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Simulating the effects of vegetation and landscape structure on fire behavior in northeastern Portugal: the case of holm oak (*Quercus rotundifolia*)

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« Si tu vois un homme qui a faim, donne-lui un poisson : tu le nourriras pour un jour. Mais apprends-lui à pêcher et il se nourrira toute sa vie »

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Abstract

Fire is a common process in the landscapes of northern Portugal. Previous studies showed that holm oak woodlands persist after fire and help to decrease fire intensity and rate of spread of wildfires. The main objectives of this study were to understand and model the effects of holm oak woodlands on fire behavior at the landscape level in the Upper Sabor watershed, located in northeastern Portugal, near Bragança city.

Holm oak (*Quercus rotundifolia*) was tested in terms of area and configuration of woodlands in the landscape according to scenarios built based on the likely expansion of these vegetation units in the area of study, considering the following percentage of holm oak in the area: 2.2% (Low), 18.1% (Moderate), 26.0% (High), and 39.8% (Rivers). The scenarios were built to test (1) the role of holm oak in fire behavior, and (2) how spatial configuration of holm oak patches help to decrease burned areas and fire intensity.

We used the FlamMap model to simulate fireline intensity and rate of spread based on land use and land cover data, combined with topographic data (elevation, slope and aspect) and weather data (fuel moisture and wind speed). Additionally, we used two fuel models for holm oak developed based on field data collected in the region (woodland inside and edge). Moreover, we applied FRAGSTATS to analyze the spatial patterns of fireline intensity classes using the landscape metrics Class Area (CA), Number of Patches (NP) and Large Patches Index (LPI).

The results showed that fireline intensity and rate of spread varied among scenarios and holm oak fuel models. Moreover, the average of fire intensity and average of rate of spread have decreased along increasing the percentage of holm oak in the area for both holm oak fuel models. The analysis of spatial pattern of fire intensity classes showed that landscape metrics had decreased along increasing the percentage of holm oak in the area for both holm oak fuel models.

As conclusion holm oak woodlands extension and configuration affect fire behavior by reducing fire intensity and rate of spread. The results of this study suggest that holm oak can be used in preventive silviculture measures in order to decrease fire hazard in the region.

Keywords: *Fire behavior, Fire intensity, Holm oak, Fire Modeling System, FlamMap, Northeastern Portugal.*

Resumo

O fogo é um processo frequente nas paisagens do norte de Portugal. Estudos anteriores mostraram que os bosques de azinheira (*Quercus rotundifolia*) persistem após a passagem do fogo e ajudam a diminuir a sua intensidade e taxa de propagação. Os principais objetivos deste estudo foram compreender e modelar o efeito dos bosques de azinheira no comportamento do fogo ao nível da paisagem da bacia superior do rio Sabor, localizado no nordeste de Portugal.

O impacto dos bosques de azinheira no comportamento do fogo foi testado em termos de área e configuração de acordo com cenários que simulam a possível distribuição destas unidades de vegetação na paisagem, considerando uma percentagem de ocupação da azinheira de 2.2% (Low), 18.1% (Moderate), 26.0% (High), e 39.8% (Rivers). Estes cenários tiveram como principal objetivo testar 1) o papel dos bosques de azinheira no comportamento do fogo e 2) de que forma a configuração das manchas de azinheira podem ajudar a diminuir a intensidade da linha de fogo e área ardida.

Na modelação do comportamento do fogo foi usado o modelo FlamMap para simular a intensidade de linha do fogo e taxa de propagação do fogo com base em modelos de combustível associados a cada ocupação e uso do solo presente na área de estudo, e também com base em fatores topográficos (altitude, declive e orientação da encosta) e climáticos (humidade e velocidade do vento). Foram ainda usados dois modelos de combustível para a ocupação de azinheira (áreas interiores e de bordadura), desenvolvidos com base em dados reais obtidos na região.

Usou-se o software FRAGSATS para a análise dos padrões espaciais das classes de intensidade de linha do fogo, usando-se as métricas Class Area (CA), Number of Patches (NP) e Large Patches Index (LPI).

Os resultados obtidos indicaram que a intensidade da linha de fogo e a taxa de propagação do fogo variou entre cenários e entre modelos de combustível para o azinhal. A intensidade média da linha de fogo e a taxa média de propagação do fogo decresceu à medida que a percentagem de área de bosques de azinheira aumentou na paisagem. Também foi observado que as métricas CA, NP e LPI variaram entre cenários e modelos de combustível para o azinhal, decrescendo quando a percentagem de área de bosques de azinheira aumentou.

Este estudo permitiu concluir que a variação da percentagem de ocupação e configuração espacial dos bosques de azinheira influenciam o comportamento do fogo, reduzindo, em termos médios, a intensidade da linha de fogo e a taxa de propagação, sugerindo que os bosques de azinhal podem ser usados como medidas silvícolas preventivas para diminuir o risco de incêndio nesta região.

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1. Introduction

Fire is a common process in different regions of the world. Fire is considered as the major agent of disturbance that affects terrestrial ecosystems with profound consequences on global climate, air quality, and vegetation structure and functioning (Bowman et al., 2009; Marlier et al., 2012). For example, wildfires in Alaska are the most important natural disturbance processes in the landscape. Dewilde and Chapin (2006) examined the extent of human impact on fire and they concluded that two thirds of interior Alaska has an essentially natural fire regime with few human ignitions, negligible suppression activity and a large number of lightning caused fires. Fires are very familiar and common in the Mediterranean region as well, to the point of being one more constituent of Mediterranean ecosystem’s dynamics (Velez, 1982; Allen, 2008) and a part of landscape and community dynamics (Pausas and Vallejo, 1999).

In Portugal, forest fires have increased in importance over the last years in comparison with other southern Mediterranean countries and the Portuguese forests have the highest incidence of forest fires in the whole Europe relatively to the forest surface (Silva and Catry, 2006). Fire, although an ecological process in the country occurs today in a regime that is far away from natural. Several approaches have been tested in Portugal to decrease fire hazard and to decrease the number and area of wildfires. One that has not been tested in a significant way is the use of vegetation to control the spread of wildfires. In this context, we focus our study in the Northeastern Portugal, specifically in the Sabor River’s upper basin, to analyze the potential role of holm oak in fire spread and fire intensity in the landscape, and how holm oak patches configuration can help to decrease burned areas and fire intensity in the region.

For that, we followed a modeling and simulation approach considering that fire behavior is related to many conditions and circumstances, including landscape and vegetation structure (Ellsworth et al., 2014). The study is based on several scenarios of holm oak abundance and distribution in the Upper Sabor landscape. Previous research has provided evidence that holm oak woodlands have a role in the control of fire disturbance events and in the maintenance of biodiversity, and could act as fire barriers in Northeastern Portugal (Azevedo and Caçador, 2000; Azevedo et al., 2013).

In this work, we used knowledge and fuel models from previous research to analyze how fire behavior and burned areas change with changing holm oak scenarios, and based on our results we understand better the role of holm oak woodlands in fire behavior.

2. Literature Review

2.1. Fire behavior and landscape structure

Wildfires are a very common type of disturbance in different parts of the world, occurring from a large percentage of natural origin especially lightning (Alexander et al., 1998) or human causes like cigarettes and sparks from cutting (Plucinski, 2014). For example, in Alaska, fires are the major natural agent of disturbance (Dewilde and Chapin, 2006), while in Mediterranean regions, fires are considered as an integral constituent of the dynamics of landscapes (Velez, 1982; Allen, 2008). In European Mediterranean areas, the number of fires and surface burned have increased recently (Pausas and Vallejo, 1999). This increase is mainly due to two factors: land use changes derived from rural depopulation, which increases land abandonment and fuel accumulation, and climatic warming, an increase in air temperature and reduction in summer rainfall, humidity and fuel moisture (Pausas and Vallejo, 1999). In Portugal, forest are characterized by the highest incidence of forest fires in the whole of Europe (Silva and Catry, 2006). Comparing the average relationship between total burned area and forest surface in the south of Europe, Portugal takes the first place. In terms of distribution, forest fires are mostly concentrated in the northern part of the country (Silva and Catry, 2006).

Fire behavior is influenced by the interaction of three main components: fuel models or vegetation (Agee, 1996; Nunes et al., 2005; Perera et al., 2009; Viedma et al., 2009), topography and weather (Agee, 1996; Alexander et al., 2006). They represent the “fire behavior triangle”, but the fuel component is the most related to the landscape structure and the only one that we can control (Agee, 1996).

The description of fire behavior can be made using many parameters as fire length, rate of spread, and fire intensity which is one of the most useful metrics to understand fire behavior in forests (Keeley, 2009). According to Alexander (1982), fire intensity can be defined as a valid measure of forest fires that represents the energy output rate per unit length of fire front and it is the only physical attribute of fire. Moreover, fire intensity can be defined as the product of net heat of combustion, representing also the quantity of fuel consumed in the active combustion zone, and the spreading fire’s linear rate of advance (Alexander, 1982). Fire intensity is a concept that provides a quantitative basis for fire description, useful in evaluating the impact of fire on forest ecosystems.

In recent papers dealing with post-fire studies (e.g. Simard 1991; Parsons 2003; Jain et al., 2004; Lentile et al., 2006), there has been a disturbing number that have acknowledged problems in terminology associated with fire intensity and fire severity. According to Keeley (2009), the problem with fire intensity is that is sometimes used incorrectly to describe fire effects when actually it is justifiably restricted to measures of energy output. Lentile et al., (2006) suggested replacing fire intensity and fire severity with new categories such as "active fire characteristics" and "post-fire effects". Fireline intensity and fire severity are two different parameters. The first one is a physical parameter referring to energy release rate per unit length of fireline (Agee, 1996; Keely, 2009) which is related to flame length, and it can be determined from rate of spread of the fire. The second parameter, fire severity, is considered as an ecological parameter that measures the effects of fire (Agee, 1996). The fire line intensity and potential fire severity are both related to fuels surface.

In general, fires are selective. Depending on the land cover type where fire occurs, the incidence is higher (preferred) or lower (avoided) in a selectivity process that is expressed by the number of fires expected in a given land cover and by the mean surface area each fire will burn (Bajocco and Ricotta, 2008). Fire risk assessment at the landscape scale indicates that risk of wildfires is closely related to land cover (Bajocco and Ricotta, 2008). There is a close relationship between the timing of fire occurrence and land cover, that is mainly controlled by two complementary processes: climatic factors, acting indirectly on the timing of wildfires, determining the spatial distribution of land use types as well, and human population and human pressure that directly influence fire ignition (Bajocco et al., 2010).

According to Azevedo et al., (2011) changes caused by human abandonment affect the structure of landscapes and their composition in Northeastern Portugal, which can lead to changes in fire behavior, increasing fireline intensity and average burned area, enhancing the landscape conditions for the occurrence of intense fire events over time.

Ellsworth et al., (2014) determined how potential fire behavior could differ between land cover types. These authors tested how land cover changes along two grassland/forest ecotones in Hawaii would influence fire behavior, analyzing repeated fires during a time period of 61 years using the BehavePlus fire modeling program. Their results demonstrated that when forests are converted to grasslands fire intensity increases significantly.

The impact of fire on landscape pattern is variable depending on the regions. This variability is due to the different regeneration abilities of main land cover types, topographic constraints and the fire history of each region (Viedma, 2008).

One of the most noticeable characteristics of the Portuguese forest is the fact that it has the highest surface of cork oak stands in the whole Europe. The cork in these trees is very resistant to fire which help somehow to mitigate the effects of wildfires in cork oak stands, although fire causes a high risk of tree decay and other accumulated stress like bark stripping (Silva and Catry, 2006).

Catry et al., (2010) studied the effects of fire on woody species analyzing 1040 burned trees from 11 different species in mixed forests of central Portugal. These authors found that almost all broadleaves trees survived but most coniferous died. Despite the low mortality of broadleaves, most of them were top-killed and regenerated only from basal resprouts. *Quercus suber* showed a strong post-fire crown resprouting and it was found to be the most resilient of the species studied (Catry et al., 2010). Fires damaged also soils because during burning they lose nutrients and after burning the risk of erosion increases (Pausas and Vallejo, 1999).

Catry et al., (2014) studied the impacts of wildfires in cork oak patterns in the Mediterranean basin and its relation with post-fire disturbances. They observed an apparent outbreak of bark beetles in 47% of burned trees, which was related to tree diameter, fire severity and pre-fire trunk wounded surface, while in unburned trees there was no evidence of bark beetles attacks.

In the Mediterranean basin, species such as *Quercus ilex* and *Pinus halepensis* are common trees and they can regenerate reliably after fire. *Quercus ilex* resprouts vigorously after disturbances, while *Pinus halepensis* colonize disturbed areas by effective seedlings recruitment. The monospecific forests of *Pinus* or *Quercus* have a high probability of remaining in their original composition after fire, while mixed forest of the two species was quite low (Brancano et al., 2005). For both species, plots that changed to another forest type are mainly those that burned more severely, and in the mixed forests, low fire severities involve high probabilities of change to monospecific forests (Brancano et al., 2005).

Quercus ilex plays an important role in Western Mediterranean ecosystems, but in the Eastern Mediterranean part, it is poorly developed and often replaced by *Quercus calliprinos (*Barbero et al., 1992*).*

Holm oak woodlands have an important role in landscape patterns and processes, and they participate in the control of perturbation events and in the maintenance of biodiversity (Azevedo et al., 2013)

Observations and studies in the Northeast of Portugal suggest that holm oak woodlands are resistant to fire and this resistance is due to modifications in fire behavior at the shrublands-woodland interface level (Azevedo and Caçador, 2000; Dias and Azevedo, 2008; Azevedo et al., 2013). A high variation was observed in fire behavior along the exterior-interior gradients in holm oak woodland edges, which are related to variations in the structure of the vegetation (Azevedo et al., 2013). As a conclusion, the study indicated that wildfire spread and intensity decrease when in contact with holm oak woodlands which can lead to their natural extinction (Azevedo et al., 2013).

2.2- Fire behavior modeling

Simulation is an important tool to predict fire behavior and effects for a wide diversity (Keane et al., 2011). Fire simulation modelling has been concentrated on describing the growth and intensity of fires, because more than 90% of all wildland fires are confined to the surface fire stage where fire control forces can be effective (Rothermel, 1982).

Deterministic and probabilistic geospatial fire behavior analyses are conducted with different modelling systems such as BEHAVE FARSITE, FlamMap, FSPro, WindWizard, and FIRETEC to simulate fire behavior and predict fire growth process (Hollingsworth et al., 2012; Forghani et al., 2014).

Andrews (1986), described BEHAVE as a fire prediction and fuel modelling system. The BEHAVE is of limited use for predicting fire effects, but it is a flexible system that can be adapted to different specific wildland fire management needs. According to Andrews (2013), among the most widely used systems for wildland fire prediction there is the BehavePlus fire modelling system. It is successor to BEHAVE, which was developed in 1977. The BehavePlus is designed to use in several tasks including wildfire behavior, prediction prescribed fire planning, fire investigation fuel hazard assessment, fire model understanding.

This fire modelling system is based on mathematical models for fire behavior, fire effect and fire environment.

Finney (2006) gives an overview of FlamMap fire modeling capabilities and describe this fire behavior modeling system. According to him, the FlamMap is designed to examine spatial variability in fire behavior; it may also be used for several fires management activities, and for pre and post fuel treatment evaluation.

FARSITE (Finney, 2004) is a fire growth simulation modeling system, used for short period of time, in order to project the fire growth of ongoing fires and hypothetical fires for planning. It requires an eight spatial data layers for a comprehensive evaluation of surface and crown fire behavior. FARSITE spreads fire across a landscape using the fire behavior routines found in the one-dimensional fire model BEHAVE (Andrews 1986; Rothermal 1972).

Duncan et al., (2015) conducted a study to compare fuels reduction and patch mosaic fire regimes for reducing fire hazard, adapting a spatial modelling approach using a computer simulation with the FARSITE fire model. In the same context, Pimont et al., (2016) presented a spatially-explicit-fuel-modelling system, fuel manager, using a physics based model: FIRETEC to model fuels, vegetation growth, fire behavior and fire effects.

Fire behavior modelling could be done using mathematical models to relate physical and chemical properties of fuel arrays to specific fire behavior (Albini, 1976). One of those mathematical models is nomographs, used to describe fire behavior by using Rothermel’s equations (Rothermel, 1983) and some stylized fuel models to draw a set of graphs (Albini, 1976).

3. Methods

3.1. Study area

The study area is the Sabor River’s upper basin located in the Northeast of Portugal (Figure 1). This area is extended approximately over 30 629 hectares. The climate is Mediterranean with continental influence; the average of precipitation varies from the West to the East, the highest annual average value is 1262.8 mm in the Montesinho Mountain range and the lowest value is 806 mm in the plateau of Lombada. The annual average temperature varies from 8.5°C to 12.8°C (IPB/ ICN, 2007). The elevation is between 484 m as a minimum and 1487 m as a maximum and slope ranges between 0 and 114 %. Granites in the upper regions and schists in lower areas dominate the geology of the Sabor River’s upper basin (IPB/ ICN, 2007).

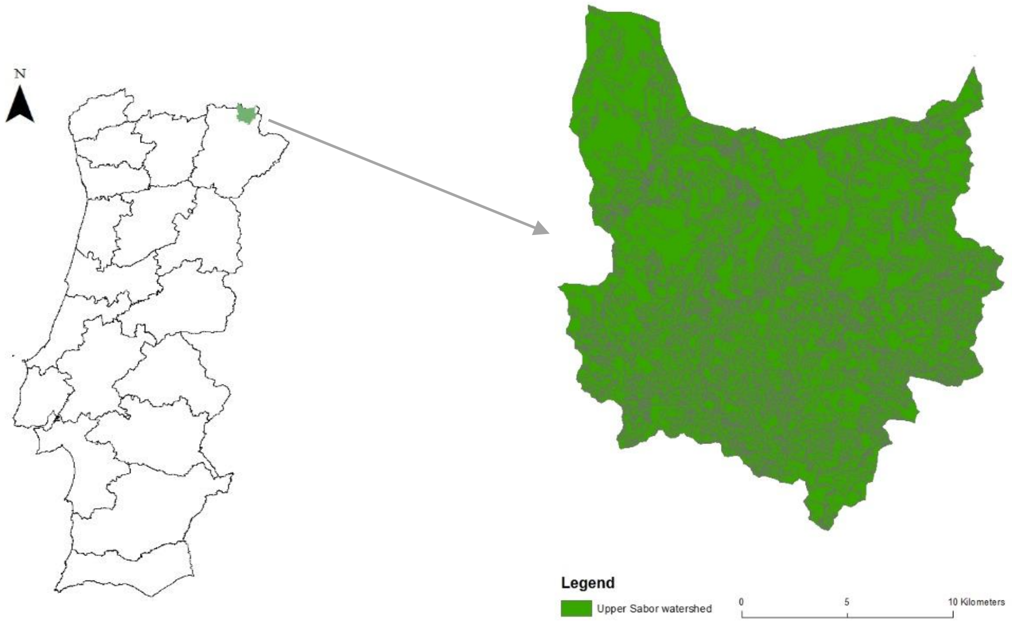

Figure 1. Location of the study area, the Sabor River’s upper basin, in Northeastern Portugal.

According to the major land use / land cover (LULC) COS2007 classes (Caetano et al., 2009)/IGP) we can divide the landscape in urban areas, agriculture and agroforestry areas, water bodies, shrublands and semi-natural areas, and forest. Forests in turn can be divided in 3 subclasses: coniferous, broadleaves, and mixed forest (Figure 2).

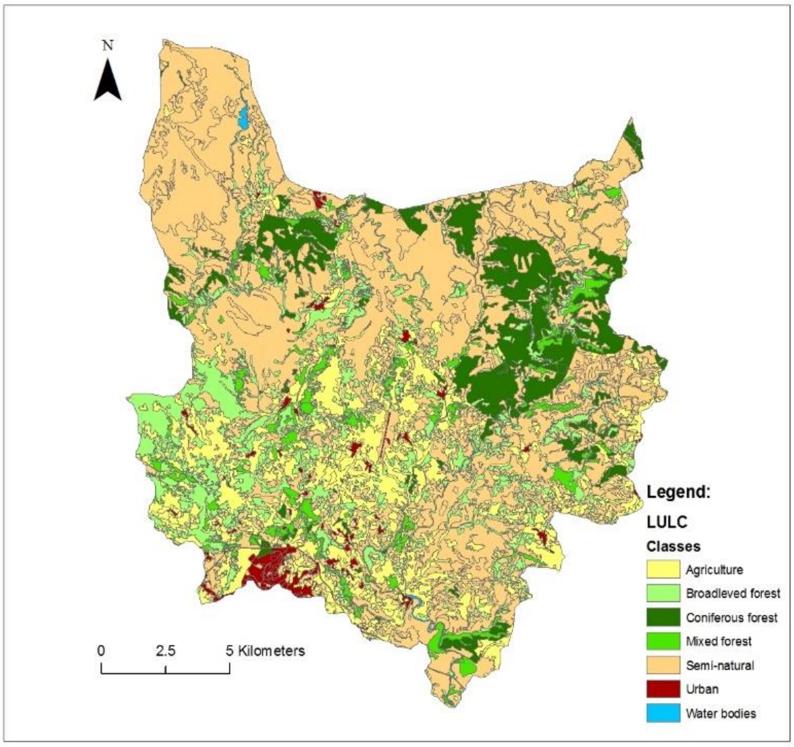

Figure 2.Spatial distribution of the five major LULC classes, with forests subdived in subclasses in the Sabor River's upper basin, Northeastern Portugal Data source: COS2007 (Caetano et al., 2009)/IGP).

As shown in Table 1, the study area is dominated by shrublands and semi-natural areas followed by forests (including sub-classes coniferous, broadleaves and mixed forest), and agricultural areas, while urban and water bodies are the classes with the lowest area (Table 1 and Figure 2). Currently, the total holm oak area in the Sabor River's upper basin is 671.4 ha (LiGEO laboratory, ESA, IPB) corresponding to 2.2% of the total of the study area (Figure 3).

Table 1. Area of Land use/ Land cover in (ha) and (%) in the Sabor River's upper basin, Northeastern Portugal. Calculated in GIS from COS2007 data (Caetano et al., 2009)/IGP)

Classes	Area	
	(ha)	(%)
Agriculture	6281.4	20.51
Urban areas	541.7	1.77
Mixed forest	1491.1	4.87
Coniferous Forest	3193.5	10.43
Broadleaves forest	3959.1	12.93
Shrublands and semi-natural	15106.7	49.32
Water bodies	55.9	0.18
Total	30629.3	100

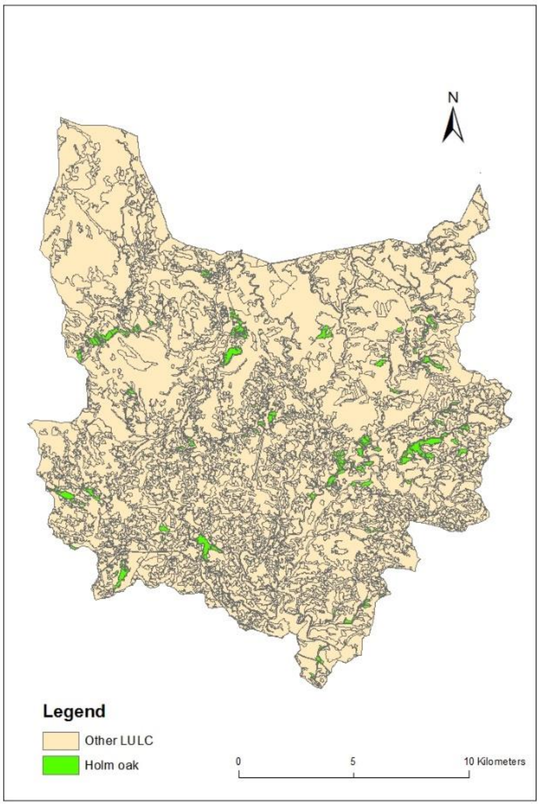

Figure 3. Spatial distribution of holm oak woodlands in the Sabor River's upper basin.

Source: LiGEO laboratory (ESA, IPB).

Holm oak (*Quercus rotundifolia)* is an evergreen oak in the Fagaceae family approximately 20-25 m in height. This tree is adapted to the Mediterranean climate, with a large population in the Iberian Peninsula. However, it can be found in any part of the Mediterranean region. Holm oak forests are dominant type of vegetation in a transition zone between temperate forests and scrublands. In this transition zone, plants have to cope with a selective pressure that result from double stress, winter cold and summer drought, which determine their morphological and ecophysiological evolutive response (Terradas, 1999). Holm oak can grow in heavy clay and acid, neutral or basic soils and it tolerates a wide range of soil textures (Figure 4).

The species has once been dominant in many landscapes of the Northeastern region of Portugal but it is today confined to steep slopes and unproductive soils where agriculture could not expand to (Azevedo et al., 2013). The species has also suffered from overexploitation for fuelwood. Holm oak woodlands are today in the region mainly facing East, West and North-West, and most of them are on slopes steeper than 6° and slopes steeper than 12° (Dias and Azevedo, 2008).

Figure 4. Holm oak forest (Quercus rotundifolia). Photo by Azevedo João

3.2 Fire modeling and simulations

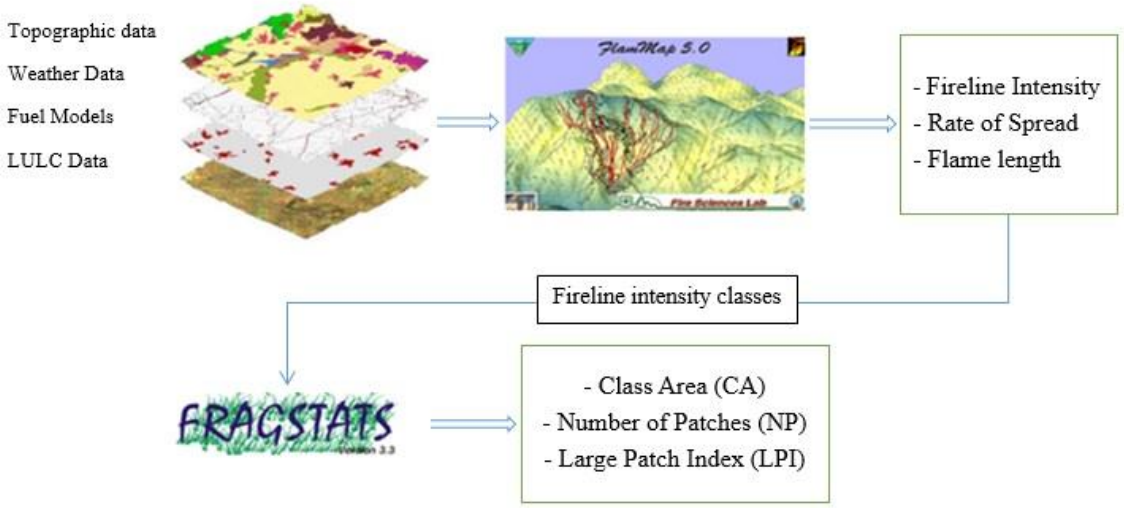

Figure 5. Diagram of the methodology followed for fire modelling.

3.2.1 FlamMap

In this study we used FlamMap (version 5.0) to map and analyze the spatial variability of fire behavior (fireline intensity and rate of spread) at landscape level. The FlamMap calculates fire behavior parameters (e.g. fireline intensity, flame length, and rate of spread) for each pixel within the landscape independently, and for constant environmental conditions, such as fuel moisture and wind parameters. Therefore, FlamMap does not calculate fire spread across a landscape. For each pixel, FlamMap permits conditioning of dead fuels based on slope, elevation, aspect, and weather. The topographic inputs in FlamMap are slope, elevation, and aspect, while fuel models and canopy cover, are considered as inputs required forest characteristic data layers (Finney, 2006).

FlamMap uses spatial inputs including eight GIS raster themes that describe fuels and topography combined into a Landscape (LCP) file. Any raster resolution (X, Y) could be used, however all the layers should have the same resolution, extent, and co-registered. The user is required to input initial fuel moisture conditions for each surface fuel model and the fuel model parameters for any custom surface fuel models present. All outputs can be saved in ASCII Grid or Shapefile formats for import and analysis in a GIS.

According to Finney, (2006), there are three-calculation modes in FlamMap: Basic fire behavior, Minimum travel time fi regrowth, and Treatment optimization. In our case, we focus on Basic fire behavior calculation, which is the simplest use of FlamMap to characterize fire behavior under constant set of environmental conditions for the whole landscape.

3.2.2 Experimental design

The simulations run in this work followed a very simple experimental design. We built scenarios for different abundances of holm oak woodlands in the landscape (2.2%, 18.1%, 26.0%, and 39.8%) as well as for different configurations, testing them in FlamMap under the same terrain and weather conditions. We considered that observed changes in fire behavior should be due to changes in the levels and configuration of holm oak woodlands. Effects of holm oak woodlands on fire behavior will be accessed based on average fire intensity and average size of areas within the same fire intensity class. In addition, we considered in the simulations two holm oak fuel models (edge and inside).

3.2.3 Scenarios

We built scenarios based on abundance, distribution and spatial configuration of holm oak woodlands considering physical factors such as slope and aspect that affect the distribution of holm oak woodlands in the region (Dias and Azevedo, 2008).

The area and the percentage of holm oak in each scenario established for the analysis is shown in Table 2, and each scenario is described as follows: :

- Low scenario (Figure 3): corresponds to the actual distribution of holm oak woodlands in the study area.
- Moderate scenario (Figure 6): corresponds to a hypothetical distribution of holm oak, based on the most suitable aspects for the maintenance of holm oak found for this study area, according to Dias and Azevedo (2008), namely East (E), West (W) and Northwest (NW) and considering all the slopes higher than 9 degrees where holm oak is usually found (Dias and Azevedo, 2008).
- High scenario (Figure 7): this scenario further expands the potential area of holm oak by adding areas with slope above 3 degrees (Dias and Azevedo, 2008) to the area in the Moderate scenario.
- Rivers scenario (Figure 8): it assumes a distribution of holm oak woodlands nearby streams. The scenario was built including all the areas within a 300 m buffer along streams in the study area. This scenario does not take into consideration physical factors as slope and aspect.

Table 2. Area of holm oak woodlands in the study area for each scenario.

Scenarios	Holm oak area	
	(ha)	(%)
Low	671.4	2.2
Moderate	5551.4	18.1
High	7973	26.0
Rivers	12183	39.8

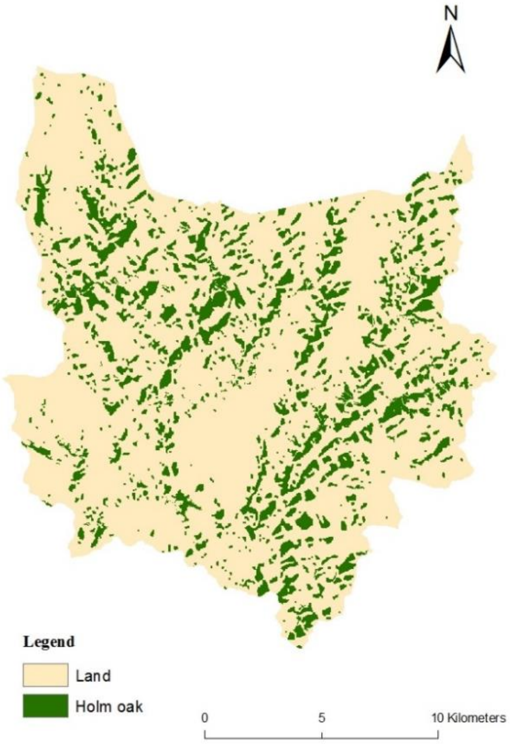

Figure 6. Holm oak distribution in the Sabor river's upper basin according to the Moderate scenario.

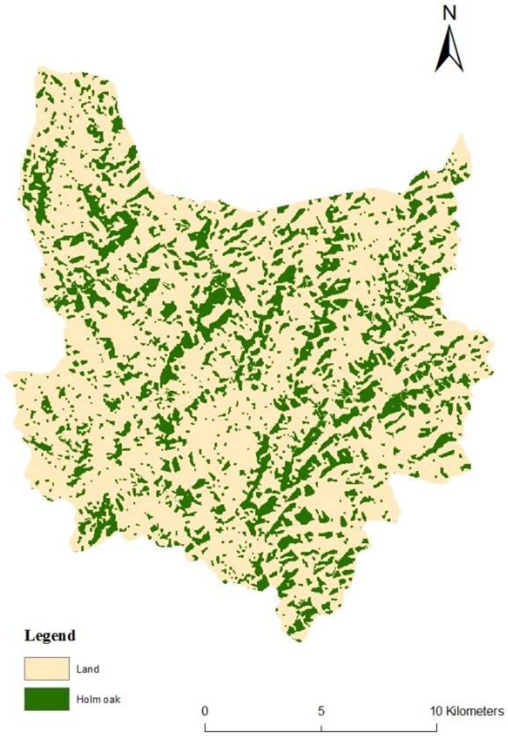

Figure 7. Holm oak distribution in the Sabor River's upper basin according to the High scenario.

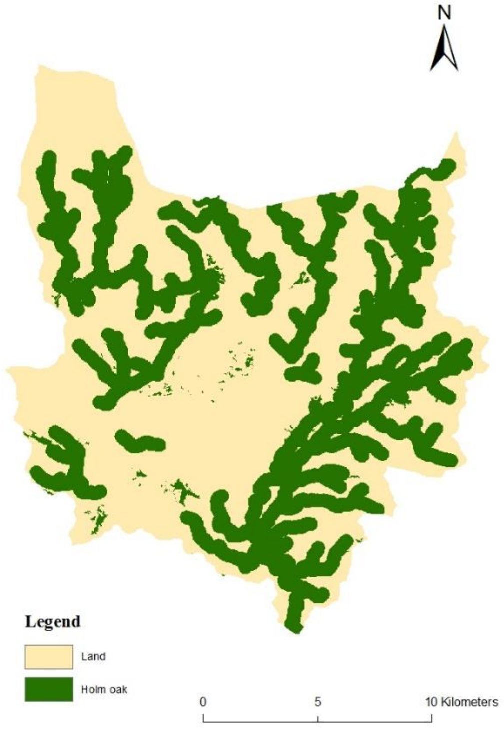

Figure 8. Holm oak distribution in the Sabor River's upper basin according to the River scenario.

3.3 Data

The data used in this study are mostly those required as inputs or in the preparation of inputs for FlamMap, such as weather conditions, elevation, slope, and aspect, fuel models and canopy cover.

3.3.1 Land use and weather

Spatial land use data were adapted from COS2007 (IGP) except for the distribution of holm oak woodlands in 2010 that was obtained from the LiGEO laboratory (ESA, IPB).

For the weather conditions (fuel moisture conditions and wind speed) are similar to those in Azevedo et al., (2011). We adopted the moisture and wind speed conditions fixed for all surface of the fuel models and all the landscape independently of topography or canopy cover. The values of moisture are as follows: 1h=4%; 10h=5%; 100h=6%; live woody=70%; live herbaceous=70%, and are correlated with the extreme summer weather conditions. The wind speed was assumed to be constant of 25 km/h at 6 meters elevation, and for azimuth degree is equal to 90° (Barros, et al., 2012). For fire behavior characteristics calculation we assumed an uphill wind direction (Azevedo et al., 2011).

3.3.2 Terrain

Elevation (DEM) data was obtained from University of Porto website[1] (Gonçalves and Fernandes, 2005; Gonçalves and Morgado, 2008) with a spatial resolution of 25meters, while slope and aspect were obtained from DEM in GIS environment, using ArcGIS tools.

Aspect: considered as reflection of slope direction faces, measured in degrees (the north is 0°). This theme is used to calculate the combined effect of wind and slope on fire spread by determining the upslope direction (STARFIRE Project, 2011).

Elevation: is the vertical distance above the sea level, measured in meters (m) or feet (ft), used to adjust temperature and humidity for changes in elevation (STARFIRE Project, 2011).

Slope: defined as the inclination from the horizontal, it can be measured in percentage or degrees; in our case the units is percentage. Slope has a double use in FlamMap: computation

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[1] http://www.fc.up.pt/pessoas/jagoncal/srtm/

of slope effects on fire spread and solar radiance at a location (raster cell) (STARFIRE Project, 2011).

3.3.3 Fuel models

In the fire management, the prediction of the potential behavior and effects of wildland fire is an essential task. Mathematical surface fire behavior and fire effects models and prediction systems are driven in part by fuelbed inputs like load, bulk density, fuel particle size, heat content, and moisture of extinction. To smooth use in models and systems, fuelbed inputs have been formulated into fuel models. A fuel model is a set of fuelbed inputs needed by a particular fire behavior or fire effects model (Scott and Burgan, 2005).

Albini, (1976), developed the nomograms using fuel models for calculating fire behavior. They are 13 NFFL (Northern Forest Fire Laboratory) fuel models where 11 models developed by Anderson, (1982) and published by Rothermel (1972).

The selection of the fuel model that better describes the fuel conditions involved the following steps (Rothermel, 1983):

- At first, we should determine the general vegetation type: Grass, Shrub or Timber.
- Secondly, determine or estimate the stratum of surface fuel, which is most likely to carry the spread fire.
- Third, we need to note the depth and compactness of the fuel.
- Fourth, we need to determine which fuel classes are present and how they influence fire behaviour.
- Fifth, based on those observations, and the descriptions provided by Anderson (1982) we are able to select the most suitable fuel model.

Land use and land cover (LULC) data was converted to NFFL Fuel models by converting the LULC classes of each landscape element to fuel models considering the correspondence in Table 14.1 in Azevedo et al., (2011). Eight out of the 13 standard NFFL fuel model (Anderson, 1982) were considered for the study area (Table 3).

Table 3. Fuel model classification, distribution and correspondence with Land use and Land cover classes in the Upper Sabor watershed. Adopted from Azevedo et al., 2011

Fuel group	**Fuel model**	**LULC in study area**
Grass	1	Annual dry Crop
	2	Maritime pine new plantation , Natural Herbaceous Pastureland
Shrub	4	Dense Cytisus and Genista Shrublands
	5	Dense Cytisus Shrublands, Dense Erica-Ulex Shrubland, Maritime pine forest, Softwood Forest, Hardwood-Softwood Mixed Forest, Low Density Cistus Shrubland
	6	Low Density Cytisus and Genista Shrubland, Low Density Erica, Ulex, and Mixed Erica-Ulex Shrubland
Timber	8	Sweet Chestnut Orchard, Holm Oak-Other Hardwood Mixed Forest, Riparian Forest
	9	Oak Forest, Oak-Other Hardwood Mixed Forest
No fuel	99	Urban Areas
	98	Water Bodies

The particular fuel models that we used for holm oak were supplied in the Custom fuel model file (.FMD). Using the Custom fuel Model Editor of FARSITE we had created and edited the custom fuel model file (.FMD) based on a specific format including the following parameters:

- *FM*Num is Fuel model number used in computer code and mapping applications.
- FMCode is Fuel model code used for oral and written communication and input to fire modeling systems.
- 1H 10H 100H LiveH LiveW are the fuel loading, by size class and category representing the mass of fuel per unit area, live and dead, grouped by particle size classes.
- FMType is Fuel model type: Grass, Shrub, Timber or Nonburnable.
- 1HSAV LiveHSAV LiveWSAV represent the Surface-area-to-volume (SAV) ratio by component and size class.

- XtMoist is the Moisture of extinction, it represent the upper limit of fuel moisture content beyond which the fire will no longer spread with a uniform front.
- FMName is Fuel model name used for description and longhand written communication.

The description of each parameter in the format was taken from Scott and Burgan, (2005) (Table 4).

Table 4. Custom fuel models Format parameters.

Field	**Name**	**Data Type**	**English unit**	**Metric unit**
FMNum	Fuel model number	Integer	number 14-89	number 14-89
FMCode	Fuel model code	String	user defined up to 7 characters	user defined up to 7 characters
1H,10H, 100H, LiveH, LiveW	Fuel loading	Decimal	tons/acre	metric tonnes/hectare
FMType	Fuel model type	String	"static" or "dynamic"	"static" or "dynamic"
1HSAV, LiveHSAV, LiveWSAV	Surface to volume ratio	Integer	1/ft	1/cm
Depth	Fuel bed depth	Decimal	ft	cm
XtMoist	Moisture of extinction	Integer	percent	percent
DHt, LHt	Heat content, live and dead fuels	Integer	BTU/lb	J/Kg
FMName	Fuel model name	String	user defined up to 256 characters	user defined up to 256 characters

To determine the role of holm oak in fire behaviour at the landscape level and to define how it can help to decrease fire intensity and size of burned areas, we considered two different holm oak fuel models based on the research from Azevedo et al. (2013). In this research Azevedo et al., (2013) take 12 sampling transects placed across the contact zones of woodlands and shrublands. In each transect they marked sampling points at distances of -20, -10, -5, -1, 0, 5, 10, 20 and 40 m from the boundary. The positive distances are inside, and the negative ones are outside. The following figure summarizes what has been done.

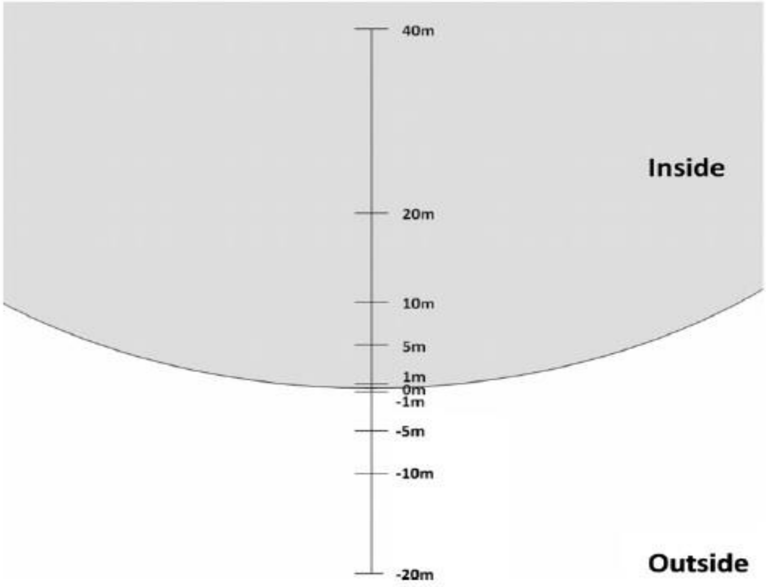

Figure 9. Sampling procedure: placement of transects across edges and schematic of the sampling transects and points (from Azevedo et al., (2013))

Azevedo et al. (2013) refer to different fuel conditions in holm oak stands according to the position along inside-outside gradients. The use of different fuel models will therefore affect the simulated fire behavior (Azevedo et al., 2013)**.** To consider this variability in our study we used two different fuel models for holm oak: one for inside conditions (model 15) and one for edge conditions (model 14) as shown in Figure 10. The inside model was built by calculating the average of each parameter (following the format of the custom fuel model) for both distances 20 and 40 m from the boundary. The edge conditions model was built in a similar way but for both distances 0 and 1 m from the boundary (Figure 9).

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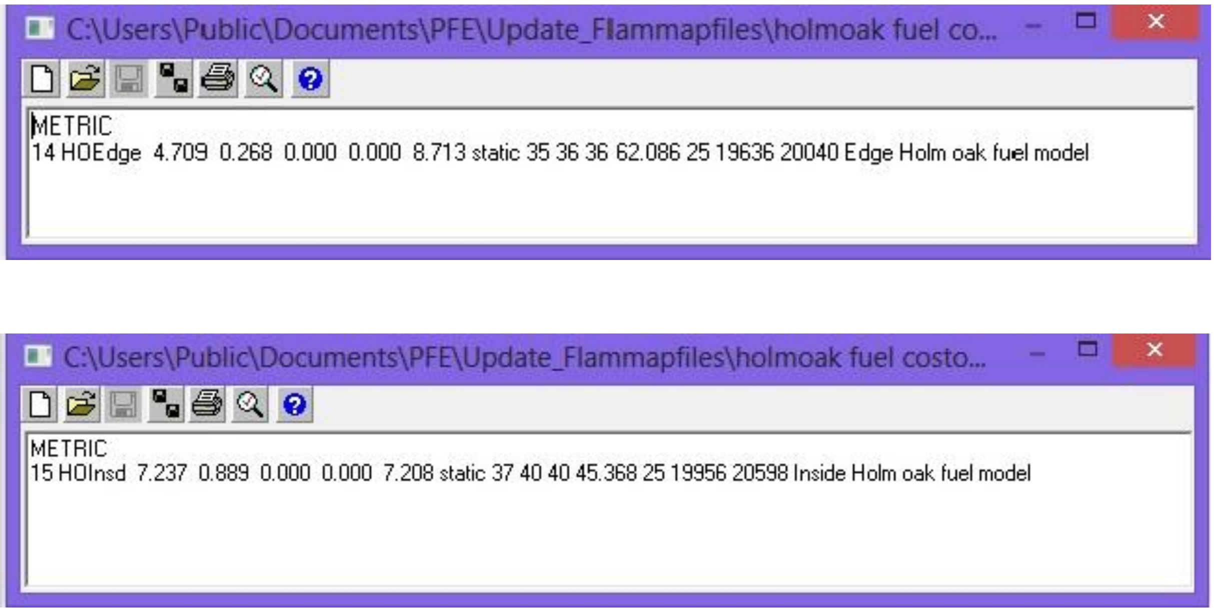

```
METRIC
14 HOEdge  4.709  0.268  0.000  0.000  8.713 static 35 36 36 62.086 25 19636 20040 Edge Holm oak fuel model
```

```
METRIC
15 HOInsd  7.237  0.889  0.000  0.000  7.208 static 37 40 40 45.368 25 19956 20598 Inside Holm oak fuel model
```

Figure 10. Custom fuel model format as an (.FMD) file for both Holm oak fuel models (inside and edge), created with FARSITE

3.3.4. Canopy Cover

The canopy cover represents the horizontal percentage of the ground that is covered directly by plant canopies such as tree crowns. This variable is used to calculate the wind reduction factor for a forest stand and shading of fuels. In FlamMap it can be presented by classes (1: 1-20%, 2: 21-50%, 3: 50-80%, 4: 81-100%) or percentage values (0-100) with “no cover” specified by 0, as an ASCII files. In this work, we used the information of canopy cover from Azevedo et al. (2011), as shown in Table 5.

Table 5. Canopy cover values used for different forest types in the fire behavior simulations source: Table14.2 Azevedo et al., (2011).

Forest type	**Canopy cover (%)**
Riparian	80
Others softwoods	80
Holm oak	80
Oak-chestnut	70
Holm oak- other hardwood	70
Mixed Hardwood-Softwood	60
Maritime pine-other softwoods	60
Sweet chestnut orchards	50
Poplar	50
New maritime pine plantation	30
New hardwood plantation	30

3.4 Analysis

The FlamMap outputs were analyzed in terms of fire behavior, by describing the average of fire intensity and rate of spread. Calculating specific metrics at the class level like class area of fire intensity and comparing it with the spatial distribution of holm oak woodlands (scenarios), gives us an idea about the interaction of these forest communities with fire and how it affects fire hazard.

The fireline intensity outputs were reclassified in five classes using ArcGIS according to Alexander and Lanoville (1989) classification as shown in Table 6.

Table 6. Fire line intensity classes adopted from Alexander and Lanoville (1989).

Fire danger class	Fire line intensity (kw/m)
Low	<500
Moderate	500 – 2000
High	2000 – 4000
Very high	4000-10000
Extreme	>10000

Moreover, the calculating specific metrics at class level, such as class area of fireline intensity, and comparing it with the spatial distribution of holm oak woodlands (scenarios), gives us an idea about the interaction of these forest communities with fire and how it affects fire hazard. Hence, we used the reclassified fireline intensity maps as inputs for FRAGSTATS (McGarigal and Marks, 1995) to analyze their spatial pattern.

In FRAGSTATS, we selected the following metrics to be calculated at the class level for each of the classes established based of fireline intensity:

- CA: Class Area (ha), a specific measure of landscape composition; specifically, how much of the landscape is comprised of a particular class.
- NP: Number of patches corresponding to each class
- LPI: Largest patch index quantifies the percentage of the landscape area comprised by the largest patch of each class.

After running FRAGSTATS, we obtained outputs with results of the metrics calculations that will be analyzed to compare scenarios and fuel models

4. Results

From simulating fire behavior in the Upper Sabor watershed with FlamMap, we had the first results for each scenario in the form of maps of the distribution of the variables flame length, rate of spread and fire line intensity and statistics

The results show that in general there is a decrease in average fire line intensity along the gradient of increasing percentage of the landscape occupied with holm oak (scenarios) either using model 14 or 15 (Table 7; Figures 11). Fire line intensity was, however, slight higher when model 15 was used to represent holm oak. The same pattern was also observed for rate of spread (Table 8; Figure 12) except for the differences between fuel models that were not observed for this variable.

Table 7. Mean fire intensity (kW/m) for each scenario in both holm oak fuel models.

Scenarios	Model 14 (edge)	Model 15 (inside)
Low	7701	7712
Moderate	6529	6623
High	6288	6413
River	5195	5397

Table 8. Mean rate of spread (m/min) for each scenario in both holm oak fuel models.

Scenarios	Model 14 (edge)	Model 15 (inside)
Low	19.78	19.78
Moderate	17.43	17.43
High	16.43	16.43
River	14.08	13.75

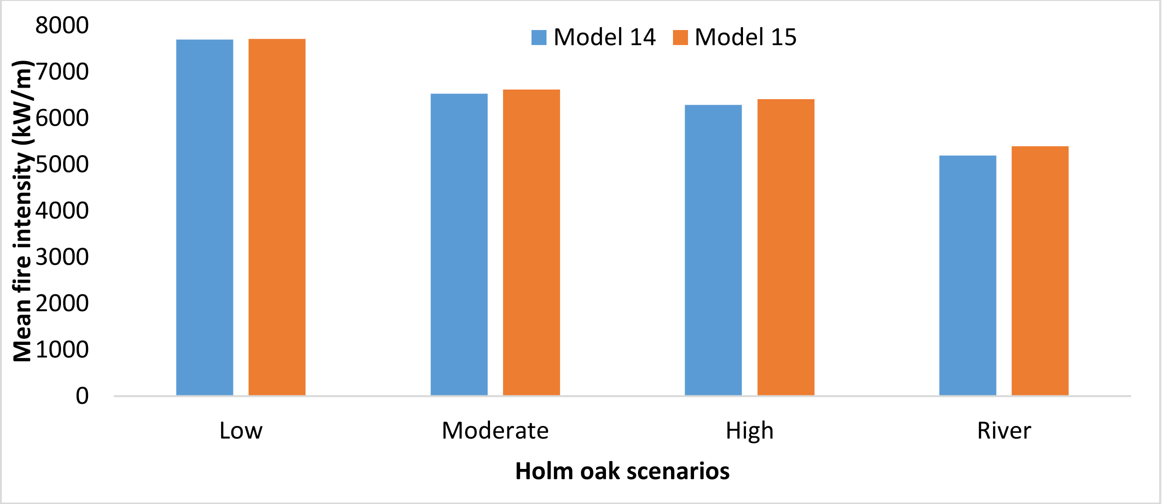

Figure 11. Mean value of fire intensity (kW/m) in terms of scenarios and holm oak fuel models.

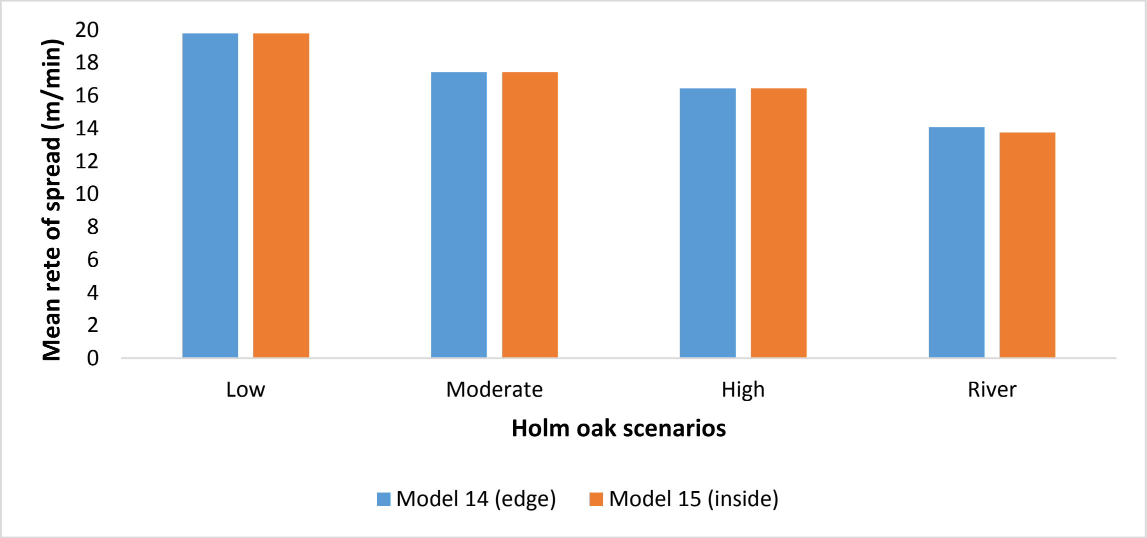

Figure 12. Mean value of rate of spread (m/min) in terms of scenarios and holm oak fuel models.

The areas of fire line intensity classes have changed among scenarios, either using holm oak model 14 or 15 (Table 9; Figure 13 and 14). In the Low scenario with the exception of High and Very high all classes occupied large areas. By increasing the area of holm oak woodlands in the landscape, the area of High and Very high becomes larger but there is a decrease in Low, Moderate and Extreme. Distribution of areas by fire intensity tends to become more even as holm oak increases in the landscape, while the area of the low, moderate and extreme start to decrease.

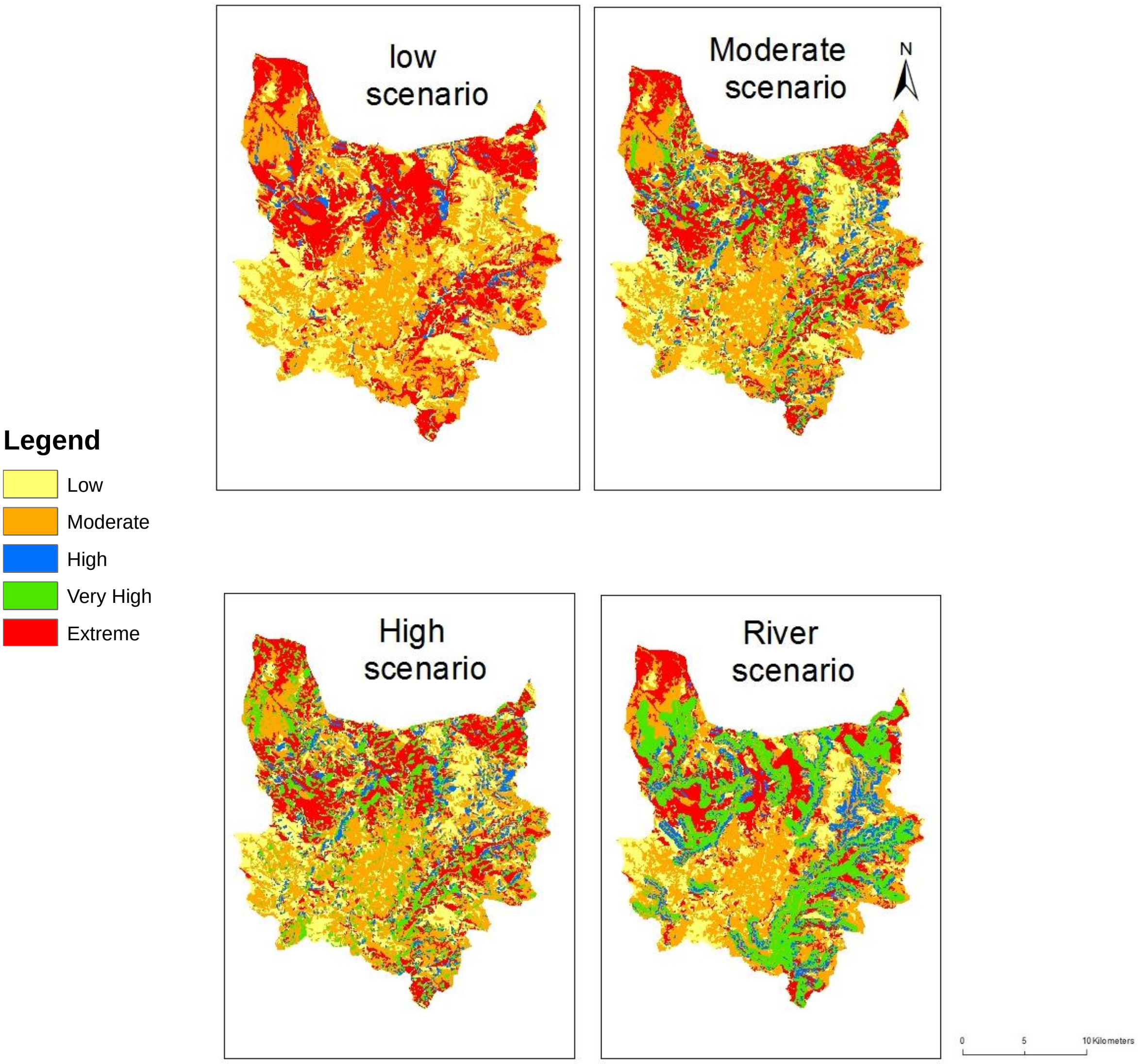

Figure 13. Maps of fire intensity classes for Low, Moderate, High and River scenario showing how fire intensity and fire behavior is changing over scenarios, created by ArcMap.

Table 9. Class area (ha) of fire line intensity for scenarios Low, Moderate, High and River.

Scenarios	FI Classes	Model 14	Model 15
Low	Low	7791.4	7791.4
	Moderate	12404.9	12263.1
	High	1042.8	1116.3
	Very high	33.3	89.3
	Extreme	9355.3	9367.6
Moderate	Low	6729.8	6729.8
	Moderate	11150.2	10665.4
	High	2150.1	2236.3
	Very high	3051.5	3398.6
	Extreme	7546.1	7597.6
High	Low	6006.3	6006.3
	Moderate	10516.2	9677.9
	High	2381.8	2812.3
	Very high	4726.1	5082.3
	Extreme	6997.3	7048.9
River	Low	4787.1	4787.1
	Moderate	9921.3	8950.4
	High	3010.8	3333.6
	Very high	7517.7	8070
	Extreme	5390.8	5486.6

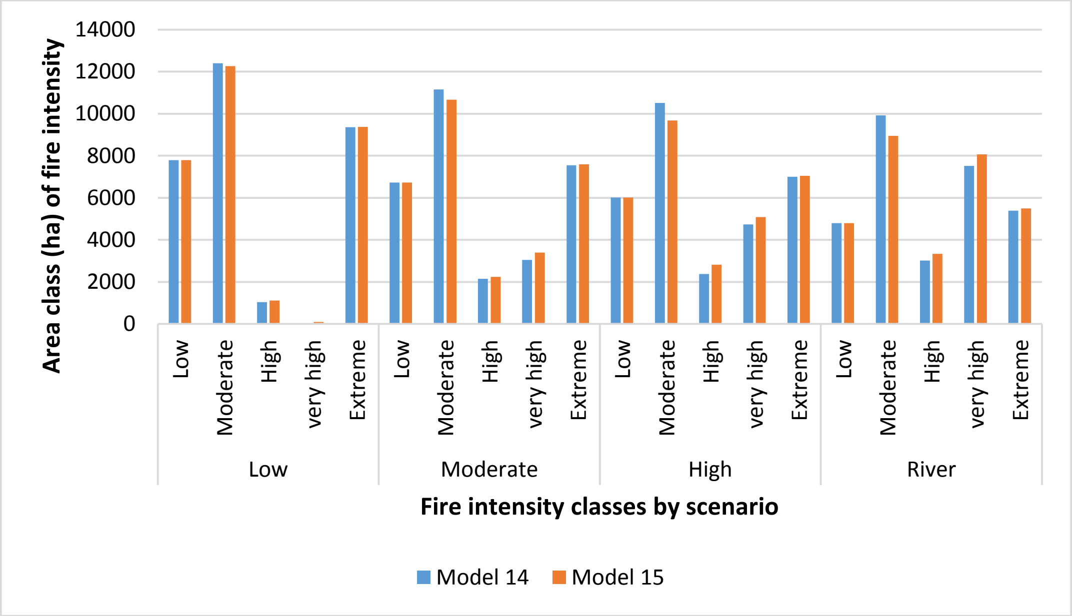

Figure 14. Area class (ha) of fire line intensity in each scenario for both fuel holm oak models (inside and edge).

Table 10. The largest patch index (LPI) in percentage of each fire intensity class.

Scenarios	FI Classes	Model 14	Model 15
Low	Low	2.0	2.0
	Moderate	6.9	6.8
	High	0.2	0.2
	Very high	0.0	0.0
	Extreme	3.8	3.8
Moderate	Low	1.5	1.5
	Moderate	5.2	4.9
	High	0.1	0.1
	Very high	0.2	0.2
	Extreme	1.9	1.9
High	Low	1.2	1.2
	Moderate	6.2	3.7
	High	0.2	0.1
	Very high	0.3	0.3
	Extreme	1.3	1.3
River	Low	1.2	1.2
	Moderate	4.3	4.2
	High	0.3	1.0
	Very high	3.6	4.5
	Extreme	1.2	1.3

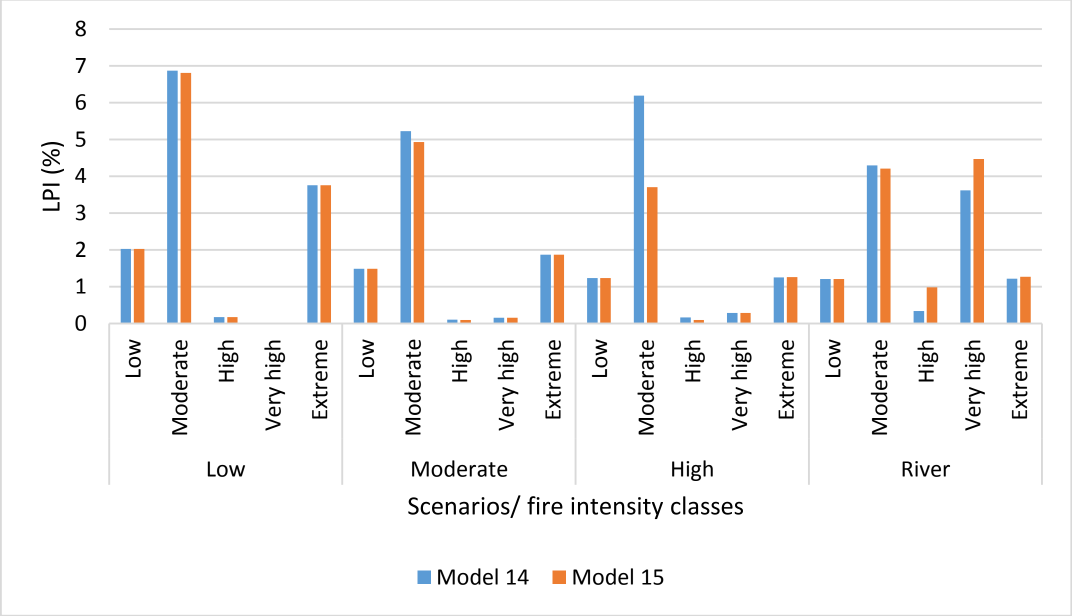

Figure 15. Graphic representation of the largest patch index (LPI %) for the 4 scenarios.

Table 10 and Figure 15 show that the large patch index (LPI) also changed considerably among scenarios. In general, LPI decreased with increasing holm oak in the landscape. Extreme class showed however very pronounced decreasing from Low to High scenarios. For River scenario, we noticed that LPI increased for the Very High class in a noticeable way in comparison to the remaining scenarios (Table 10; Figure 15).

In the High scenario in the Moderate fireline intensity class, LPI was much higher for fuel model 14 than for model 15, which is unusual considering the other differences between models that were never too large (Table 10; Figure 15).

Table 11. Average patch size (ha) per fire line intensity class and the 4 holm oak scenarios.

Scenarios	FI Classes	Model 14	Model 15
Low	Low	8.08	8.08
	Moderate	14.34	13.76
	High	2.02	1.92
	Very high	0.18	0.40
	Extreme	22.71	22.63
Moderate	Low	5.46	5.46
	Moderate	6.54	7.56
	High	1.47	1.37
	Very high	2.12	2.46
	Extreme	7.72	7.61
High	Low	4.33	4.33
	Moderate	5.88	5.36
	High	1.51	1.57
	Very high	2.60	2.92
	Extreme	6.85	6.75
River	Low	5.76	5.76
	Moderate	7.38	6.67
	High	2.33	2.47
	Very high	9.65	14.86
	Extreme	6.96	6.59

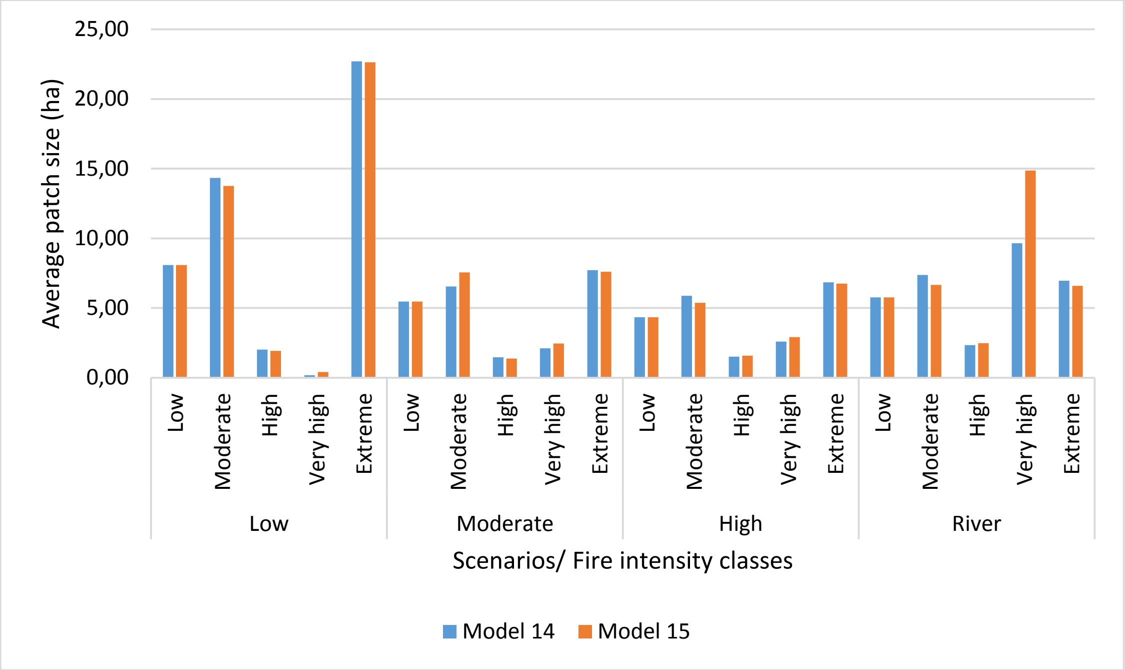

Figure 16. Graphic representing the average patch size in each fire intensity class.

The average patch size followed a pattern similar to that found for LPI for all scenarios, except River where average patch size has increased in all classes as compared to the Moderate and High scenarios, especially the Very High class (Table 11; Figure 16).

To analyze changes among scenarios in a much more detailed way, in GIS we compared fire line intensity classes on two successive scenarios using cross tabulation (Tables 12 to 17).

Table 12. Crossing surfaces of fire intensity classes (ha) between Low (rows) and Moderate (columns) scenarios based on the edge holm oak fuel model.

Class area	Low	Moderate	High	Very high	Extreme
Low	6729.8	383.1	484.4	96.4	97.6
Moderate	0.0	10767.1	838.1	747.6	52.1
High	0.0	0.0	827.6	214.6	0.7
Very High	0.0	0.0	0.0	31.4	1.8
Extreme	0.0	0.0	0.0	1961.4	7393.9

Table 13. Crossing surfaces of fire intensity classes (ha) between Low (rows) and Moderate (columns) scenarios based on the inside holm oak model.

Class area	Low	Moderate	High	Very high	Extreme
Low	6729.8	41.7	723.3	188.8	107.8
Moderate	0.0	10623.7	611.9	955.1	72.4
High	0.0	0.0	901.1	212.6	2.7
Very High	0.0	0.0	0.0	87.4	1.8
Extreme	0.0	0.0	0.0	1954.7	7412.9

Major differences in terms of fire hazard between Low and Moderate scenarios were observed in the moderate fire intensity since more than 1600 ha have changed from Moderate to High and Very High and, in a much smaller extent, to Extreme. In classes Low and High there were large areas that moved to classes of higher hazard (Moderate - High and very high). However, the Extreme class in the Low scenario is 1961 ha smaller than in the Moderate scenario (Table12 and 13).

Table 14.Crossing surfaces of fire intensity classes (ha) between Moderate (rows) and High (columns) scenarios based on the edge holm oak model.

Class area	Low	Moderate	High	Very high	Extreme
Low	5997.3	503.8	172.2	56.1	0.4
Moderate	3.8	9998.3	85.0	1062.5	0.6
High	3.9	6.5	2122.3	17.4	0.0
Very High	0.9	7.3	2.4	3024.6	16.3
Extreme	0.4	0.3	0.0	565.5	6979.9

Table 15. Crossing surfaces of fire intensity classes (ha) between Moderate (rows) and High (columns) scenarios based on the inside holm oak model.

Class area	Low	Moderate	High	Very high	Extreme
Low	5997.3	147.1	526.5	58.5	0.4
Moderate	0.4	9516.8	76.1	1071.1	0.9
High	6.6	4.9	2207.3	17.4	0.0
Very High	1.4	8.9	2.3	3369.8	16.3
Extreme	0.5	0.3	0.1	565.5	7031.3

Table 14 for fuel model 14 and Table 15 for model 15 show differences between Moderate and High scenarios, where 1148 ha have changed from Moderate to High and Very high. In the High and Very High classes a small changes were observed in classes of lower hazard (Low and Moderate). However, the Extreme class for the Moderate scenario is smaller than in the High scenario.

Table 16. Crossing surfaces of fire intensity classes (ha) between High (rows) and River (columns) scenarios based on the edge holm oak model.

Class area	Low	Moderate	High	Very high	Extreme
Low	3819.6	1012.8	773.7	250.3	150.0
Moderate	577.6	7169.3	772.0	1910.4	86.8
High	306.5	480.4	1357.4	234.0	3.5
Very High	72.4	1243.4	107.6	2114.3	1188.4
Extreme	11.0	15.4	0.2	3008.6	3962.1

Table 17. Crossing surfaces of fire intensity classes (ha) between High (rows) and River (columns) scenarios based on the inside holm oak model.

Class area	Low	Moderate	High	Very high	Extreme
Low	3819.6	392.6	1221.1	402.1	171.0
Moderate	88.9	6818.1	572.1	2086.4	112.4
High	774.9	367.2	1432.7	232.4	5.1
Very High	91.4	1347.1	107.6	2347.9	1188.4
Extreme	12.3	25.6	0.2	3001.2	4009.7

The High to River scenarios cross tabulation showed a high dynamics with many changes among intensity classes. Large areas had moved from Very High classes in High scenario to Extreme class in River Scenario. A larger area moved from Moderate to Very High. Also from Low to Moderate, High and Very High. Many and large areas that in the High scenario were in classes of higher intensity are in lower intensity classes in the River scenario (Table 16 and17).

Differences of the previous indicators (average value of fire intensity, average value of rate of spread, CA, LPI, and the average patch size) between holm oak fuel models (edge and inside) are usually small, except when mentioned.

5. Discussion

The main objective of this study was to understand and model the effects of holm oak woodlands on fire behavior at the landscape level in Northeastern Portugal. Previous research support the fact that holm oak woodlands have an effect on the spread and intensity of fire (Azevedo et al., 2013), by controlling fuel loads at the ground level that decrease with distance to woodland edge. Our results seem to further support that hypothesis since there is an effect of decreasing average value of fire intensity and rate of spread over the gradient of holm oak woodland occupancy in the landscape represented by the 4 scenarios tested.

Analysis of the spatial pattern of fire intensity classes with FRAGSTATS also seem to provide evidence that increasing holm oak tends to reduce the size and dominance of higher fire line intensity patches in the landscape.

The area of each fire intensity class among scenarios has changed (Figure 13). The classes with high intensity have decreased in size, while those with low area have increased (High and Very High) (Table 9; Figure 14).

Figure 17 represent two maps. The first one shows the distribution of fire intensity classes (River scenario as example) and the second one shows the spatial location of holm oak woodlands in the case of the River scenario. Comparing the two maps, it is visible that areas occupied by holm oak woodlands are the same areas where fire intensity class is High and Very High. The same procedure resulted in similar results in all scenarios. .

Fuel loads of holm oak differ from the other vegetation communities. According to Anderson (1982), fire behavior differs depending on vegetation groups because it is related to fuel models. Each fuel model is described by a fuel load and the ratio of surface area to volume for each fuel size class, the depth of the fuel bed involved in the fire front, and fuel moisture, including that at which fire will not spread, called the moisture of extinction (Anderson, 1982).

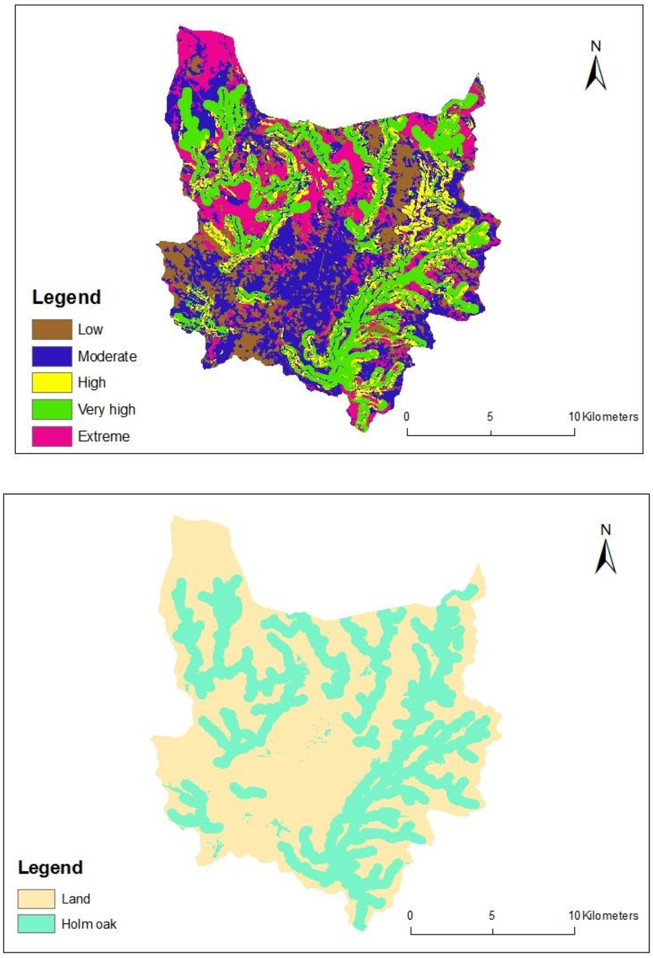

Figure 17. Comparison between holm oak woodlands and fire intensity classes, Holm oak woodlands correspond to high and very high classes.

Comparing fuel loads of holm oak and in other fuel models (Table 18), we found that only fuel models 4 and 6 (dense Shrubland communities) are higher in terms of fuel loads (Table 18). Therefore, when we changed areas represented by fuel model 4, which is corresponding to the Extreme class of fire intensity (Figure 18) to holm oak it explains the tendency of areas under the Extreme fire intensity class to become High or Very High intensity class area. The same happens when we changed areas represented by the fuel models (1, 2, 5, 6, 8, 9) corresponding to Low, Moderate and High fire intensity classes, which explain to the decay of those classes.

Table 18. Total fuel load dead and live (tons/ ha) for fuel models represented in the landscape of study; values adapted from Anderson (1982).

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Fuel model	Fuel load (tons /ha)
1	0
2	9.88
4	32.12
5	7.41
6	14.82
8	12.35
9	7.41
14	13.69
15	15.334

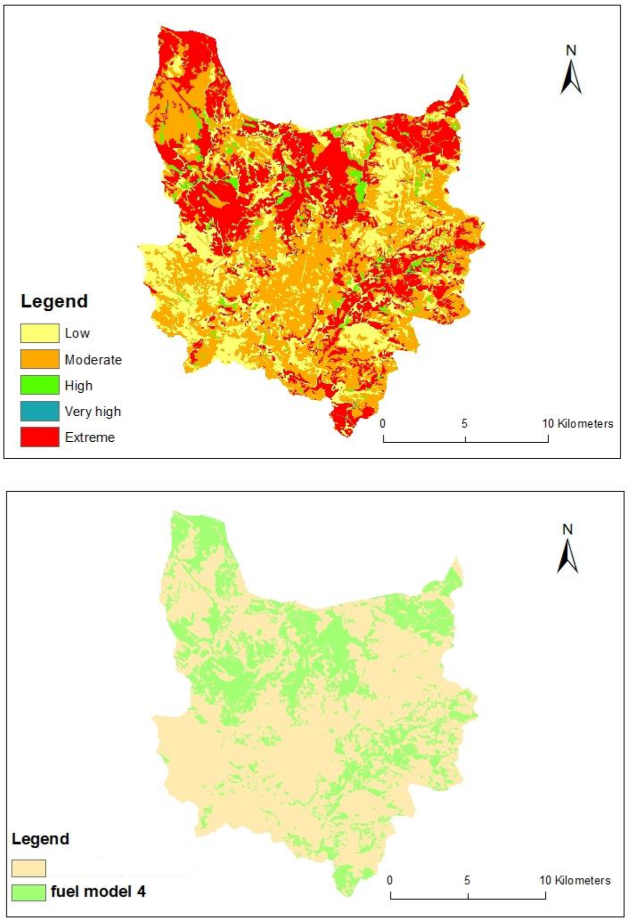

Figure 18. Maps showing that fuel model 4 areas are occupied by the areas of Extreme fire intensity class.

Another explanation that can contribute in the analysis of our results is the fact that holm oak fuel models are calibrated fuels for the northeastern Portugal region, contrarily to the others fuels that are a standard ones and not specific for our study region.

Fire behavior in our study region, and the distribution of fire intensity classes are related especially to the distribution of fuel models. This means that potential fire behavior for a fuel type is expressed by fire hazard (MOF, 1997; Bachmann and Allgower, 2000; Hardy, 2005). The fire hazard is applied to the fuel itself, for an instant or a period of time, without including the weather or environs in which the fuel is distributed (Hardy, 2005).

6. Implications to management

Our results (Class area, LPI, and average patch size) provide information about potential landscape structure and functioning and that can contribute also to improve our understanding of the dynamics of landscape systems, which can be useful to suggest planning and managements practices and activities at different scales.

The fact that all metrics (Class area, LPI, and average patch size), of all fire intensity classes (Low, Moderate, High, Very High and Extreme) had decreased in scenarios with higher percentage of holm oak (with exceptions). It means that higher fire intensity classes have less relevance in the landscape and are also more fragmented which can be attributed to of holm oak distribution. These results reveal that holm oak have a potential impact in the reduction of fire hazard in the study area.

In the river scenario, metrics (Class area, LPI, and average patch size) had increased compared to other scenarios, and this amount to the fact that holm oak areas are more continuous comparing with the other scenarios; the holm oak woodlands are concentrated in both sides of streams. According to Azevedo et al., (2011) the management priorities should include: decreasing fire hazard at the patch level, increasing landscape heterogeneity and decreasing connectivity of the most flammable land cover areas. In our case the results obtained allows the identification of the most critical areas where management is more exigent. Those areas correspond to Extreme fire intensity class (Figure 18).

The fact that holm oak woodlands affect fire behavior, eventually acting as barriers (Azevedo et al. 2013) or just because they decrease the likelihood of large areas of very intensive wildfires can have a significant in planning and management of landscapes for fire hazard reduction, such as in preventive silviculture. From the results of our study, it seems reasonable to admit that expanding holm oak woodlands in a scattered pattern to increase fragmentation of higher fire intensity classes can contribute to an overall reduction of hazard. This expansion, as was suggested by Azevedo et al. (2013), may be conducted artificially by afforestation, or by promoting natural regeneration in abandoned areas that are those corresponding to the areas where holm oak woodlands expanded in scenarios Moderate and High.

Furthermore, in terms of landscape planning and management, additional information is required to better address the use of holm oak woodlands in programs of conservation and landscape fire hazard mitigation, including optimal patch size, shape, and orientation and optimal proportion for holm oak woodlands and configuration in the landscape.

7. Conclusion

The main objective of our study was to understand and model the effect of holm oak woodlands on fire behavior at the landscape level. The role of holm oak was determined in terms of area and configuration of woodlands in the landscape according to the results obtained from the scenarios built, based on the probable extension of these vegetation units.

The results demonstrate that holm oak woodlands have an effect on fire behavior by decreasing the mean value of both fire intensity and rate of spread through scenarios (Low, Moderate, High and River). The spatial pattern analysis of fire intensity classes (Low, Moderate, High, Very High and Extreme) with FRAGSTATS also afford evidence that increasing holm oak tends to reduce the size and dominance of higher fire line intensity patches in the landscape. However, it is reasonable to admit that extending holm oak woodlands in a sprinkled pattern to increase fragmentation of higher fire intensity classes can contribute to an overall reduction of hazard.

To conclude, all the results that we had may contribute to improve the understanding of the dynamics of landscape systems, which is useful to suggest planning and managements practices and activities at different scales.

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