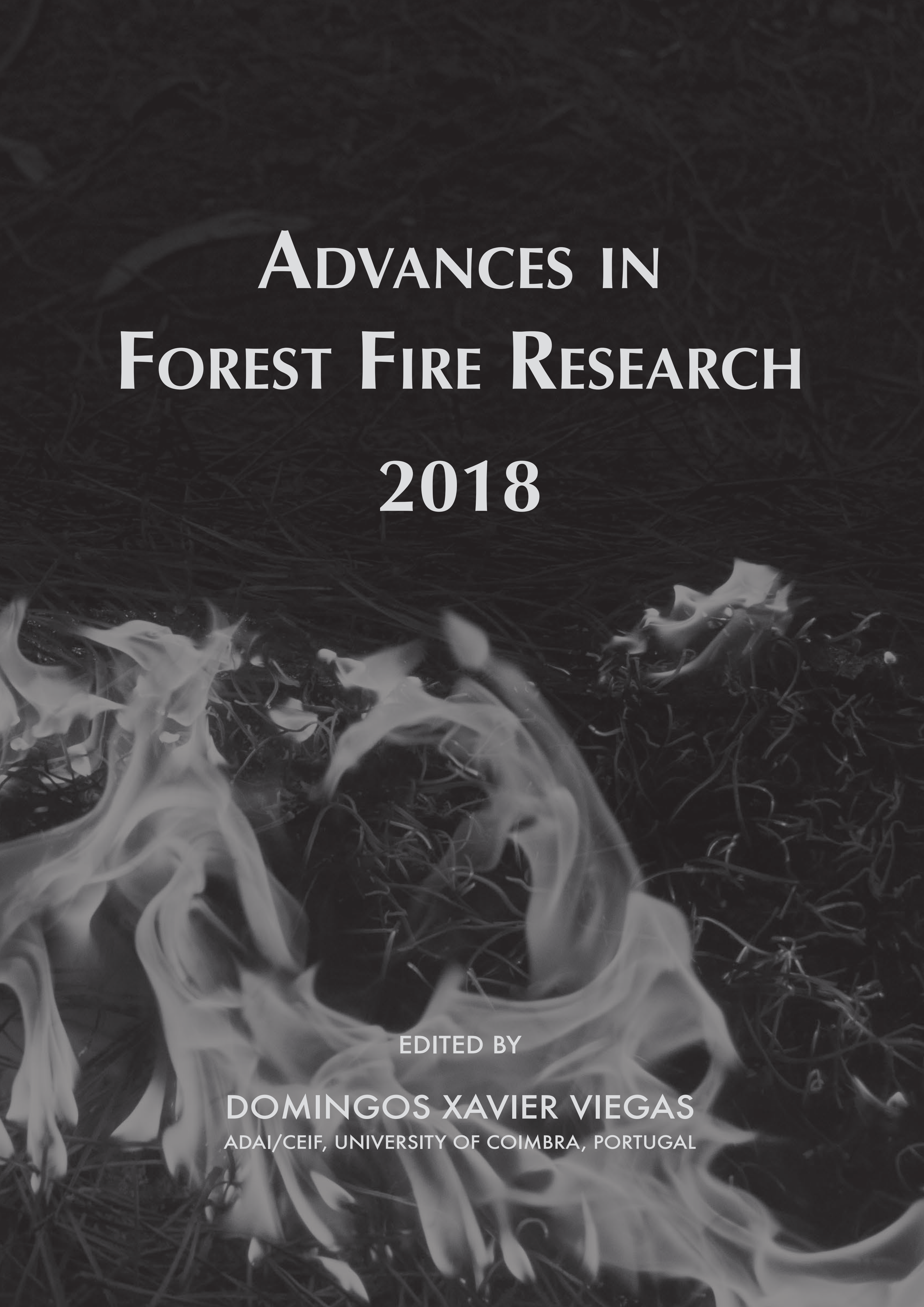

Advances in Forest Fire Research 2018

EDITED BY

DOMINGOS XAVIER VIEGAS

ADAI/CEIF, UNIVERSITY OF COIMBRA, PORTUGAL

https://doi.org/10.14195/978-989-26-16-506_28

Optimisation of fuel treatments at landscape level in NW Spain

Enrique Jiménez*; José M. Fernández-Alonso; Cristina Fernández; Teresa Fontúrbel; José A. Vega

Centro de Investigación Forestal-Lourizán, Xunta de Galicia
{enrique.jimenez.carmona@xunta.es}*

Abstract

In the current framework of forest fires incidence, climate change and forest management budget constraints, fuel treatment activities should be located in strategically areas to meet a set of prevention, economic and ecological criteria. Characterizing potential forest fire behavior is critical to develop effective fuel treatment plans in order to reduce the negative impacts of wildfires. This study was carried out in the District XIX Caldás – Salnés (Pontevedra, Spain) with 132004 ha, an area with high occurrence of wildfires. Fire behavior characteristics at landscape level were obtained with Flammap fire modeling software using as inputs spatially explicit data. This software requires as inputs weather, terrain, stand and fuel characteristics. Simulations were carried out under extreme fire weather conditions. Fuel layers used for the simulations were obtained combining the Spanish National Forest Map (4th Spanish National Forest Inventory) and a new fuel classification developed for forest fuels in Galicia. The software WindNinja was employed to include in the simulations the spatial variability of wind speed and direction as a consequence of topography. After computing output data from fire behavior simulation, Landscape Treatment Designer (LTD) was the software employed to obtain the optimal treatment locations. LTD creates a sequence of spatially defined project areas that maximizes the objectives with the provided constraints and treatment thresholds. Flame length was selected as treatment threshold variable. Priority stands for treatment were defined as a function of a set of preventive, ecological and economic parameters (presence of human infrastructures, fire risk according to fire frequency and ecological value, fuel model and stand structure). The maximum area to treat was constraint to 3000 ha for the whole scenario. After obtaining flame length for each stand with Flammap, LTD creates both aggregated and dispersed treatment schedules, each representing a different spatial treatment scenario, taking into account the priority functions.

The results highlight the potential of this methodology as a very useful tool for fuel treatments at landscape level, taking into account that the effective allocation of resources is critical.

Keywords: FlammMap; Lanscape Treatment Designer; fuel treatments

1. Introduction

Fuel load and continuity increased notably in southern Europe during the second half of the twentieth century leading to more intense wildfires (Moreira et al. 2011). Annually, some 51,200 forest fires burn approximately 477,400 ha in southern European countries (from 1980 to 2013, in Portugal, Spain, France, Italy and Greece; Rodriguez-Aseretto et al. 2014). Moreover, the Mediterranean forests are expected to suffer higher frequency of fire in the future (Turco et al. 2014). In the current framework of forest fires incidence, climate change and forest management budget constraints, fuel treatment activities should be located in strategically areas to meet a set of prevention, economic and ecological criteria. The efficacy of fuel treatments decreasing fire severity and size has been previously elucidated (Agee and Skinner, 2005; Jiménez et al. 2016). It has been also found that the strategic allocation of fuel treatments reduced the predicted growth rates of modeled fires more effectively than random placement (Finney et al. 2006).

Characterizing potential forest fire behavior is critical to develop effective fuel treatment plans in order to reduce the negative impacts of wildfires. The great complexity of wildfire risk assessment and fuel treatment planning has resulted in the increase in the employment of different fire behavior simulation software in research and operational context(Ager et al. 2011; Calkin et al. 2011). Wildfire modeling can be employed as general indicators of wildfire exposure and fuel treatments planning for optimization of fire prevention activities (Salis et al. 2013). There is an increased interest in the use of decision support tools to mitigate wildfire risk (Matin et al. 2016). These tools include wildfire simulation models allow managers to quantitatively evaluate management decisions in fuel treatment activities planning (Martin et al. 2016).

The aim of this study was to simulate fire behavior (Flammap) within an entire landscape and use a decision support tool (Landscape Treatment Designer, LTD – Ager et al. 2012) to spacially allocate fuel treatments taking into account a set of preventive, ecological and economic parameters.

2. Data and methods

2.1. Study area

This study was carried out in the District XIX Caldas – Salnés (Pontevedra, Spain) with 132,004 ha (Figure 1). It covers 28 municipalities. Topography is dominated by uplands and lowlands, ranging from 0 m.a.s.l (at the coastal areas) to 1010 m.a.s.l. The climate is oceanic, with a mean annual precipitation between1200 - 1800 mm and a dry period of 2 months. The mean annual temperature is between 12 - 14°C. North-east winds are those associated with the period of higher fire frequency.

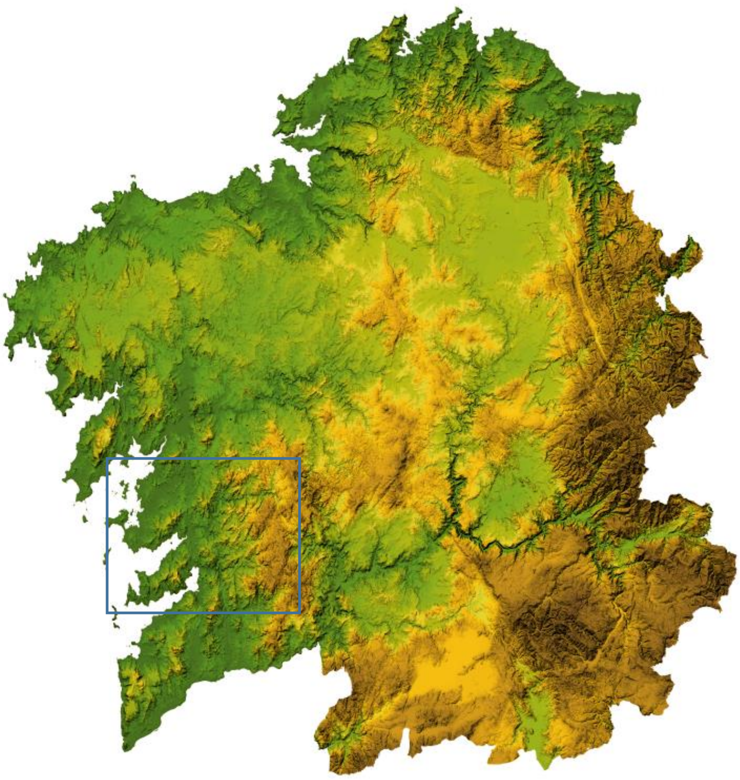

Figure 1 - Location of the study area, in Galicia (NW Spain)

The forest covers 65.25% of the total area. The main forest land cover type is eucalypt (26.9%), followed by shrublands (18.8%), mixed pine and eucalypt forest (17.9%) and pine forest (13.1%).

The District XIX Caldas-Salnés is an area with high occurrence of wildfires. From 2002-2007, the mean annual number of fires was 709, burning 4097 ha. Wildfires occurred mainly in summer season (August). Most of these wildfires are man-caused, with a high level of intentionality. The preventive and fire fighting plan of the District XIX Caldás-Salnés define every year the areas with higher fire risk according to fire frequency and ecological value.

2.2. Fire behaviour simulations

Fire behavior characteristics at landscape level were obtained with Flammap fire modeling software (Finney 2006) using as inputs spatially explicit data. Flammap was selected because it is the single available option to estimate maximum fire potential for any given point (pixel) of a landscape (Botequim et al. 2017). We analyzed FlamMap outputs for flame length. This software requires as inputs weather, terrain, stand and fuel characteristics (Figure 2). Terrain inputs consisted of elevation, aspect and slope extracted from a digital elevation model (DEM) at horizontal resolution of 25 m was obtained for the study area from the Spanish Geographic National Institute. Fuel-related data layers used for the simulations were obtained combining the Spanish National Forest Map (4th Spanish National Forest Inventory) – standard fire behavior fuel models (Anderson 1982) -, and a new fuel classification developed for forest fuels in Galicia based on main species, age class and understory fuel characteristics – canopy fuels (Arellano et al. 2016).

Simulations were carried out under extreme fire weather conditions. Extreme wildfire risk conditions were defined as wind speed of 30 km h^{-1} - value proposed by Mitsopoulos and Dimitrakopoulos (2007) and Fernández-Alonso et al. (2013) in other Mediterranean areas - and dead fine fuel moisture of 6%. Crown and undercanopy live fuel moisture was established as 100 %. The previous DEM was employed to simulate the wind fields within the fire perimeters with WindNinja (Forthofer 2007). WindNinja is a mass-consistent fluid flow dynamics models that estimates the modifying effects of topography on synoptic winds.

2.3. Optimal treatment locations

After computing output data from fire behavior simulation, Landscape Treatment Designer (LTD) was the software employed to obtain the optimal treatment locations (Ager et al. 2012, Ager et al. 2013, Vogler et al. 2015). LTD creates a sequence of spatially defined project areas that maximizes the objectives with the provided constraints and treatment thresholds. Flame length was selected as treatment threshold variable. Fuel treatments were triggered when a stand exceeded a flame length of 1.5 meters. Any classifiable stand feature, such as habitat value, proximity to human communities, and wildfire hazard, may be combined in prioritizing stands for treatment. Priority stands for treatment were defined as a function of a set of preventive, ecological and economic parameters (presence of human infrastructures, fire risk according to fire frequency and ecological value, following the fire fighting plan of the District XIX Caldás-Salnés, fuel model and stand structure) – Table 1. Prior to LTD runs, each stand was assigned numeric rating scores according to these parameters (Table 1). The maximum area to treat was constraint to 3000 ha for the whole scenario. LTD can create both aggregated and non-aggregated project areas. In this study we only employed the non-aggregated method allowing the model to distribute selected stands over the landscape. LTD creates a map of treatment priority resulting in a sequence of project areas and respective priorities.

Table 1 - Presence of human infrastructures, fire risk according to fire frequency and ecological value, fuel model and stand structure, and assigned wildfire hazard ratings for LTD runs

Presence of infrastructure	Value	Fire risk	Value	Fuel model	Value	Stand structure	Value
Yes	0	Low	1	1, 2, 8, 9	0	Shrub	0
No	2	Medium	2	3, 5	1	Seedlings/saplings	0
		High	3	6, 7	2	Pole	1
		Very High	4	4, 10, 11	3	Saw	3

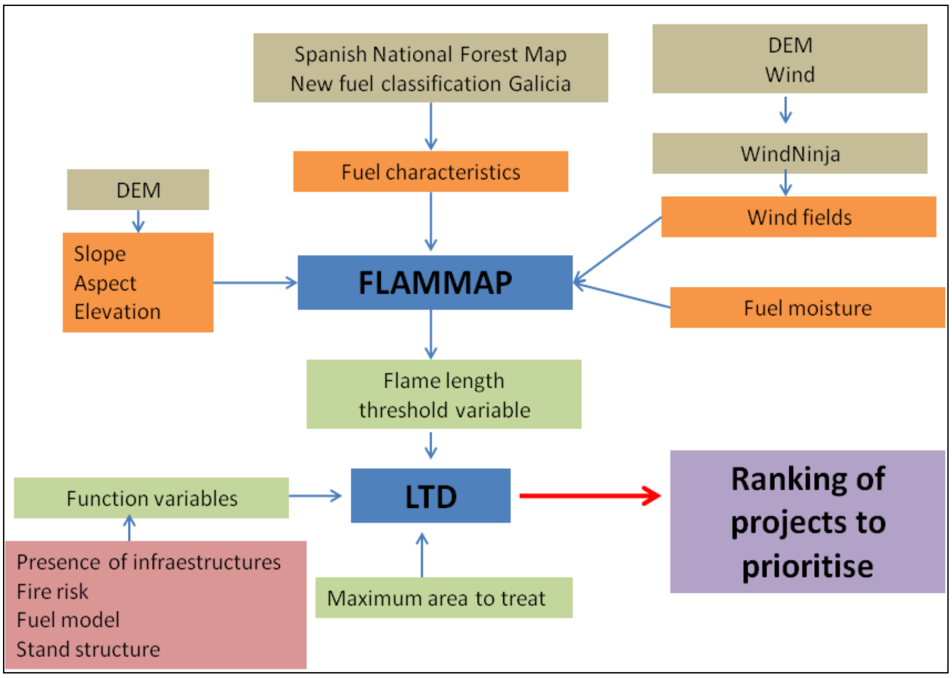

Figure 2 - Scheme of inputs employed for fire behavior simulations (FLAMMAP) and optimal treatment locations by LTD.

3. Results and discussion

The Figure 3 shows the spatial variation of flame length for the whole landscape obtained from FLAMMAP under the extreme meteorological conditions.

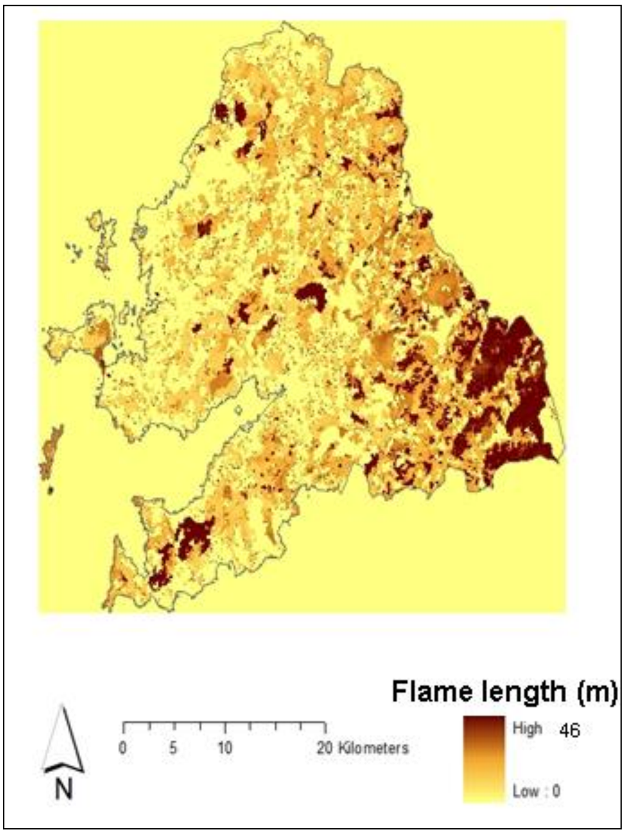

Figure 3 - Spatial variation of flame length of the study area obtained from FLAMMAP

Taking into account the standard fuel models for each stand defined in the Spanish National Forest Map, mean flame length ranged from 0.90 m (fuel model 8) to 3.17 m (fuel model 4) – Table 2. If we consider the main species of the stand, mean flame length ranged from 0.70 m (*Agrostis curtisii* areas) to 1.50 m (*Ulex* sp. areas) for pastures and shrubland stands, and from 0.75 m (*Pinus radiata* stands) to 1.27 m (*Castanea sativa* stands).

Table 2 - Mean flame length (range between brackets) obtained from FLAMMAP of the study area stands as a function standard fuel models and main species

Standard fuel model	Flame length (m)	Main species	Flame length (m)
1	0.93 (0.01-2.20)	*Agrostis curtisii*	0.70 (0.01-1.70)
2	1.09 (0.03-8.53)	*Cytisus multiflorus*	0.90 (0.08-2.22)
3	1.47 (0.02-2.75)	*Pteridium aquilinum*	1.26 (0.66-2.55)
4	3.17 (0.01-10.22)	*Ulex* sp.	1.50 (0.01-8.38)
5	1.06 (0.00-14.73)	*Betula* sp.	1.14 (0.06-7.32)
6	1.32 (0.00-8.53)	*Castanea sativa*	1.27 (0.05-8.28)
7	1.13 (0.00-9.46)	*Eucalyptus* sp.	1.22 (0.00-14.73)
8	0.90 (0.30-2.94)	*Pinus pinaster*	1.16 (0.00-9.96)
9	1.02 (0.40-8.19)	*Pinus radiata*	0.75 (0.00-3.06)
10	1.77 (0.05-3.12)	*Quercus robur*	1.23 (0.00-8.19)
11	2.29 (0.59-7.84)		

The non-aggregate option of LTD created a dispersed treatment schedule based on fire hazard and fire risk (Figure 4). This option creates a ranking of projects to priorities the whole landscape into a sequence of project areas. The project labeled with number 1 represents the highest priority area for the given objectives, and the project labeled with the number 7 represents the lowest priority.

For the project 1 (highest priority), the fuel model 5 represented the 54.6% of the 3000 ha to treat, followed by the fuel model 6 (31.7%) and fuel model 4 (11.9%). The high percentage of area to treat covered by fuel model 5 could be consequence of the high surface covered by this fuel model in the entire area (23.3%). Taking into account the main species, *Ulex* sp. areas represented 48.5% of the area to treat, followed by *Eucalyptus* sp. stands (26.9%) and *Pinus pinaster* stands (16.0%). Although *Ulex* sp. areas only cover 9.8% of the entire landscape, the high flame length obtained with simulation for these areas could explain the high percentage of area to treat represented by this species.

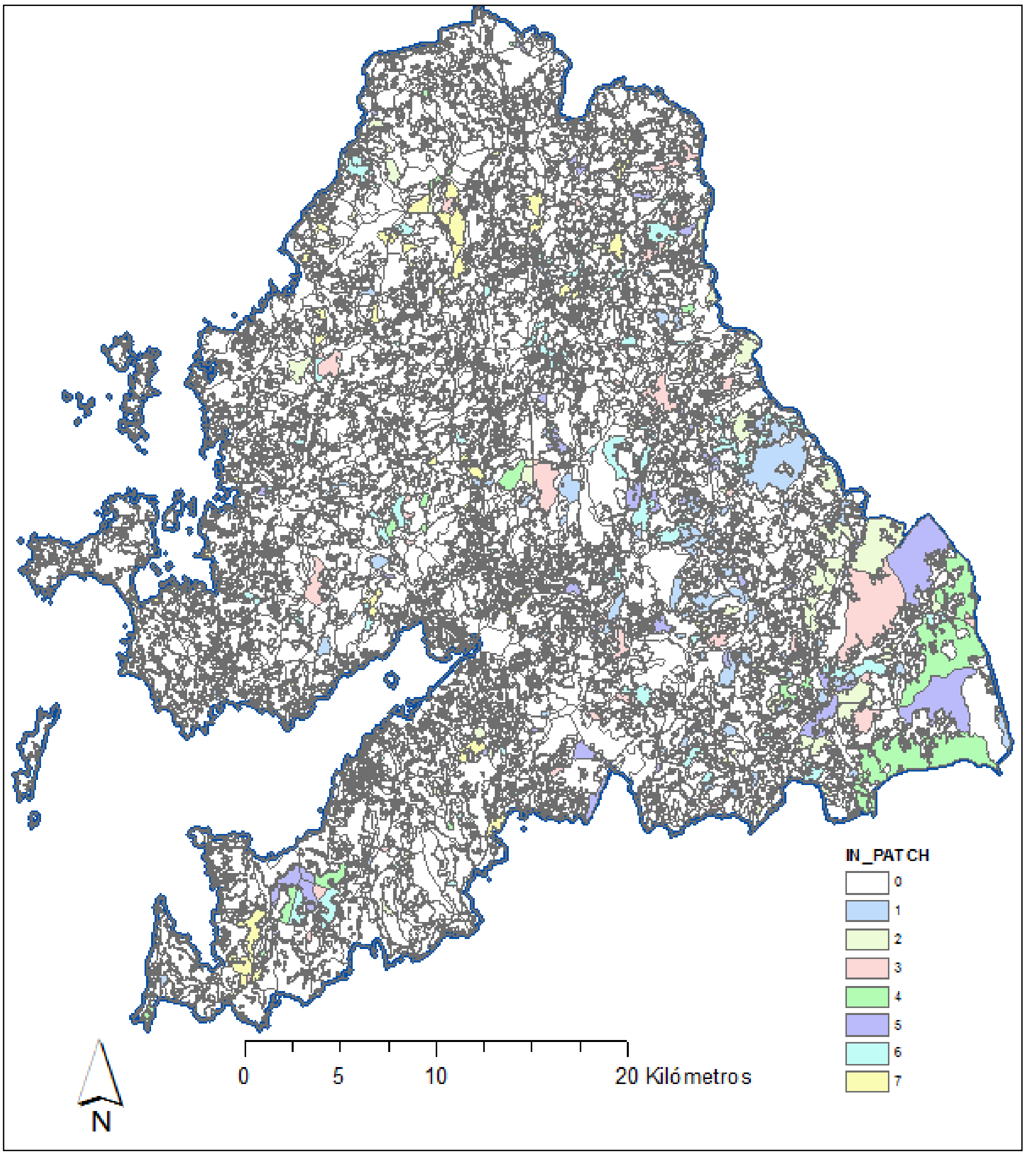

Figure 4 - Ranking of projects to priorities the whole landscape into a sequence of project areas.

Table 3 - Percentage of area to treat for the project of highest priority as a function of standard fuel model and main species

Standard fuel model	Percentage of area to treat (%)	Main species	Percentage of area to treat (%)
1	0	*Agrostis curtisii*	0
2	1.6	*Cytisus multiflorus*	0
3	0	*Pteridium aquilinum*	0
4	11.9	*Ulex* sp.	48.5
5	54.6	*Betula* sp.	2.3
6	31.7	*Castanea sativa*	4.8
7	0.2	*Eucalyptus* sp.	26.9
8	0	*Pinus pinaster*	16.0
9	0	*Pinus radiata*	0
10	0	*Quercus robur*	1.5
11	0		

Although it has been suggested limitations of wildfire models (Mell et al. 2007; Alexander and Cruz, 2013), the results highlight the potential of this methodology as a very useful tool for strategically locate fuel treatments at landscape level, taking into account the cost of carrying out preventive activities.

4. Acknowledgments

This research was funded by the INTERREG-SUDOE PLURIFOR project.

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