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Quantification and characterization of surface fuel material in different stands in the north-east of Portugal

Quantificação e caracterização do material combustível superficial em diferentes povoamentos no nordeste de Portugal

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ABSTRACT
The aim of this study was to characterize the surface fuel material, based on its quantification and classification of hazardousness in four forest stands (Pinheiro manso, Castinçal, Sobreiral and Carvalhal) in the northeast of Portugal. The fuel material was classified according to its diameter, in dangerous (<1cm), semi-hazardous (>1cm) and green, moisture was assessed with drying in greenhouse. The Chestnut stand presented the largest quantity of fuel material (30.54 ton/ha; 16.40 ton/ha). Carvalhal had the lowest moisture content for summer (6.87%) and Pinheiro, the highest average value for winter (149.65%). The cork oak presented the greatest risk, due to the high quantity of fuel material coupled with low humidity in the summer.

Keywords: forest fires, fuel accumulation, flammability categories.

RESUMO
Objetivou-se com este estudo caracterizar o material combustível superficial, a partir da sua quantificação e classificação de perigosidade em quatro povoamentos florestais (Pinheiro manso, Castinçal, Sobreiral e Carvalhal) no nordeste de Portugal. O material combustível foi classificado de acordo com seu diâmetro, em perigosos (<1cm), semi-perigosos (>1cm) e verdes, a umidade foi avaliada com secagem em estufa. O povoamento de Castanheiro apresentou a maior quantidade de material combustível (30,54 ton/ha; 16,40 ton/ha). O Carvalhal teve o menor teor de umidade para o verão (6,87%) e o de Pinheiro, o maior valor médio para o inverno (149,65%). O sobreiro apresentou o maior risco, devido a elevada quantidade de material combustível atrelada a baixa umidade no verão.

Palavras-chave: incêndios florestais, acúmulo de combustível, categorias de inflamabilidade.

1 INTRODUCTION

In recent years, forest fires have received increasing attention due to their high material and immaterial damage. Mediterranean Europe suffers around 47,000 fires per year, being hit by fire, natural and forest areas (average 1980-2019) of approximately 440,000 hectares (EUROPEAN COMMISSION, 2019).

In the case of Portugal, an average of 17 000 occurrences occur every year in areas of 120 000 hectares affected, causing the loss of 3% of the country's forest area and placing it in the fourth position in the world with the most forest loss, a figure that is likely to increase in the coming decades due to climate change (EUROPEAN COMMISSION, 2019). Although fuels strongly influence the occurrence and spread of forest fires, their characteristics are temporal and spatially complex (KEANE, 2013). Its characteristics will directly interfere with the intensity, propagation, duration, and consequently, the proportions taken by a forest fire, as well as the quantity and changes of gas emission patterns by fires (GOODRICK; SHEA; BLAKE, 2010; GOULD; MCCAW; CHENEY, 2011).

The description of surface fuels can be approached in several ways, considering factors such as load, height, density and moisture content. In addition, a characterization can be performed based on the division of components such as dead manta, dead woody debris of different diameter classes, and herbaceous and shrub vegetation (KEANE, GRAY and BACCIU, 2012).

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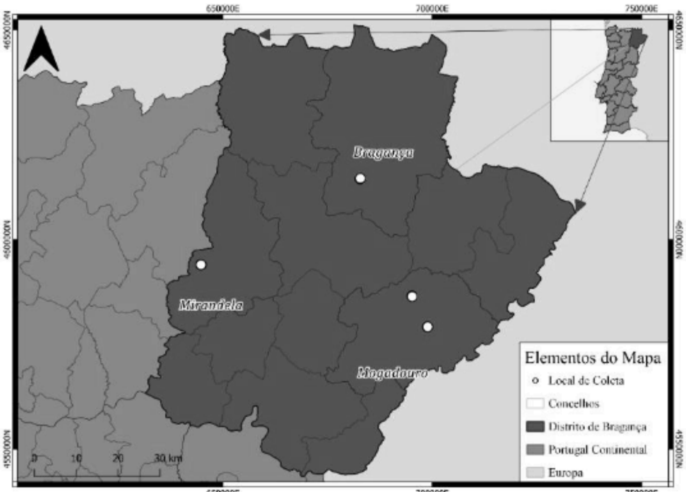
Knowledge of this crucial component in the fire triangle is essential not only to understand carbon stock, but also to assess the rate of fuel accumulation, especially in relation to the substantial amount of organic matter present. This understanding is indispensable for the implementation of treatments aimed at reducing these loads when necessary (RICCARDI et al., 2007; COLLINS and ROLLER, 2012). Therefore, understanding the quantification of fuels linked to the dynamics of the seasons during the year are fundamental for the realization of good practices in fire management (BATTAGLIA et al., 2010; KEANE et al., 2012).

Thus, the objective of this study was to characterize the surface fuel material, performing its quantification and classification of hazardousness in two seasons of the year, covering four different forest stands (Pinhal manso, Castinçal, Sobreiral and Carvalhal) in the northeastern region of Portugal.

2 MATERIALS AND METHODS

The study area is located in northeastern Portugal, in the region of Trás-os-Montes under Mediterranean climate between the coordinates 41°40'"N and -6°66'"W (Figure 1) and altitude varying between 353 and 840 m.

Figure 1. Location of the study area



Source: Directorate-General of the territory, adapted by Mariana Budnik Chinikoski. 2023.

It is composed of four forest stands of Castanea sativa Mill. (Chestnut), Pinus pinea L. (Manso pine), Quercus rubra L. (Oak) for wood production, and Quercus suber L. (Cork oak) for cork production, as shown in Table 1.

Table 1. Characteristics of the study plots

City	Bragança	Mirandela	Mogadouro	Mogadouro
Settlement	Chestnut	Pine meek	Cork oak	Oak
Age (years)	33	22	25	25
Latitude Longitude	41°39'26 N, 6°48'17" W	41°31'43.59" N, 7°16'0.31" W	41°40'57.83"N, 6°66'50.49" W	41°34'08.67"N, 6°62'35.25" W
Altitude (m)	840	353	695	776
Average temperature	11.9°C	14.2°C	12°C (7°F)	12°C (7°F)
Average annual rainfall (mm)	1052.6	520.1	738	738

Source: Self-Authored (2023).

Sampling techniques for the quantification and characterization of combustible material were based on research carried out by different authors (SOARES, 1979; BROWN, OBERHEU and JOHNSTON, 1982; SCHEIDER and BELL, 1985; SOUZA, SOARES and BATISTA, 2003, BEUTLING et al., 2005).

Quantification of the surface fuel material was carried out by the destructive method, and all vegetation present up to 1.8 m in height was collected, including the dead mantle, herbaceous plants and poorly developed regeneration. Ten samples were taken randomly in summer and winter from each stand. The samples were made up of plots of 1 m² of area, distanced at least ten meters from each other and between the edges. The number of samples followed the recommendation of Brown, Oberheu and Johnston (1982), which indicate that a good estimate of the load of combustible material of different vegetation types consists of carrying between 15 and 20 samples over an area of up to 20 hectares.

Subsequently, the division into classes was performed based on their diameter and hazardousness, as shown in Table 2.

Table 2. Classification of materials according to their diameter and risk

Fuel material class (diameter)	Classification of material
< 1cm	Hazardous (MP)
>1cm	Semi-hazardous (MSP)
Green	Non-hazardous (MV)

Source: Self-Authored (2023).

The weighing of each class and the determination of humidity in an oven were carried out with 100 g samples representative of each collection. Then, with the help of the geographical coordinates of each collection, maps were drawn up of each place and station with the quantity of dangerous material, in order to better represent each environment in a visual manner.

The experimental design was entirely casualized in a 4 x 2 factorial scheme (settlement type x season), with ten repetitions. The data were submitted to the analysis of variance and, in case of significance, the comparison of averages was carried out by the Tukey test at 5% significance.

3 RESULTS AND DISCUSSION

The different fuel classes and humidity varied significantly ($p<0.05$) with the type of settlement (Chestnut, Sobreiro, Carvalho, Pinheiro manso) and season (summer, winter). Only the MV class did not vary significantly with the stand type, probably because this category was not present in all samples, changing the mean. (Table 3).

Table 3. Significance of combustible materials

	MP	MSP	MV	Humidity
Settlement	0.000*	0.001*	0.584ns	0.000*
Season	0.000*	0.000*	0.001*	0.000*
	R^2 0.88	R^2 0.71	R^2 0.29	R^2 0.82

Where: * Significant; ns not significant.
Source: Self-Authored (2023).

The Chestnut stand was the one with the highest average value for hazardous and semi-hazardous material for both winter (MP) 3054,714 g/m² (30,547 Ton/ha) and summer 1640,848 g/m² (16,408 Ton/ha), as shown in table 4. While this figure is considerable, it does not yet reach an extreme level of concern. This is due to the humidity being consistently maintained at averages above 50%, as well as due to the intrinsic characteristics of the species. This is because Chestnut trees are one of the main "fire trees" for being leafy and keeping the environment relatively humid (FERNANDES, 2016).

Table 4. Averages for each fuel class in winter

Winter			
Settlement	**MP (g/m²)**	**MSP (g/m²)**	**MV (g/m²)**
Oak	1,309.136 b (210.562)	0 b 11 Other assets	7.06 ns (15.787)
Chestnut	3 054,714 to (352,173)	267,826 to 206,127	3.392 ns (10.726)
Pine	1,801.424 b (578.581)	29.100 b (65.07)	0 ns
Cork oak	1,927.124 b (516.172)	0 b 11 Other assets	4.98 ns (11.136)
Summer			
Oak	408.12 b (105.857)	0 ns	18.84 ns (25.907)
Chestnut	1 640,848 to (225,857)	106.78 ns (180.868)	28.832 ns (32.274)
Pine	571.188 b (211.449)	0 ns	0 ns
Cork oak	863,136 b (138,597)	0 ns	0 ns

Averages followed by the same letter in the same column per season do not differ from each other by Tukey's test at 5% probability. Values within the parentheses represent the standard deviation.
Source: Self-Authored (2023).

Carvalhal presented dangerous material in a noticeable way only in winter, with an average load of 1309,136 g/m² (13,091 Ton/ha), due to the species manifest deciduous leaves in the critical season for growth, as is the case of winter, the intake of hazardous material increases considerably.

The Sobreiro forest exhibited an average value of 1927,124 g/m² (19,271 Ton/ha) and 863,136 g/m² (8,631 Ton/ha) of hazardous material. These results point to a high risk, since loads greater than 1.2 Ton/ha made up of hazardous materials favor easier spread of surface fire, if it occurs (WHITE et al., 2014). In dry periods, together with the substantial value of the hazardous material, the risk of propagation increases significantly. In this scenario, it is crucial to implement more effective rural landscape management (SARDO, 2019).

The Pinhal meek for winter averaged 1801,424 g/m² (18,014 Ton/ha) and for summer 571,188 g/m² (5,711 Ton/ha), respectively. The reduction can be attributed to the increase in decomposition in the summer, with the increase in temperature, coupled with the small dimensions and the chemical composition of the aciculi, this combustible material ends up decomposing rapidly (WHITMORE, 1990).

Through cartographic representation, it was possible to visualize the distribution and quantity of hazardous combustible materials. This allowed for the identification of areas with greater concentrations, as well as observing how

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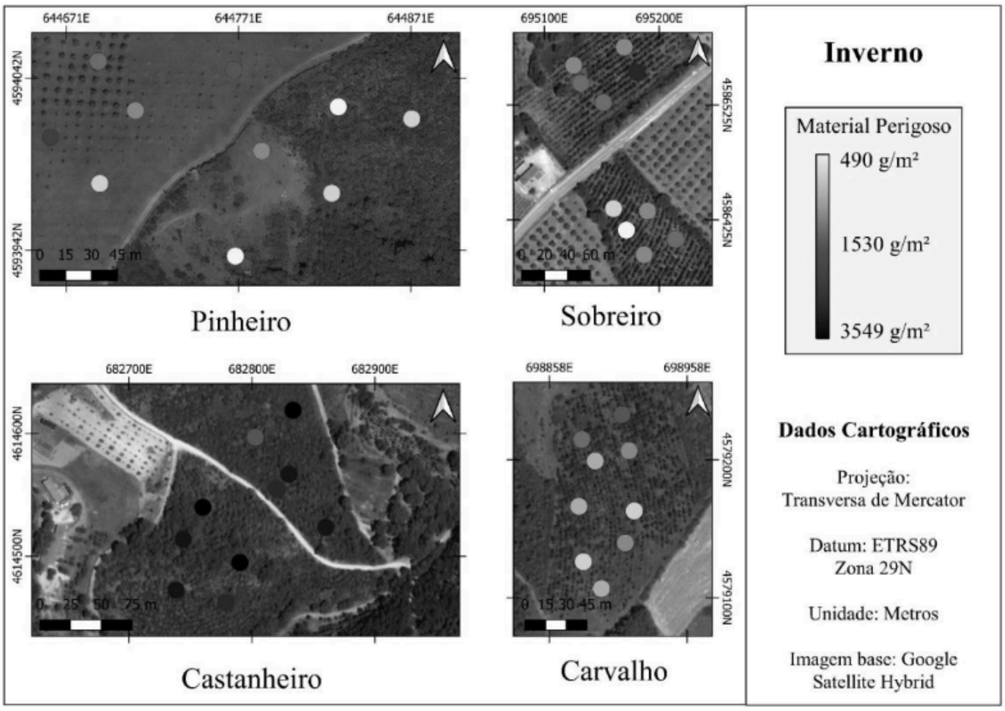
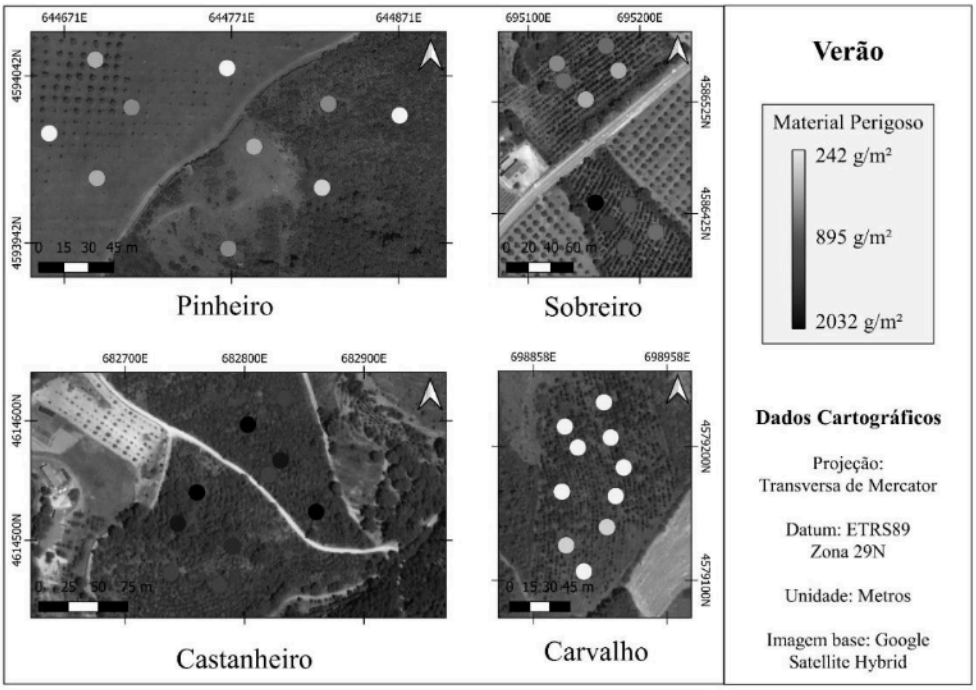
clearings or embroidery influenced the accumulation of these materials in the two seasons, as illustrated in Figures 2 and 3.

Figure 2. Cartographic representation of dangerous material for the settlements in winter



Source: General Directorate of the territory, adapted by Mariana Budnik Chinikoski. 2023.

Figure 3. Mapping depiction of material dangerous to settlements in summer



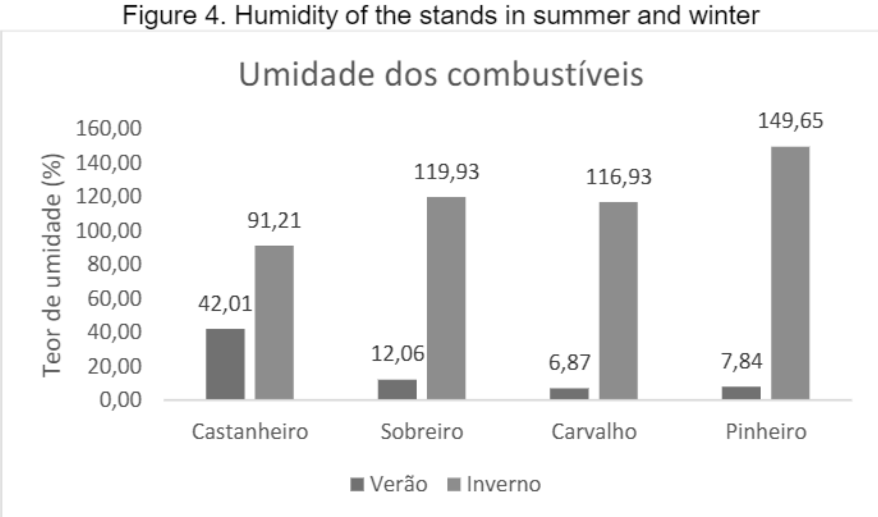
Source: General Directorate of the territory, adapted by Mariana Budnik Chinikoski. 2023.

The green material presented enormous variation between the samples, raising the standard deviation and consequently the significance of the means. This can be explained by the low or non-existent natural regeneration caused by the maturity of the stands (KEELING; PHILLIPS, 2007). The presence of green materials, due to the addition of evaporative surfaces, assists in the control and maintenance of humidity in the interior of the forest, (YU and HIEN, 2006) preventing sudden falls dangerous for the occurrence of fires.

Regarding humidity, the settlements showed a very significant difference between the seasons of the year (Figure 4). The variation evidenced occurs due to dead mantle with small dimensions (<1cm) suffer faster climatic responses, and may exhibit moisture levels between 2 and 300% (BATISTA, 1990).

The settlements of Sobreiro, Carvalho and Pinheiro manso showed extremely low values (less than 20%) of humidity in the most critical period of the year, summer. This figure highlights the substantial risk of fire, as humidity below 30% is considered hazardous. Under these conditions, the ignition probability of combustible materials is significantly high, especially when combined with a relative air humidity of less than 60%, as verified during sampling (SOUTO, 2009).

Figure 4. Humidity of the stands in summer and winter



Source: Self-Authored (2023).

4 CONCLUSION

The settlement of Castanheiro stands out for the largest quantity of fuel material during the winter, totaling 30,547 Ton/ha, while in the summer, this quantity decreases to 16,408 Ton/ha, mainly due to the predominance of hazardous materials. Even during the summer, which is considered the most critical period for the occurrence of fires, the combustible materials of this settlement maintain a high humidity, thus minimizing the risk in comparison with other species.

The Oak reveals the lowest level of humidity in the summer, with 6.87%, while the Pine tree shows a greater amplitude of humidity between the settlements, oscillating from 149.65% in the winter to 7.84% in the summer. These differences highlight the marked variability in the humidity characteristics of these species throughout the seasons.

For the fuel classes, the predominance in all the analyzed stands are of hazardous materials (<1 cm). When assessing the levels of danger, classifying the highest to the lowest risk, the Sobreiro is evidenced as the most susceptible settlement, driven by the considerable presence of combustible material and by the humidity during the critical period. Subsequently, Carvalho's settlement demonstrates a significant influence of humidity during the critical period. Soon afterwards, the Pine Tree, due to its low humidity, and finally the Chestnut Tree, which is influenced by humidity in different seasons. These analyzes highlight the specific hazardousness characteristics with respect to combustible materials in the various stands studied.

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REFERENCES

BATISTA, A.C. Forest fires. Recife: University Press - UFRPE. 115pp. 1990.

BATTAGLIA, M.A. Rocca, M.E. Rhoades, C.C. Ryan, M.G. Surface fuel loads in dead-cover treatments in Colorado conifer forests. **Ecology and Management**. 260: 1557-1566. 2010.
BEUTLING, A. Modeling of fire behavior based on laboratory and field experiments, Thesis (PhD in Forest Sciences). Federal University of Paraná. Curitiba. 2009.

BROWN, J. K. OBERHEU, R. D. JOHNSTON, C. M. **Handbook for inventorying surface fuels and biomass in the Interior West**. Odgen, Intermountain Forest and Range Experiment Station, 48p. 1982.

European Commission. **European Green Deal**. Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_pt. 2019. accessed on: 25 apr. 2022.

Fernandes, P. "Fire trees" prevent fires. Available from https://utadtv.utad.pt/info/regiao-sociedade/arvores-bombeiras-previnem. 2016. accessed: 30 Apr. 2022.

GOODRICK, S.L. SHEA D. BLAKE, J. Fuel consumption estimate for the Upper Coastal Plain of South Carolina. **Southern Journal of Applied Forestry** 34, 5-12. 2010

GOULD, J. S. MCCAW, W. L. CHENEY, N. P. Quantifying fine fuel dynamics and structure in dry eucalypt forest (Eucalyptus marginata) in western Australia for fire management. **Forest Ecology and Management**, Amsterdam, v. 262, p.531-
546. 2011

KEANE, ROBERT E.; GRAY, KATHY; VALENTINA, B. Spatial variability of wildland fuel characteristics in northern Rocky Mountain ecosystems. USDA Forest service. Res. Pap. RMRS.-RP-98 Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 56 p. 2013.

KEANE, R. E. GRAY, K. Bacciu, V. Spatial variability of wildland fuel characteristics in northern Rocky Mountain ecosystems. USDA Forest Service, 54 Rocky Mountain Research Station, Research Paper RMRS.-RP98. (Fort Collins, CO), (2012).

KEELING, H.C. PHILLIPS, O.L. The global relationship between forest productivity and biomass. **Global Ecology and Biogeography**, v.16, p.618-631, 2007.

SOUTO, P. C.; JÚNIOR, J. C.; ARAÚJO, I. E. L.; SOUTO, J. S. Quantification of combustible material in forest plantations and in remnant of Atlantic Forest in Paraíba, Brazil. **Environmental Engineering**: Research and Technology, v. 6, n.3, pp. 473-48, 2009.

SARDO, F. Fire risk at the urban-forest interface: conceptual reflection. Portuguese Association of Risk, Prevention and Security. 2019.

SOUZA, L. J. B. SOARES, R. V. BATISTA, A. C. Shaping of surface fuel material in stands of Eucalyptus dunnii, in Três Barras, SC. **Cerne**, v.9, n.2, p.231-245, 2003.

WHITE, B.L.A. RIBEIRO, A.S. WHITE, L.A.S. RIBEIRO, G.T. Characterization of surface combustible material in Serra de Itabaiana Sergipe National Park, Brazil. **Forest Science**, v.24, n.3, p.699-706, 2014.

WHITMORE, T.C. An Introduction to tropical rain forests. Oxford University Press, New York. 1990.

YU, C.; HIEN, W. N. Thermal benefits of city parks**. Energy and Buildings**, vol. 38, pp. 105-120, 2006.