula pendula* or *Betula pubescens*, and 8 % of other broadleaf trees (Swedish University of Agricultural Sciences 2024).

Ownership. Private individuals own 47 % of Sweden's forests, while 30 % are owned by the National Property Board of Sweden (Statens fastighetsverk), other state-owned entities, state-majority-owned companies such as Sveaskog, as well as municipal, county, and other publicly owned land. The remaining 23 % belong to private limited companies that are not owned by the state, municipalities, or county councils (Swedish Forestry Agency 2024).

Relevance to the national economy. Forestry is crucial for the national economy, even though Sweden has less than 1 % of the world's forests, the country is the world's second-largest exporter of pulp, paper and other wood products (Swedish Forest Industries Federation, 2025). Wood production in Sweden has been growing annually. It is estimated that the Export Value of Forest Industry Products is about 15 billion euros per year (Skogsindustrierna 2021).

Legislation and main purpose. The Swedish Forestry Act regulates forest management to ensure a balance between sustainable timber production, economic returns, and other interests, such as biodiversity conservation, cultural heritage, and reindeer husbandry (Skogsstyrelsen, 2023). The dominant silvicultural method in Sweden is clear-cut forestry, where a new generation of trees is established simultaneously within a stand. This practice creates a mosaic of clear-cut areas across the forest landscape, harvested at different times. The Forestry Act requires forest owners to restock clear-cut areas through planting, seeding, or natural regeneration.

During a stand's development, it undergoes various thinning operations before reaching maturity and being harvested through final felling. Conifers such as spruce and pine are typically planted, while birch primarily regenerates naturally, often forming mixed stands with the conifers (Holmstrom et al. 2017). However, birch trees are commonly removed during thinning as they reach maturity before spruce and pine. During the last decades, planting birch improved by classical breeding has increased on clear-cuts on productive soils. Forest certification standards mandate a minimum proportion of broad-leaved species to be maintained: 10 % in southern Sweden and 5 % in the north (FSC Sweden 2010). Therefore, certified private owners retain birch trees in their forests.

The primary goal of forest management operations is to maximize timber production for the final harvest. Once a stand is harvested, the cycle begins again with the establishment

of a new generation of trees. The Forestry Act sets minimum final felling ages based on tree species, geographic location, and site productivity.

As an alternative to clear-cut forestry, some forest owners are experimenting with continuous cover forestry, a silvicultural method that aims to maintain forest cover while promoting biodiversity, preserving wildlife habitats, and enhancing the recreational value of forests for society. The Swedish Forest Agency shares science-based knowledge on the basics of forest management strategies, nature-based forest management methods with forest owners and managers through online courses and in-person meetings (Albrektson et al. 2012).

France

Forest area. According to the National Forest Inventory (2022), France has about 17.1 million ha of forests, representing ~30 % of the country's land use. The portion of forest surface in France has increased in the past decades, as it has practically doubled in area since 1850 (Živojinović, I., Weiss, G., Lidestav, G., Feliciano, D., Hujala, T., Dobšínská, Z., Lawrence and Nybakk, E., Quiroga, S., Schraml 2015). Planted forests cover 2.1 million hectares, which represents 13% of the mainland production forest area (Du Puy et al. 2017).

Ownership. Nearly 75 % of the French forest area is under private ownership, held by approximately 3 million owners. State or public forests account for 10%, while municipalities own the remaining 15%. However, the distribution of ownership categories can change between different regions.

Relevance to the national economy. The forestry sector is a substantial part of the country's economy, and presents a GVA of 4 billion euros each year (Eurostat 2023). According to the France FACESMAP Country Report (Živojinović, I., Weiss, G., Lidestav, G., Feliciano, D., Hujala, T., Dobšínská, Z., Lawrence and Nybakk, E., Quiroga, S., Schraml 2015), only 6 % of the forest surface provides regular financial returns to the landowners, so they need to have other main sources of income. Cooperatives play a crucial role in France as an alternative form of ownership.

Legislation and main purpose. This study was conducted in the Landes region, the largest planted forest in Western Europe, covering an area of 13,000 km² and mainly (95%) composed of monocultures of *Pinus pinaster*. In this area, most of the area is dedicated to wood production. However, these production plantations can also supply several associated services, which include recreation (hunting, living environment and landscape, water quality) and biodiversity (allowing natural regeneration, maintaining

dead wood, planting hedgerows made of broadleaves). In addition, a very small fraction of the area is not actively managed (“passive” forest owners) (Brahic and Deuffic 2017; Deuffic et al. 2018).

Forest managers commonly aim to produce a variety of wood products throughout the life cycle of the plantation, rather than planting for just one product type (Brahic and Deuffic 2017; Banos et al. 2022). For them, the ideal lifecycle is in general: at year 0, plantation of 1250 maritime pine saplings; at year 15+, 1st thinning where 25 % of trees are cut for wood energy or paper pulp; at year 25+, second thinning, and trees look like roundwood and are used for OSB/MDF (wood panels); at year 35+, 3rd thinning for pallets and some timber; at years 40-45, final cut of the 300 remaining trees for high quality timber. However, a minority of forest owners attempt to shorten rotation by making the final cut at t+35 and even t+25. In contrast, most forest owners who plant maritime pine aim to preserve the cascade of products along the life cycle of the stand.

A national program, “France 2030 Recovery Plan” (Ministry of Agriculture and Food Sovereignty 2025) was launched in 2020, aiming at adapting mainland French forests to climate change by planting 1 billion trees and regenerating 10% of the total forest area by 2030. As part of this effort, funds were allocated to the forest plantation sector, with important consequences for forest management in the Landes region.

Portugal

Forest area. Forests in Portugal, which include forests, shrubs and unproductive land, occupy 6.1 million hectares (69 %) of mainland and are mainly composed of native forest species (72 %). Wooded and temporarily deforested land (cut, burnt, and regenerating areas) represents around 36 % and is organized into four main forest formations: pine forests (mostly *Pinus pinaster* and *Pinus pinea* stands); evergreen hardwoods (‘montados’, cork oak forests, *Quercus suber*, and holm oaks, *Quercus rotundifolia*); deciduous hardwoods (oaks, chestnut trees and others); and silvo-industrial hardwoods (*Eucalyptus*, mostly *Eucalyptus globulus*) (Institute for Nature Conservation and Forests 2015).

Ownership. A total of 91 % of the Portuguese forests are private, with 4 % managed by industrial companies. Only about 3 % of forest lands are owned by public entities (the state or the municipalities), with the remaining being held by local communities.

Relevance to the national economy. The total volume of Portuguese forests is approximately 188 million m³ and annually produces an average of 11.5 million m³ of wood, mainly *Eucalyptus* and maritime pine logs, along with 100 thousand tons (kt) of

cork, which represents 50 % of the world's production. Other relevant products are the resin (8 kt), pine cones (70 kt), and chestnuts (25 kt), in addition to numerous other wild products that supply several silvo-industrial sectors. The GVA of Forestry and Forest Exploitation is around 1 billion euros (Eurostat 2023). The main sector represents about 1.7 % of the national GVA, while the overall forestry sector is worth 1.5 % of the national GDP. Forestry products account for, on average, 9 % of exports (in value), with a high rate of national value incorporation (71 %), and almost cover the entire deficit of the Portuguese food trade balance (Institute for Nature Conservation and Forests 2021).

Legislation and main purpose. In Portugal, forest management is regulated to ensure sustainable use of resources, biodiversity conservation, and wildfire prevention. The Legal Regime for Afforestation and Reforestation (RJAAR) and the Forest Policy Framework Law require that planting activities follow specific procedures and that properties over 50 hectares have a certified Forest Management Plan (PGF). Legislation also mandates fuel management to reduce fire risk, in line with the National Plan for Integrated Rural Fire Management (PNGIFR) and EU sustainability guidelines (ICNF, 2023; Decree-Laws No. 96/2013, 55/2021, 16/2009, 124/2006; Law No. 33/96).

In the ‘montados’, cork oak forests and holm oaks are the main forest cover, with more than 1 million hectares and representing 1/3 of the total forest area. These are multiple-use forest ecosystems whose main function is the production of cork. Pine forests occupy the second largest forest formation, covering an area of over 900,000 ha, with a growth trend for stone pine and a decrease in maritime pine. *Eucalyptus* clonal areas for pulp production occupy 844,000 hectares, representing 26 % of the Portuguese forest, with a systematically increasing growth trend over the last 50 years. Deciduous hardwoods (oaks, chestnuts and others) have also been systematically increasing in area over the last 20 years, despite being the least representative forest cover in terms of occupied area (Institute for Nature Conservation and Forests 2015).

General Questionnaire:

1. If your company/organization was interested in transitioning from single-species settlements of forest land (e.g. fir fields) to more tree species that grow in the same forest settlement, which of the options below would be feasible/profitable for you?
 - ☐ Mixing of different clones
 - ☐ Planting of only one species, but allowing natural regeneration
 - ☐ Planting 2 different tree species
 - ☐ Planting 2 different tree species and allowing natural regeneration

- ☐ Planting 3-10 different tree species
- ☐ Planting more than 10 different tree species
- ☐ More than one species of tree in a single settlement would not be feasible for us

2. Does the organization you represent **ALREARY** manage any mixed tree plantation, or monoculture allowing natural regeneration (even if testing level)?
- ☐ Yes, mixture of clones
 - ☐ Yes, we plant only one species but we allow natural regeneration
 - ☐ Yes, we plant 2 different tree species
 - ☐ Yes, we plant 2 different tree species and allow natural regeneration
 - ☐ Yes, we plant more than 3 tree species
 - ☐ No, we just plant monocultures

a. If so, what is the purpose of these multi-species settlements?

☐ Commercial plantings ☐ Tests/ experiments ☐ Reforestation/ forest conservation

3. What species do you or the organization you represent cultivate?
4. Are these species planted in different plots or in the same plot? (Consider most of your plantings here)
- ☐ We just plant 1 species in all our area
 - ☐ We plant different species in separated plots
 - ☐ Mixed tree plantations/same plot
 - ☐ Most plantations are in separated plots but there are mixed species plots too
 - ☐ Others:
 - a. How old are your stands?
 - b. Where are they located?
 - c. What is the total area of each cultivated species?
 - d. If it is a company, what is the company's name?

5. **Exclusively for those who have already planted mixtures/or allowed natural regeneration in monocultures:**

- a. What were the biggest operational difficulties, and how did you overcome them to develop these mixed plantations?
- b. What were the biggest economic difficulties, and how did you overcome them to develop these mixed plantations?

6. Does climate change have any influence on how plantations are currently being managed in your organization?

☐ Yes ☐ No

a. If so, how?

7. What **operational challenges** might a possible transition from single-species to multi-species populations (at least 2-species) arise in terms of establishment, management and harvesting?
8. What **economic challenges** might a possible transition from single-species to multi-species populations (at least 2-species) arise in terms of establishment, management and harvesting?

9. Do you think that allowing natural regeneration in forest plantations hinders the management of cultivated species? Have you had any experience with allowing natural regeneration in your plantings?
10. Is your organisation/company/farm interested in increasing the proportion of mixed forests/multi-species stands on your land?
- ☐ Yes, the company is interested in starting to establish mixed forests
- ☐ Yes, the company is interested in increasing the proportion of mixed forests
- ☐ No, not interested
- ☐ I don't know

Thank you very much!!

If you want to receive the research's results, please provide your email:

References

- Albrektson, A., B. Elfving, L. Lundqvist, and E. Valinger. 2012. *The Basics And Relationships Of Forest Management*. Skogsskötselserien, Skogsstyrelsen. doi:<https://doi.org/10.1023/B:PLSO.0000047777.23344.a3>.
- Banos, V., P. Deuffic, and E. Brahic. 2022. Engaging or resisting? How forest-based industry and private forest owners respond to bioenergy policies in Aquitaine (Southwestern France). *Forest Policy and Economics* 144. Elsevier B.V.: 102843. doi:10.1016/j.forpol.2022.102843.
- Batista, A., A. Prado, C. Pontes, and M. Matsumoto. 2017. *VERENA Investment Tool: Valuing Reforestation with Native Tree Species and Agroforestry Systems*. World Resources Institute - Brasil.
- Brahic, É., and P. Deuffic. 2017. Comportement des propriétaires forestiers landais vis-à-vis du bois énergie. *Économie Rurale*: 7–25. doi:10.4000/economierurale.5176.
- Brazilian Institute of Geography and Statistics. 2021. Plant extraction and silviculture production. *Statistics*.
- Brazilian National Institute for Space Research. 2020. Technical note - PRODES 2020 estimate. *Ministry of Science, Technology and Innovation*.
- Brazilian Tree Industry. 2024. *IBÁ Annual Report 2024*. IBÁ.
- Busch, J., and K. Ferretti-Gallon. 2017. What Drives Deforestation and What Stops It? A Meta-Analysis. *Review of Environmental Economics and Policy* 11: 3–23.
- Coalizão Brasil. 2021. *Research and Development Program in Silviculture of Native Species (PP&D-SEN)*.
- Delalibera, H. C., P. H. Weirich Neto, A. R. C. Lopes, and C. H. Rocha. 2008. Alocação de reserva legal em propriedades rurais: do cartesiano ao holístico. *Revista Brasileira de Engenharia Agrícola e Ambiental* 12: 286–292. doi:10.1590/s1415-43662008000300010.
- Deuffic, P., M. Sotirov, and B. Arts. 2018. “Your policy, my rationale”. How individual and structural drivers influence European forest owners’ decisions. *Land Use Policy* 79. Elsevier Ltd: 1024–1038. doi:10.1016/j.landusepol.2016.09.021.
- Embrapa, and L. and S.-M. Ministry of Agriculture. 2018. *National Plan for the Development of Planted Forests*.
- Eurostat. 2023. *Forests, Forestry and Logging*. Eurostat-Statistics Explained.
- Feistauer, D., P. E. Lovato, A. Siminski, and S. A. Resende. 2014. IMPACT OF THE

- NEW BRAZILIAN FORESTRY CODE ON THE ADEQUACY OF SMALL FARM HOUSEHOLDS TO THE ENVIRONMENTAL LAW. *Ciência Florestal* v.24, n.3: 749–757.
- Ferraz Filho, A. C., J. R. S. Scolforo, and B. Mola-Yudego. 2014. The coppice-with-standards silvicultural system as applied to Eucalyptus plantations - a review. *Journal of Forestry Research* 25: 237–248. doi:10.1007/s11676-014-0455-0.
- FSC Sweden. 2010. Swedish FSC Standard for Forest Certification. *Structure*.
- Gaudin, P. 2014. A new natural repellent against deer damage. *Phytoma*.
- Holmstrom, E., M. Karlsson, and U. Nilsson. 2017. Modeling birch seed supply and seedling establishment during forest regeneration. *Ecological Modelling* 352: 31–39. doi:https://doi.org/10.1016/j.ecolmodel.2017.02.027.
- Institute for Nature Conservation and Forests, I. 2015. *Sixth National Forest Inventory - Final Report*.
- Institute for Nature Conservation and Forests, I. 2021. Portugal - Forest profile. *Institute for Nature Conservation and Forests, INFC*.
- Juvany, L., P. O. Hedwall, Adam Felton, K. Öhman, M. Wallgren, C. Kalén, A. Jarnemo, H. Johansen, et al. 2023. From simple metrics to cervid forage: Improving predictions of ericaceous shrub biomass. *Forest Ecology and Management* 544. doi:10.1016/j.foreco.2023.121120.
- Maule, C. F., T. Mendlik, and O. B. Christensen. 2017. The effect of the pathway to a two degrees warmer world on the regional temperature change of Europe. *Climate Services* 7. The Authors: 3–11. doi:10.1016/j.cliser.2016.07.002.
- Ministry of Agriculture and Food Sovereignty. 2025. France Relance: the renewal of French forests.
- Paquette, A., and C. Messier. 2010. The role of plantations in managing the world's forests in the Anthropocene. *Frontiers in Ecology and the Environment* 8: 27–34. doi:10.1890/080116.
- Du Puy, S., N. Derriere, and S. Wurpillot. 2017. *La forêt plantée en France : état des lieux. Institut national de l'information géographique et forestière (IGN)*. Vol. 40.
- Rezende, G. D. S. P., J. L. Lima, D. da C. Dias, B. M. de Lima, A. M. Aguiar, F. de L. G. Bertolucci, and M. A. P. Ramalho. 2019. Clonal composites: An alternative to improve the sustainability of production in eucalypt forests. *Forest Ecology and Management* 449. Elsevier: 117445. doi:10.1016/j.foreco.2019.06.042.
- Ruggiero, P. G. C., A. Pfaff, E. Nichols, M. Rosa, and J. P. Metzger. 2021. Election cycles affect deforestation within Brazil's Atlantic Forest. *Conservation Letters* 14. John Wiley & Sons, Ltd: e12818. doi:10.1111/CONL.12818.
- Sinacore, K., E. H. García, A. Finkral, M. van Breugel, O. R. Lopez, C. Espinosa, A. Miller, T. Howard, et al. 2023. Mixed success for carbon payments and subsidies in support of forest restoration in the neotropics. *Nature Communications* 14. Springer US: 1–13. doi:10.1038/s41467-023-43861-4.
- Skogsindustrierna. 2021. Forest Industry's importance for the Economy 2021. *Statistics Sweden*.
- SKOGSSTYRELSEN. 2023. *FOREST PROTECTION LAW BOARD RULES IN VALIDITY SEPTEMBER 1, 2022*.
- Souza, C. M., J. Z. Shimbo, M. R. Rosa, L. L. Parente, A. A. Alencar, B. F. T. Rudorff, H. Hasenack, M. Matsumoto, et al. 2020. remote sensing Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. *Remote sensing* 12: 27–35. doi:10.3390/rs12172735.
- Sparovek, G., A. Barretto, I. Klug, L. Papp, and J. Lino. 2011. A revisão do Código Florestal brasileiro. *Novos Estudos CEBRAP* 89: 111–135.

- doi:<https://doi.org/10.1590/S0101-33002011000100007>.
- Swedish_Forest_Industries_Federstion. 2025. *Statistics - Contribution to economy and society*. CEPI, FAO.
- Swedish Forestry Agency. 2024. Support and contributions. *SKOGSSTYRELSEN*.
- Swedish University of Agricultural Sciences. 2024. Skogsdata 2024 Species. *Official Statistics of Sweden*. Umea.
- Teuvo Ahti, L. H.-A. and J. J. 1968. Vegetation zones and their sections in northwestern Europe. *Annales Botanici Fennici* 5. Finnish Zoological and Botanical Publishing Board: 169–211. doi:<https://ci.nii.ac.jp/naid/10006680931>.
- TreeDivNet. 2026. The Tree Diversity Network.
- Trees For Me - Annual Report*. 2023.
- Verra. 2025. VERRA - Verified Carbon Standard (VCS).
- Vinicius Britto. 2024. Production of Plant Extraction and Forestry 2023. *Brazilian Institute of Geography and Statistics News*.
- Živojinović, I., Weiss, G., Lidestav, G., Feliciano, D., Hujala, T., Dobšínská, Z., Lawrence, A., and U. Nybakk, E., Quiroga, S., Schraml. 2015. Forest Land Ownership Change in Europe. COST Action FP1201 FACESMAP. In *EFICEEC-EFISEE Research Report*. University of Natural Resources and Life Sciences, C:693.