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EUCALYPTUS TERRITORIALIZATION AND ENVIRONMENTAL IMPACTS IN BRAZIL AND PORTUGAL

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Abstract

From a geographical view and through bibliographic and documentary research, mapping, and fieldwork, this study employed the SWOT matrix to analyze the eucalyptus environmental impacts on two study areas in these countries. We found that their physical aspects favor its growth, providing economic benefits. Extreme weather events have worsened the water deficit in the Brazilian Cerrado, leading to user conflicts. In northwestern mainland Portugal, wildfires have been more recurrent and severe, causing human and property losses and compromising the natural systems' resilience.

Keywords: Eucalyptus forestry, Forest policy, Territorial planning.

Resumo / Resumen

TERRITORIALIZAÇÃO DO EUCALIPTO E IMPACTOS AMBIENTAIS NO BRASIL E EM PORTUGAL

Sob o prisma geográfico e por meio de pesquisa bibliográfica e documental, mapeamento e trabalho de campo, este estudo aplicou a matriz SWOT para analisar os impactos ambientais da eucaliptocultura em duas áreas de estudo destes países. Verificamos que seus aspectos físicos favorecem a produtividade do eucalipto, proporcionando benefícios econômicos. Eventos climáticos extremos têm agravado o déficit hídrico no Cerrado brasileiro, levando a conflitos entre usuários. No noroeste de Portugal continental, os incêndios florestais têm sido mais recorrentes e severos, causando perdas humanas e patrimoniais e comprometendo a resiliência dos sistemas ambientais.

Palavras-chave: Silvicultura do eucalipto, Política florestal, Ordenamento Territorial.

TERRITORIALIZACIÓN DEL EUCALIPTO Y IMPACTOS AMBIENTALES EN BRASIL Y PORTUGAL

Desde una perspectiva geográfica y investigación bibliográfica y documental, cartografía y trabajo de campo, este estudio utilizó la matriz DAFO para analizar los impactos ambientales de este cultivo en dos zonas de estudio de estos países. Se constató que sus aspectos físicos favorecen el crecimiento del eucalipto, aportando beneficios económicos. Los fenómenos meteorológicos extremos han agravado el déficit hídrico en el Cerrado brasileño, provocando conflictos entre los usuários. En el noroeste de Portugal continental los incendios forestales han sido más recurrentes y graves, causando pérdidas humanas y materiales y poniendo en peligro la resiliencia de los sistemas medioambientales.

Palabras-clave: Silvicultura del eucalipto, Política forestal, Planificación territorial.

INTRODUCTION

Silviculture is the large-scale forest planting and exploitation for commercial use. *Eucalyptus* spp., native to Australia and some nearby islands, is widely employed in forestry in tropical and Mediterranean regions due to its easy edaphoclimatic adaptability (SELLERS, 1910). Brought to Brazil and Portugal in the 19th century for ornamental and medicinal purposes (ANDRADE, 1942, RADICH, 2007), it became a key commodity because of its high-quality wood, and fast growth in short rotation. Today, its multiple uses support many industries, which feed a growing wood-dependent consumer market. Despite significant economic aspects, some claim it is a low-carbon activity while others argue about its adverse impacts on hydrological integrity, biodiversity, and land tenure (RODRIGUES; TEIXEIRA; SANTIAGO, 2024).

Thus, this work aimed to analyze the eucalyptus environmental impacts of Brazilian and Portuguese silviculture by applying the SWOT (strengths, weaknesses, opportunities, and threats) matrix from a geographical view, focused on the natural resources' potentials, the natural systems' fragilities, and the social systems' vulnerabilities (ROSS, 2009). We selected two study areas for their importance in the eucalyptus forest sector: João Pinheiro, in northwestern Minas Gerais, Brazil, and the NUTS III AVE region, in northwestern mainland Portugal. As the geographical spatial category, we analyzed the used territory which is the material and social basis of human activities (SANTOS, 2006). The timeframe concerns the eucalyptus forestry introduction in João Pinheiro from the mid-1970s to 2020, and in the NUTS III AVE from the 1950s to the most recent forest data from 2015 and 2018.

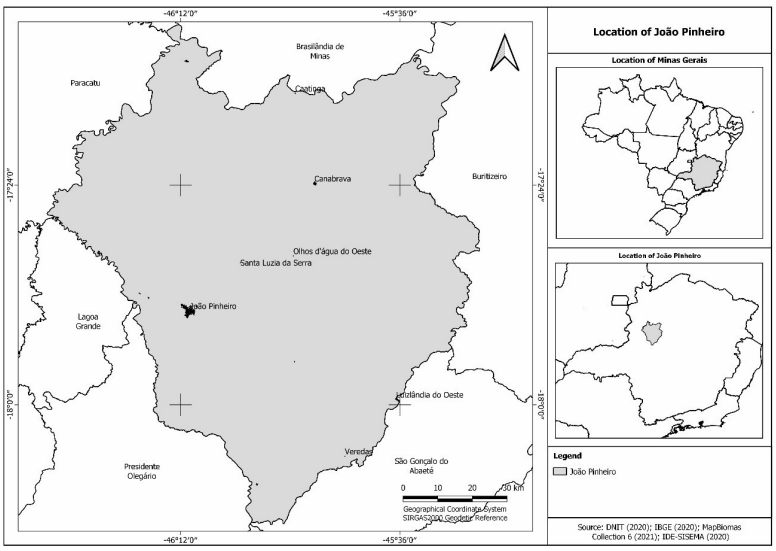
MATERIALS AND METHODS

STUDY AREAS

JOÃO PINHEIRO

João Pinheiro is the largest municipality in land area in Minas Gerais, covering 10.727,097 km². It is composed of the city and six districts: Canabrava, Caatinga, Luizlânda do Oeste, Olhos d'água do Oeste, Santa Luzia da Serra, and Veredas (Figure 1) (IBGE, 2021).

Figure 1. Location of João Pinheiro in northwestern Minas Gerais, Brazil.

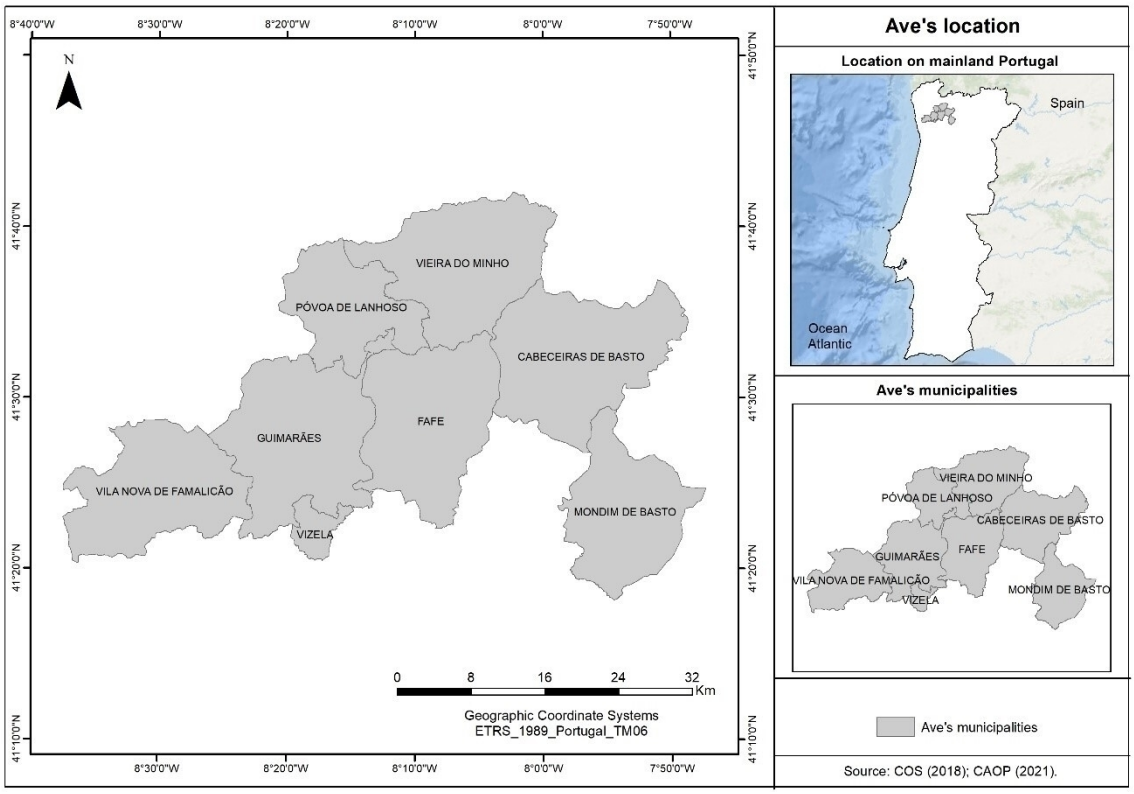


Source: Authors

THE NUTS III AVE

The NUTS III AVE comprises eight municipalities: Cabeceiras de Basto, Fafe, Guimarães, Mondim de Basto, Póvoa do Lanhoso, Vieira do Minho, Vila Nova de Famalicão and, Vizela within 1.451 km² (Figure 2) (PORDATA, 2023).

Figure 2. Location of the NUTS III AVE in northwestern mainland Portugal.



Source: Authors

DATA GATHERING

We did a comprehensive literature review from books, theses, journals, websites, and digital libraries to understand eucalyptus forestry consolidation, in the light of political, economic, environmental, and cultural factors. For statistical data, we used the 2020 Production of Vegetal Extraction and Silviculture (PEVS) by the Brazilian Institute of Geography and Statistics (IBGE), and from Portugal, the 6th National Forest Inventory (INF6) of 2015 by the Institute for Conservation of Nature and Forests (ICNF) and the 2018 land use and land cover map (COS2018) from the Directorate-General for Territory (DGT). Social information for 2020 was collected from official sources.

MAPPING, SOCIOENVIRONMENTAL DIAGNOSES, AND FIELDWORK

By mapping geodiversity, we identified physical aspects and their dynamic interrelationships that influenced the development of eucalyptus forestry and its spatial distribution. Then, we elaborated a socioenvironmental diagnosis of each area, synthesizing knowledge of their natural and socioeconomic

systems. Next, we visited eucalyptus stands managed by important stakeholders to check and collect additional data by using semi-structured interviews and to verify the silvicultural techniques they adopt to mitigate the adverse impacts and optimize the positive impacts of the activity. In João Pinheiro, we visited the stands in charge of Vallourec Florestal and the Association of Steel Mills for Forestry Development (ASIFLOR), and in the NUTS III AVE, of the Navigator Company, and the Ave Valley Foresters Association (ASVA).

SWOT ELABORATION

The SWOT matrix is a widely used tool to order and summarize the internal (strengths and weaknesses) and external (opportunities and threats) factors of organizations and activities, which helps planners in decision-making processes. Although it originated in business for strategic planning in the 1950s, it has been applied several fields such as agriculture, and forestry owing to its easy comprehension, quick construction (normally in a 4-quadrant diagram), and adaptability to other methods (BENZAGHTA et al., 2021). Yet, it restricts quantitative evaluation, limiting its use for qualitative research (AGARWAL; GRASSL; PAHL, 2012; PANAGIOTOU, 2003). As our last step, we elaborated a matrix for each study site, and analyzed the main environmental impacts of eucalyptus forestry.

RESULTS AND DISCUSSION

BRINGING THE SWOT TO GEOGRAPHY

In both study areas, we applied the SWOT matrix as an analytical tool to support a broad understanding of the eucalyptus environmental impacts based on their natural resources' potentials, the natural systems' fragilities, and the social systems' vulnerabilities. The matrix helped identify the strengths, weaknesses, opportunities, and threats related to forestry, offering insights into territorial planning efforts to address the challenges faced in these locations.

AN OVERVIEW OF THE BRAZILIAN EUCALYPTUS FORESTRY

At the outset of the 20th century, the Brazilian agronomist Edmundo Navarro de Andrade (1881 – 1941) introduced eucalyptus silviculture in Brazil. After graduating from Coimbra and returning to his country in 1903, the Paulista Railroad Company hired him to find an economically viable timber species for firewood and sleepers. From experiments on native and exotic trees, he concluded that eucalyptus whose seeds he had brought from Portugal had the best features for reforestation due to its fast growth and wood durability (ANDRADE, 1942; JACOBS, 1981).

From the 1960s, it expanded rapidly in the country, driven by supportive legislation such as the 1965 Forestry Code (Law n° 4.771), which required reforestation for forest raw material users, and the Fiscal Incentive Law for Reforestation (Law n° 5.106) (1966 – 1988), offering income tax deductions for forest investments. The creation of the Brazilian Institute of Forest Development (IBDF) in 1968, responsible for program analysis and approval, also contributed significantly, alongside advancements in forest science and collaboration between academia and industry. Improved silvicultural techniques boosted the Mean Annual Increment (MAI) from 10 $m^3\ ha^{-1}\ yr^{-1}$ in the 1960s to 35 $m^3\ ha^{-1}\ yr^{-1}$ today, with a seven-year rotation (FOELKEL, 2005). Earlier, however, Minas Gerais had made the first eucalyptus reforestation efforts in the 1940s, chiefly by the steel segment, as native forests used in charcoal for pig iron and steel production, declined around industrial sites (BACHA, 1991; KENGEN, 2019).

As stated by 2020 PEVS, Brazilian silviculture comprised 9.6 million ha, and eucalyptus totaled 77,3%. Minas Gerais had the highest production value (R$6.0 billion), mostly from charcoal (87,5%). João Pinheiro had the state's largest eucalyptus area and was the country's leading charcoal producer (IBGE, 2021).

SOCIOENVIRONMENTAL DIAGNOSIS OF JOÃO PINHEIRO

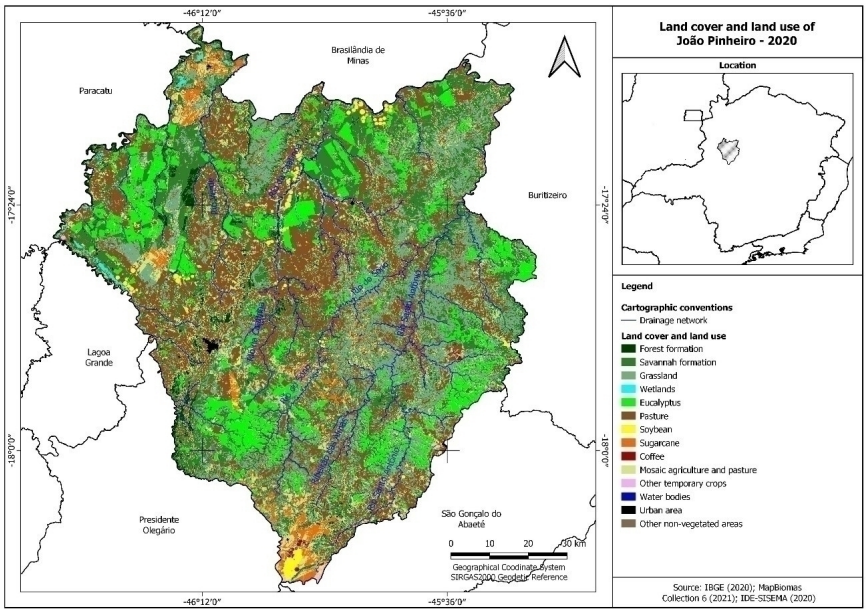
The occupation of northwestern Minas Gerais began with gold and gem extraction and extensive cattle-raising in the Cerrado biome, marked by nutrient-poor and aluminum-rich soils, and uneven rainfall. Until modern agriculture and soil improvements in the 1970s, its land was considered improper for large-scale farming, thus with low economic value (AB'SABER, 2003; ROSS, 2009). The 1950s brought key changes with the construction of Brasília, the BR-040 road, and the Três Marias hydroelectric plant, boosting immigration and job opportunities in civil construction (FJP, 1979).

By the mid-1960s, improved communication routes eased charcoal making, and João Pinheiro emerged as a major producer due to its natural forests, and strategic location near key industrial hubs. Yet, a chief turning point in the Northwest happened in the 1970s through regional development programs allied to the national integration policy, converting the Cerrado into an agricultural frontier. These changes caused the clearance of native vegetation for crops, pasture, and eucalyptus planting with capital-intensive investments and modern techniques (FJP, 1979; ROSS, 2009).

João Pinheiro lies in the Sanfranciscana depression, characterized by Precambrian rocks, Cretaceous sedimentary deposits, and Tertiary and Quaternary sediments. The region features extensive flat terrain (*chapadas)* and the prevalent soils include dystrophic red-yellow latosols, cambisols, and, some neosols (FJP, 1979; MAPBIOMAS, 2021). The climate, classified as Aw by Köppen, has a dry winter and a rainy summer, with a mean annual temperature (MAT) of 24°C and average annual rainfall (AAR) of 1.360 mm (INMET, 2022). Located in the Paracatu River basin, its watercourses are the Sono, Caatinga, Prata, and Verde Rivers, essential for agriculture and forestry. The vegetation consists of forest, savannah, and grassland (COELHO, 2014; RIBEIRO; WALTER, 1998).

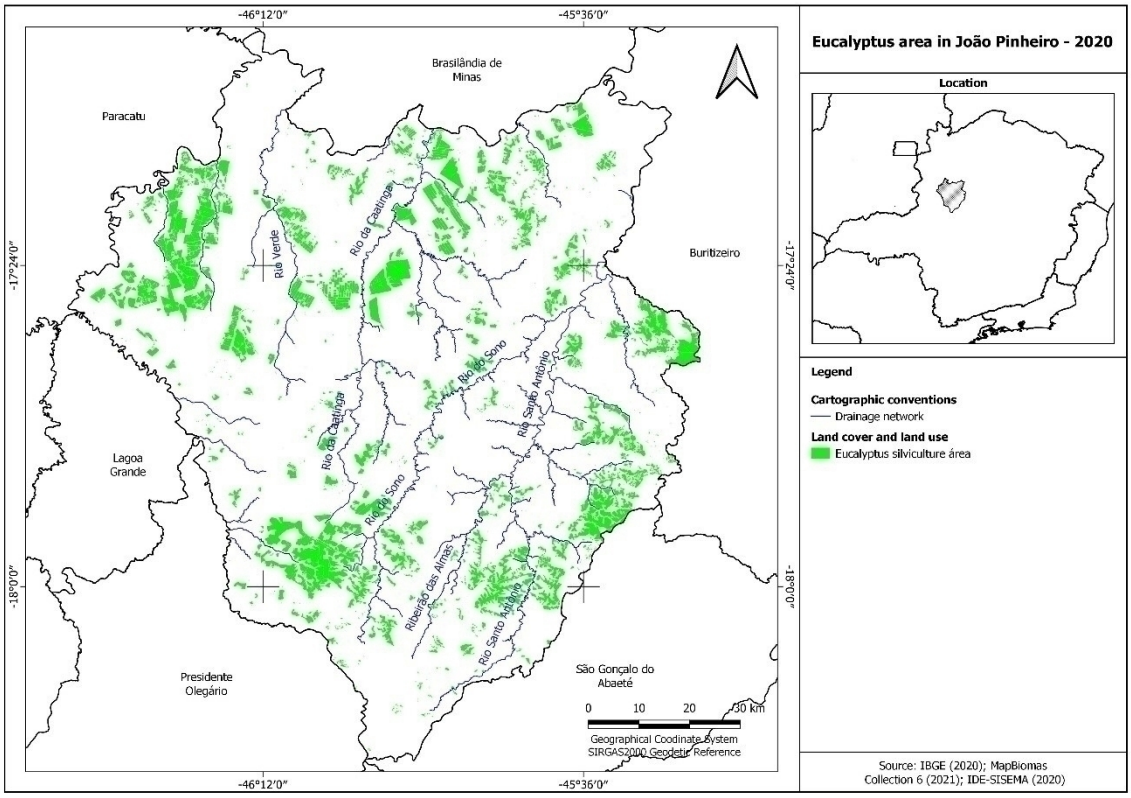
In 2020, João Pinheiro had a population of 47.726, mostly urban, and a low density of 4.3 persons/km² (IBGE, 2021). As to the land cover and land use map (MAPBIOMAS, 2021), the savannah (scattered trees and grassland) covered the largest area (29.09%), followed by planted pasture (27.87%), eucalyptus forestry (10.34%), and agriculture and pasture mosaics (9.97%). Temporary crops included sugarcane (1.74%) and soybeans (0.7%), and urban areas occupied 11.01% (Figure 3). Eucalyptus reforestation was in the whole municipality, especially in two main relief compartments: the Plateaus of the Upper São Francisco River (in the east, southeast, and southwest) and the Middle São Francisco River Depression (in the north, northwest, and parts of the northeast) (Figure 4).

Figure 3. Land cover and land use map of João Pinheiro in 2020.



Source: Authors

Figure 4. Eucalyptus area in João Pinheiro in 2020.



Source: Authors

THE FORESTRY CONTEXT IN MAINLAND PORTUGAL

The forest evolution in mainland Portugal can be roughly divided into two moments. First, after the Quaternary glaciations, the Laurissilva was largely replaced by species from the *Fagaceae* family, such as Quercus (*Quercus* ssp.) and Castanea (*Castanea* ssp.) (PAIVA, 1996). Second, extensive reforestation programs portrayed in the 19th and early 20th centuries, mainly through the Forest Settlement Plan (1938–1968) with maritime pine (*Pinus pinaster*) due to its aptness to degraded soils in communal lands in mountainous regions north of the Tagus River (DEVY-VARETA, 1993).

In the *Estado Novo* regime (1933–1974), public policies, clearly the Development Plans from 1953 to 1974, fostered the growth of pulp and paper industries. The mid-1960s saw the creation of the Forestry Development Fund (FFF) to supply wood to the forest-based sector (BENTO-GONÇALVES, 2021; RADICH; BAPTISTA, 2005). Parallel, rural depopulation increased as people migrated from rural areas to coastal urban centers, a trend intensified in the Colonial War (1961–1974), leading to a lack of agroforestry labor. With the democratization, new associations and non-governmental organizations emerged, particularly in the environmental field (BENTO-GONÇALVES, 2021).

As to eucalyptus, it was first commercially used as sleepers for the Royal Company of Portuguese Railways in 1870. Yet, major expansion began in the 1950s, widely *E. globulus*, because of its excellent wood for pulp driven by the setting up of new companies and increased production capacity (PEREIRA, 2016). Around the 1990s, the Portuguese forest sector faced reduced investment appeal, international competition, fluctuating wood prices, poor management, phytosanitary issues, and high fire risks (BENTO-GONÇALVES, 2021; RADICH; BAPTISTA, 2005).

At the end of the 20th century, Portugal's landscape featured unmanaged forests and abandoned rural areas. Urban perimeters expanded due to increased human activity and land use changes, resulting in wildland-urban interfaces (WUIs). In WUIs, built-up areas intermingle with vegetation, becoming highly fire-prone zones (BENTO-GONÇALVES; VIEIRA, 2020). Worsened by extreme weather, large wildfires (>100 ha) have become more common and severe with notable events in 2003, 2005, and 2017 (BENTO-GONÇALVES, 2021).

The 2015 IFN6 showed that forests were the main land use in continental Portugal, with native trees such as maritime pine and cork oak occupying 22% each, while the exotic *E. globulus* covered 26%. Planted in rotations from 10 to 12 years, *E. globulus* thrives in the central coast and northern areas, where milder winters and higher rainfall support optimal growth and higher productivity (PEREIRA, 2007).

SOCIOENVIRONMENTAL DIAGNOSIS OF THE NUTS III AVE

The NUTS III AVE is in a historically and culturally important region inhabited for millennia, recognized as the birthplace of Portugal in the Middle Ages, being the home of the country's first king, Afonso Henriques who from this pivotal location, conquered southward, shaping what is today the Portuguese territory (REBELO, 2013). For ages, agriculture and grazing were the main economic activities, yet, in the 19th century, it became a textile industrial center, mainly because of the expansion of cotton factories powered by the Ave River (VIEIRA; COSTA, 2017). Since the 1960s, it has undergone fast economic growth with a significant rural and agricultural exodus, and an increase in urbanization and industrialization, notably in the Middle and Lower Ave (BENTO-GONÇALVES et al., 2011).

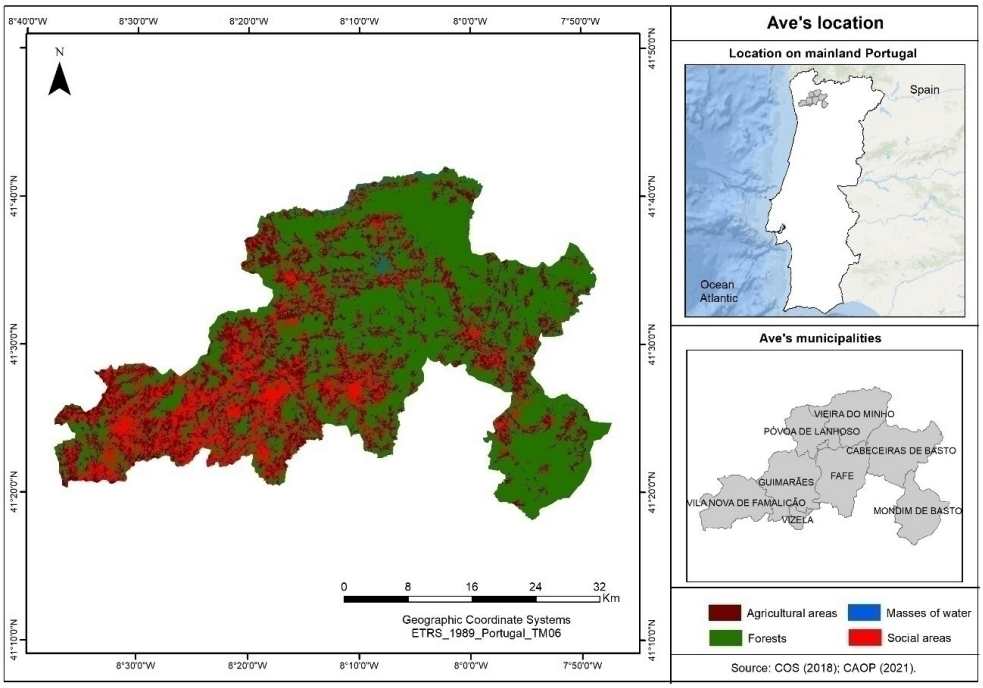
The region lies within the Hesperic Massif of the Precambrian and Paleozoic age. Its lithology consists of magmatic (mainly granites) and metamorphic rocks (schists and quartzites). Key soils include regosols, cambisols, leptosols (in specific inland areas), and fluvisols. Along with Köppen's classification, the climate is Csb, with a wet, cool season and a dry summer. Winter rainfall often exceeds 150 mm, while July and August are the driest months (

The Ave River basin covers 100 km² and rises in the Cabreira mountain. On the right bank, its major tributary is the Este River (250 km²), and on the left, the Vizela River (340 km²). Home to noble species like oak and maple (*Acer pseudoplatanus L.*), the region is now dominated by eucalyptus and maritime pine, with 18.380 ha and 13.000 ha, respectively (BENTO-GONÇALVES, 2021; ICNF, 2019).

In 2020, its population was 410. 224, with an uneven distribution that increases from east to west, strictly linked to the orography. The western part, with less dissected relief, is more urbanized and industrialized, with high population densities: Vizela (966 persons/km²), Vila Nova de Famalicão (662.9 persons/km²), and Guimarães (652.2 persons/km²). The mountainous eastern areas are sparsely populated owing to the terrain: Cabeceiras de Basto (64.6 persons/km²), Vieira do Minho (55.7 persons/km²), and Mondim de Basto (37.6 persons/km²) (BENTO-GONÇALVES et al., 2011; PORDATA, 2023).

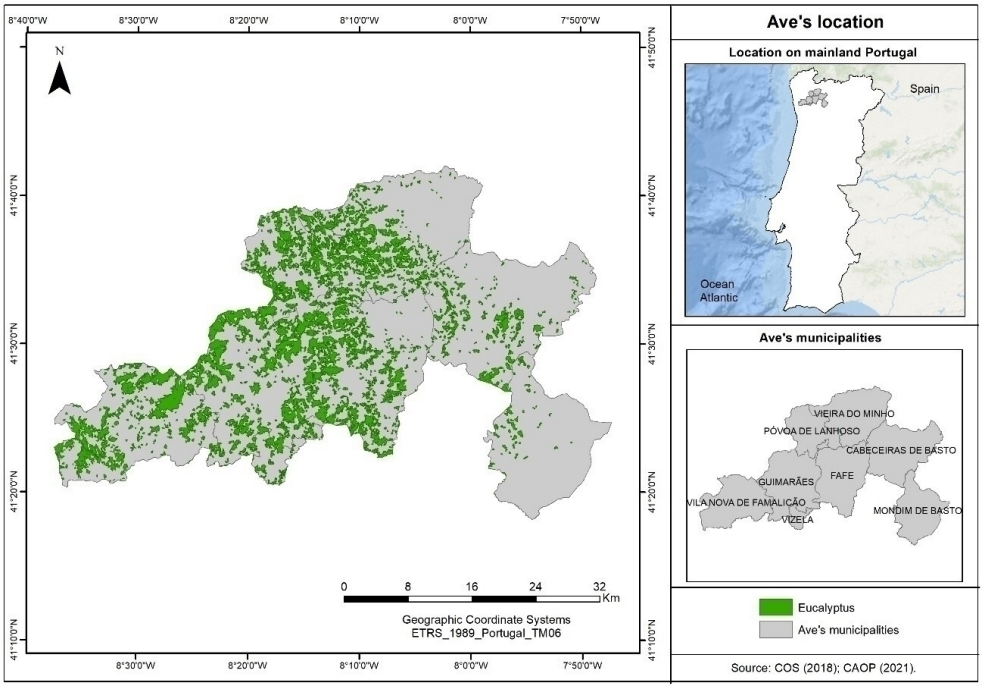
Land suitability for agriculture falls from west to east. In Guimarães and parts of Póvoa do Lanhoso, soil conditions are suitable for moderate agricultural activity, whereas the eastern side is better for forestry or silvopastoral systems (BENTO-GONÇALVES et al., 2011). Along with the IFN6, forests were the major land use (43.500 ha), followed by shrubs and pastures (44.360 ha), agriculture (32.290 ha), and urban areas (17.620 ha) (ICNF, 2019) (Figure 5). COS2018 showed that eucalyptus occupied 26.892 ha, mainly in Guimarães (6.918 ha), Vila Nova de Famalicão (4.771 ha), Fafe (4.618 ha), Póvoa do Lanhoso (4.221 ha), and Vieira do Minho (3.554 ha). Minor stands were in Cabeceiras de Basto (1.942 ha), Vizela (469 ha), and Mondim de Basto (399 ha) (Figure 6) (DGT, 2020).

Figure 5. Land use and land cover of the NUTS III AVE in 2018.



Source: Authors

Figure 6. Eucalyptus area in the NUTS III AVE in 2018.



Source: Authors

EUCALYPTUS FORESTRY SWOT MATRIX FOR JOÃO PINHEIRO

Figure 7. Eucalyptus forestry SWOT matrix for João Pinheiro.

	Positive	Negative
Internal	**STRENGTHS** S1 - Favorable physiographic conditions S2 – Reduced pressure on Cerrado forests S3 - Sustainable Forest Management (SFM)	**WEAKNESSES** W1 - Spatial concentration of land ownership, and production specialization
External	**OPPORTUNITIES** O1 – Research and Development with local institutions O2 –Degraded land recovery	**THREATS** T1 – Prolonged droughts T2 - Pest outbreak and diseases T3 - Steel market fluctuations

Source: Authors

S1 - FAVORABLE PHYSIOGRAPHIC CONDITIONS

In the homogeneous tabular dissection plateaus, the drainage in the pediplains has low density. The gentle slopes (< 3% to 8%) and the well-drained, highly weathered soils enable mechanization and forestry technologies. Erosion is often limited on these slopes but can be more significant near valley bottoms, mainly in the rainy season due to increased runoff. Despite the soil's low fertility, they are suitable for eucalyptus, as they can be effectively amended to support growth. The ample summer rainfall ensures that eucalyptus plantations remain viable across the municipality.

S2 - REDUCED PRESSURE ON CERRADO FORESTS

Since the mid-1990s, eucalyptus forestry in João Pinheiro has provided a renewable alternative for charcoal making, surpassing that of native forest. Eucalyptus charcoal has consistent quality, higher density, and better porosity, which boosts its market value and increases producer income. In 2020, the municipality produced 436.228 tons, generating R$ 479.8 million, an increase of 93.5% compared to 2019 (IBGE, 2021).

S3 - SUSTAINABLE FOREST MANAGEMENT (SFM)

Since the 1990s, Brazil's forest sector has gradually embraced SFM, evolving from a holistic ecosystem approach to enhancing silvicultural practices that conserve forest resources while optimizing yields. In João Pinheiro, vertically integrated forest companies own or lease large areas, making SFM crucial for their operations. To access markets and certification, they must adhere to management standards aligned with environmental regulations. Our fieldwork identified several SFM practices, including improved tillage to reduce soil compaction and nutrient loss, using hydrogel for water retention in seedlings, and creating mosaics of eucalyptus and native trees to establish biological corridors.

W1 - SPATIAL CONCENTRATION OF LAND OWNERSHIP AND PRODUCTION SPECIALIZATION

João Pinheiro's strategic location and the BR-040, which connects it to the pig iron market, have spurred eucalyptus expansion and charcoal production. This led to territorial specialization, a division of labor, and land ownership among major forest enterprises, meeting hegemonic actors' needs and displacing smallholders as many companies forced them to sell their land, impairing social and economic inequalities, driving rural exodus, and undermining livelihoods. Moreover, the Cerrado exploitation resulted in major land use changes, converting native forests into eucalyptus, agricultural, and pasture fields, which increased habitat fragmentation, intensified edge effects, disrupted gene flow, and raised erosion risks.

O1 - RESEARCH AND DEVELOPMENT WITH LOCAL INSTITUTIONS

In a globalized context in which objects and actions are becoming steadily intertwined with science and information (SANTOS, 2006), technological advances in forestry have required updated skills to use inputs and machinery, hugely based on artificial intelligence. This underscores the need for collaboration between educational institutions and forestry companies in João Pinheiro to promote knowledge exchange and innovation.

During the incentive law for reforestation, eucalyptus was often planted without proper environmental assessments, causing the degradation of riparian ecosystems and watershed harm. To address this, scientific research in forest hydrology at the micro-watershed scale (50–300 ha) is crucial for implementing SFM (LIMA et al., 2012). A deep understanding of hydrological processes and soil features can help minimize adverse environmental impacts on water resources, prevent conflicts, and ensure that economic growth and environmental health are achieved harmoniously (GONÇALVES et al, 2017; LIMA, 2010).

O2 - DEGRADED LAND RECOVERY

In João Pinheiro, where degraded areas have low productivity due to past land uses, eucalyptus could help restore forest ecosystem services, depending on the level of degradation. If the soil has lost its resilience, eucalyptus alone may not be effective (LIMA, 2010). It can enhance soil fertility and biodiversity by supporting more flora and fauna than pastures, sugarcane, and soybean monocultures (VITAL, 2007). A good approach is the adoption of crop-livestock-forestry systems that can diversify smallholders' production and income.

T1 - PROLONGED DROUGHTS

Commonly, the negative impacts of eucalyptus regard hydrological issues. Water consumption is proportional to biomass production and native forests and forestry usually absorb more water than shorter vegetation and non-irrigated crops. In this context, climatic water availability in micro watersheds can be evaluated by water consumption or water use efficiency (CALDER, 2007; GONÇALVES et al., 2017). Studies reveal that eucalyptus coverage < 20% does not significantly impact the micro watershed runoff patterns (LIMA, 2010).

Micro watersheds in AW climates often face water shortages due to irregular precipitation. Still, the canals in João Pinheiro keep year-round water flow, ensuring availability even during dry periods. Peak discharge rates occur from late October to April while the deficit is most severe from April to September (INMET, 2023; ROLIM et al., 2007). Still, recent extreme weather events have disrupted rainfall patterns, challenging stakeholders. Susceptible to water deficiency (WD), eucalyptus yields drop 10 m^3 ha^{-1} yr^{-1} for every 100 mm WD, causing significant economic losses (ZAKIA, 2020). Also, it impacts water quality and quantity for all users, intensifying conflicts, notably downstream. The municipality has struggled to balance water supply and demand, which has worsened caused by irrigated agriculture expansion (sugarcane and soybean).

T2 - PEST OUTBREAK AND DISEASE

Monocultures are highly prone to disturbances due to their inherent lack of genetic diversity, which lessens the effectiveness of natural predators, allowing pests to adapt and proliferate (SPALING, 1994; WILCKEN, 2014). In Brazil, leaf-cutting ants are a major threat to eucalyptus, greatly impacting wood production. Controlling it often requires excessive or improper use of chemical pesticides, which can harm human health and the environment by contaminating soil, and water resources, besides raising production costs (COSTA; ARALDI, 2014; ZANETTI; SILVA, 2021; SCHÜHLI et al., 2016).

T3 - STEEL MARKET FLUCTUATION

Silviculture is a long-term investment closely tied to the consumer market. Economic downturns and price instability can decrease steel demand, disrupting the production chain through supply shortages or foundry closures. Without replanting or proper management, wood stocks dwindle. The eucalyptus area in João Pinheiro has declined lately as sugarcane has expanded, driven by the demand from four local sugar mills. Landowners prefer leasing for sugarcane, which offers quicker and more reliable returns.

EUCALYPTUS FORESTRY SWOT MATRIX FOR THE NUTS III AVE

Figure 8. Eucalyptus forestry SWOT matrix for the NUTS III AVE.

	Positive	Negative
Internal	**STRENGTHS** S1 - Favorable physiographic conditions for *E. globulus* S2 – Forest associations S3 – Forest-based industry and producers' partnership	**WEAKNESSES** W1 - Fragmented property - and/or lack of SFM W2 - Lack of forest national property registration
External	**OPPORTUNITIES** O1 – Environmental Education (EE) and Geotechnologies	**THREATS** T1 – Large wildfires T2 – Pest outbreak and diseases

Source: Authors

S1 - FAVORABLE PHYSIOGRAPHIC CONDITIONS FOR E. GLOBULUS

The climate in NUTS III AVE is more favorable for *E. globulus* (16 m^3 ha^{-1} yr^{-1} at 10–12 years) than for maritime pine (7 m^3 ha^{-1} yr^{-1} at 40–45 years). In 2020, Portugal was Europe's second-largest producer of wood-free uncoated paper (18.1%) and the third-largest producer of chemical wood pulp (9.3%). Despite an 18% decline in sales during the COVID-19 pandemic, the segment totaled 50% of forest-based product exports (1.2% of the national GDP) and considerably contributed to the trade balance (CELPA, 2021; INE, 2022).

S2 - FOREST ASSOCIATIONS

Technical assistance from forest associations is active in guiding forest owners toward SFM and enhancing long-term wood production. In the NUTS III AVE, ASVA provides silvicultural services to reduce forest fuel, yielding significant environmental impacts. It employs four forest sappers dedicated to fuel management and civil protection.

S3 - FOREST-BASED INDUSTRY AND PRODUCERS' PARTNERSHIP

The partnership between forest producers and the industry seeks to improve eucalyptus stand management, particularly in smaller plots, to mitigate wildfire risks and enhance productivity. An initiative is the Clean and Fertilize Program (PLA) by BIOND in 2019 which provides technical and financial support for thinning and pruning eucalyptus stands. It focuses on smallholders who are either certified or in the certification process.

W1 - FRAGMENTED PROPERTY – AND/OR LACK OF SFM

Portugal's land tenure is mainly private, with 91% owned by individuals. Non-industrial forest owners hold the largest share (87%), and the forestry sector about 4%. Local communities manage 6%, and the State and other public bodies 3% (ICNF, 2021). In central and northern regions, land is fragmented in parcels

W2 - LACK OF FOREST NATIONAL PROPERTY REGISTRATION

The lack of broad land ownership data in Portugal has stuck accurate assessments of landownership, affecting SFM and fire prevention. Only 46% of forest properties have official registries, and about 20% lack ownership information due to disputes and other issues (APA, 2019). However, the Balcão Único do Prédio (BUPI), created in 2017, marks a big advance. BUPI is a free cadastral system that allows owners to map and identify their land, improving property rights protection. This system aims to mitigate environmental impacts and enhance territorial planning and forest management, contributing to public safety and forest sustainability in Portugal.

O1 - ENVIRONMENTAL EDUCATION (EE) AND GEOTECHNOLOGIES

EE is vital for raising forest ecosystem awareness and promoting conservation behaviors addressing socioeconomic and environmental aspects of sustainability. In Portugal, the focus has been more on fire suppression than prevention, stressing the need for a National Forestry Education Program that would tackle vulnerabilities, improve environmental quality, and bolster civil protection. Given the high wildfire risks, geotechnologies like remote sensing and satellite imagery can enhance exploring fire patterns, enabling early detection, and improving firefighting efforts (BENTO-GONÇALVES, 2021).

T1 - LARGE WILDFIRES

In Europe, 90% of wildfires occur in the Mediterranean basin, mostly human-induced (negligence and arson) (PYNE, 2009). In continental Portugal, they are driven by climatic conditions, land use changes, rural abandonment, an aging rural population, and decreased traditional land management, raising flammable fuel loads. The Northwest has the highest incidence because of its high biomass production and dry summers. In 2020, the NUTS III saw burning 2.069 ha, particularly shrubs (66%), followed by forests (32%). The largest burnt areas were in Fafe (682 ha), Cabeceiras de Basto (609 ha), Mondim de Basto (307 ha), Póvoa do Lanhoso (232 ha), and Vieira do Minho (179 ha), while the smallest in Guimarães (30 ha), Vila Nova de Famalicão (26 ha), and Vizela (3 ha). Although most of them were in shrubs, the landscape homogenization with highly flammable species (maritime pine and

eucalyptus) made them prone to ignition, causing soil degradation, and life and property losses. Extreme weather events have altered fire patterns, and current firefighting systems are scarce to handle these challenges.

T2 - PEST OUTBREAK AND DISEASES

The eucalyptus weevil (*Gonipterus platensis*), a defoliating insect, is a serious pest of *E. globulus*, chiefly in northern mountain regions at altitudes > 400–500 m. In these colder areas, the biological control agent *Anaphes nitens* is less powerful, increasing reliance on chemical controls (neonicotinoid pesticides) which overused can result in water contamination and harm to pollinators (CEIA et al., 2021; RODRIGUES; TEIXEIRA; SANTIAGO, 2024).

CONCLUSIONS

Eucalyptus expansion in Brazil and Portugal is closely linked with industrialization policies. In Brazil, eucalyptus forestry has largely spread into flat and low-cost lands, fostering vertically integrated companies through reforestation laws, and boosting timber for the private sector. Although these companies employ cutting-edge technology silvicultural practices, historically, small farmers have been marginalized, leading to displacement from traditional land use and rural exodus.

In Portugal, it extends into the northern coastal and mountainous areas, where abundant rainfall ensures higher yields. Private smallholdings prevail, with limited industrial use, and only a few stands undergo proper management, mainly by pulp and paper companies and forest associations. Structural changes in land use, fragmented forest properties, and a lack of human capital hamper sustainable forest management and territorial planning, despite notable initiatives to tackle these challenges.

Extreme weather events have worsened the water deficit in the Brazilian Cerrado biome and large wildfires in northwestern mainland Portugal. In this context, it is essential to integrate research, geotechnologies, and EE initiatives to enhance sustainability and recognize that the negative impacts of eucalyptus silviculture occur within their landscape matrices characterized by natural diversity and past human-induced disturbances.

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REFERENCES

AB'SÁBER, A. N.**Os domínios de natureza no Brasil: potencialidades paisagísticas**. Ateliê editorial, 2003.

AGARWAL, R; GRASSL, W; PAHL, J. Meta-SWOT: introducing a new strategic planning tool. **Journal of Business Strategy**, v. 33, n. 2, p. 12-21, 2012. https://doi.org/10.1108/02756661211206708.

ALVES, A. M.; PEREIRA, J. S.; SILVA, J. M. N. A introdução e a expansão do eucalipto em Portugal. *In* ALVES, A. M.; PEREIRA, J. S; SILVA, J. M. N. (ed). **O Eucaliptal em Portugal:** Impactes Ambientais e Investigação Científica, Lisboa: ISAPress, 2007.

ANDRADE, E. N. The Eucalyptus in Brazil. **Journal of Heredity**, v. 32, issue 7, July. p. 215–220, 1942. https://doi.org/10.1093/oxfordjournals.jhered.a105044.

APA – Agência Portuguesa do Ambiente. **National Forestry Accounting Plan 2021-2025**, Amadora, 2019.

BACHA, C. J. C. A expansão da silvicultura no Brasil.**Revista Brasileira de Economia**, v. 45, n. 1, p. 145-168, 1991.

BENTO-GONÇALVES, A.**Os incêndios florestais em Portugal**. Fundação Francisco Manuel dos Santos, 2021.

BENTO-GONÇALVES, A.; VIEIRA, A. Wildfires in the wildland-urban interface: key concepts and evaluation methodologies.**Science of the total environment**, v. 707, p. 135592, 2020. https://doi.org/10.1016/j.scitotenv.2019.135592.

BENTO-GONÇALVES, A. *et al*. **Adaptaclima:** Adaptação aos efeitos derivados das alterações climáticas. As Mudanças Climáticas e os Incêndios Florestais no Ave.L AMAVE, 2011.

BENZAGHTA, M. A. *et al*. SWOT analysis applications: an integrative literature review.**Journal of Global Business Insights**,6(1), p. 54-72, 2021. https://doi.org/10.5038/2640-6489.6.1.1148.

CALDER, I. R. Forests and water: ensuring forest benefits outweigh water costs.**Forest ecology and management**, v. 251, n. 1-2, p. 110-120, 2007. https://doi.org/10.1016/j.foreco.2007.06.015.

CEIA, R. S. *et al*. Local and landscape effects on the occurrence and abundance of the Eucalyptus weevil Gonipterus platensis (Coleoptera: Curculionidae).**Forest Ecology and Management**, v. 500, p. 119618, 2021. https://doi.org/10.1016/j.foreco.2021.119618.

CELPA - Associação da Indústria Papeleira. **Boletim Estatístico 2020**. *https://www.biond.pt/publicacoes/boletim-estatistico-2020/.*

COELHO, K. B. P. **Análise geoecológica da paisagem do município de João Pinheiro – Minas Gerais**. 2014. 222 f. Tese (Doutorado em Geografia) - Pontifícia Universidade Católica de Minas Gerais, Belo Horizonte, 2014.

COSTA, C. E.; ARALDI, D. B. Entomofauna florestal: uma visão holística.**Entomologia Florestal Aplicada,** 1 ed. Santa Maria: UFSM, p. 13-34, 2014.

DEVY-VARETA, N.**Afloresta no espaço e no tempo em Portugal:** a arborização da Serra da Cabreira 1919-1975. 1993.448f. Tese (Doutorado em Geografia) - Universidade do Porto, Porto, 1993.

DGT - Direção-Geral do Território. **Uso e ocupação do solo em Portugal:** análises temáticas, 2020.

FJP – Fundação João Pinheiro. **Diagnóstico, avaliação e perspectiva do sistema produtivo da produção de carvão vegetal:** estudo sobre o impacto social da produção de carvão no Programa do Grande Carajás. Belo Horizonte: FJP, 1988.

FJP – Fundação João Pinheiro. **Plano integrado de desenvolvimento da região noroeste de Minas Gerais (Planoroeste II).** Belo Horizonte: FJP, 1979.

FOELKEL, C. E. B. Eucalipto no Brasil: história de pioneirismo.**Visão agrícola**, v. 4, p. 66-69, 2005.

GONÇALVES, J. L. M. *et al*. Eucalypt plantation management in regions with water stress.**Southern Forests: a Journal of Forest Science**, v. 79, n. 3, p. 169-183, 2017. https://doi.org/10.2989/20702620.2016.1255415.

IBGE - Instituto Brasileiro de Geografia e Estatística. **Cidades**. http://www.ibge.gov.br.

IBGE - Instituto Brasileiro de Geografia e Estatística. **PEVS 2020**. https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?id=774&view=detalhes.

ICNF - Instituto da Conservação da Natureza e das Florestas. **6° Inventário Florestal Nacional: relatório final - 2015**. ICNF, 2019. https://www.icnf.pt/florestas/flestudosdocumentosestatisticasindicadores.

INE – Instituto Nacional de Estatística. **Contas económicas da silvicultura** – 2021. https://www.ine.pt/xportal/xmain?xpgid=ine_main&xpid=INE&xlang=pt.

INMET - Instituto Nacional de Meteorologia. **Banco de dados meteorológicos.** https://portal.inmet.gov.br/.

JACOBS, M. R. **Eucalypts for planting**. FAO Forestry Series, n. 11, 1981.

KENGEN, S. **Forestry in Brazil:** a brief history.Brasília, 2019.

LIMA, W. P. *et al*. Assessing the hydrological effects of forest plantations in Brazil.**River conservation and management**, p. 59-68, 2012. https://doi.org/10.1002/9781119961819.ch5.

LIMA, W.**A silvicultura e a água:** ciência, dogmas, desafios. Rio de Janeiro: Instituto BioAtlântica, 2010.

MAPBIOMAS. **Mapas e dados - 2021**. https://brasil.mapbiomas.org/#.

PAIVA, J. O declínio da Floresta em Portugal–.**Revista Florestal SPCF**, v. 9, n. 2, 1996.

PANAGIOTOU, G. Bringing SWOT into focus.**Business strategy review**, v. 14, n. 2, p. 8-10, 2003. https://doi.org/10.1111/1467-8616.00253.

PEREIRA, J. S.**O futuro da floresta em Portugal**. Fundação Francisco Manuel dos Santos, 2016.

PORDATA. **Estatísticas sobre Portugal e Europa -** 2023. https://www.pordata.pt/.

PYNE, S. J. Eternal flame: an introduction to the fire history of the Mediterranean.**Earth observation of wildland fires in Mediterranean ecosystems**, p. 11-26, 2009. https://doi.org/10.1007/978-3-642-01754-4_2.

RADICH, M. C. **Introdução e expansão do eucalipto em Portugal.** Lisboa: Fundação Luso-Americana, 2007.

RADICH, M. C.; BAPTISTA, F. O. Floresta e sociedade: um percurso (1875-2005).**Silva Lusitana**, 2005.

REBELO, F. **Portugal Geografia, paisagens e interdisciplinaridade.** Coimbra: Coimbra University Press, 2013. https://doi.org/10.14195/978-989-26-0630-9.

RIBEIRO, J. F.; WALTER, B. M. T. **Fitofisionomias do bioma Cerrado**, Embrapa, 1998.

RODRIGUES, G. S. S. C., TEIXEIRA, G., SANTIAGO, O. R. P. L. Silvicultura e impactos socioambientais. *In* RODRIGUES, G. S. S. C.; ROSS, J. L. S.; TEIXEIRA, G; SANTIAGO, O. R. P.; FRANCO, C. (ed.). **Eucalipto no Brasil:** expansão geográfica e impactos ambientais (Revised ed.). Uberlândia: Composer, 2024. p. 66-116. *E-book*.

ROLIM, G. D. S. *et al*. Classificação climática de Köppen e de Thornthwaite e sua aplicabilidade na determinação de zonas agroclimáticas para o estado de São Paulo.**Bragantia**,66, p. 711-720, 2011. https://doi.org/10.1590/S0006-87052007000400022.

ROSS, J. L. S. Análise empírica da fragilidade dos ambientes naturais antropizados.**Revista do Departamento de Geografia**, v. 8, p. 63-74, 1994. https://doi.org/10.7154/RDG.1994.0008.0006.

ROSS, J. L. S. **Ecogeografia do Brasil:** subsídios para planejamento ambiental. 1. reimpr. São Paulo: Oficina de Textos, 2009.

SANTOS, M. **A natureza do espaço:** técnica e tempo, razão e emoção. 4. ed. 2. reimpr. - São Paulo: EDUSP, 2006.

SCHÜHLI, G. S. *et al*. A review of the introduced forest pests in Brazil.**Pesquisa Agropecuária Brasileira**, v. 51, n. 5, p. 397-406, 2016. https://doi.org/10.1590/S0100-204X2016000500001.

SELLERS, C. H.**Eucalyptus:** its history, growth, and utilization. AJ Johnston, 1910. https://doi.org/10.5962/bhl.title.44973.

SPALING, H. Cumulative effects assessment: concepts and principles.**Impact Assessment**, v. 12, n. 3, p. 231-251, 1994. https://doi.org/10.1080/07349165.1994.9725865.

VIEIRA, A.; COSTA, F. D. S. A importância das fontes históricas para o conhecimento dos cursos de água: o caso do rio Ave (Noroeste de Portugal). **Caminhos da Geografia**, v. 18, n. 64, 2017. p. 263-282. https://doi.org/10.14393/RCG186421.

VITAL, M. H. F. **Impacto ambiental de florestas de eucalipto.** Rio de Janeiro: BNDES, 2007.

WILCKEN, C. F. Manejo integrado de pragas em plantio de eucalipto. **Opiniões**, 35, 2014.

ZANETTI, R; SILVA, W. L. P. Monitoramento de insetos-praga em plantações florestais. *In* Lemes, P. G., ZANUNCIO, J. C. (ed.). **Novo Manual de Pragas Florestais Brasileiras.** Belo Horizonte: UFMG, 2021. p. 59-91.

ZAKIA, M. J. B. **Água e florestas plantadas: o desafio da segurança hídrica**. *https://www.youtube.com/watch?v=isyTV3jVF58&ab_channel=Di%C3%A1logoFlorestal*.

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