



Fire effects in *Pinus uncinata* Ram. plantations

Adrián Cardil^{*1}, Domingo Molina¹, Jordi Oliveres² and Marc Castellnou²

¹ ETSEA, Universidad de Lleida, Av. Rovira Roure, 191. E-25198 Lleida, Spain ² Unitat Tècnica GRAF, Cos de Bombers de la Generalitat de Catalunya, Ctra. de la Universitat Autònoma, s/n, 08290 Cerdanyola del Vallès, Spain

Abstract

Aim of study: Understanding fire ecology of main forest species is essential for a sound, scientifically based on managing of wildlands and also to assess likely implications due to changes in fire regime under a global change scenario. Few references can be found about fire ecology of *Pinus uncinata* Ram. (PU). PU species grows in the Central Pyrenees where large, severe wildland fires did not occur frequently in the past. However, several fires with extreme fire behavior have affected PU stands in last years and they might disturb other PU forest in the future.

Area of study: Cabdella fire (February 2012), in Lleida province, is one of the several wildland fires occurred in 2012 (winter season) in the Central Pyrenees. Fire affected a large PU plantation (102 ha) located at 1.800-2,100 meters above the sea.

Material and methods: We have analyzed first order fire effects in three fireline intensity thresholds along three years in terms of mortality ratio, scorched height, percentage of scorched crown volume and bark char height.

Main results: PU seems to be a very tolerant species to low and medium fire line intensity but fire effects were very significant when fire line intensity was high. In medium fireline intensity sites, probability of mortality ranged from 15 to 30% and the dead trees had the highest values on scorched height and percentage of scorched crown volume.

Research highlights: Results from this work supports that prescribed burning might be used to efficiently decrease fuel load and fuel vertical continuity while avoiding considerable PU mortality. It also displayed that when fuel management has been implemented, PU mortality might be limited even under extreme fire behavior.

Keywords: *Pinus uncinata* Ram.; wildland fire; fire ecology; Spain.

Abbreviations used: PU: *Pinus uncinata* Ram.

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Correspondence should be addressed to Adrián Cardil: adriancardil@gmail.com

Introduction

Many wildland fires affect forests and wildlands in Spain in last years like in other South Europe countries (Greece, Portugal, Italy or France) or elsewhere (Pereira *et al.*, 2011). Some of them had a severe fire behavior and burned large areas, causing economic and environmental losses (Cardil & Molina, 2013; Cardil *et al.*, 2014). However, in the highest areas of the Spanish Pyrenees where *Pinus uncinata* Ram. (PU) areas can be found (Serrada *et al.*, 2008; Stähli *et al.*, 2006; Conedera & Tinner, 2004) few large, severe wildland fires occurred yet. Most of the PU forests are located in the Pyrenees, where the species is dominant at elevations from 1800 to 2500 m a.s.l. usually forming low-

density stands (Galván *et al.*, 2014). Detailed information about PU specie in Spain can be found in Blanco *et al.* (2013).

Fire is usually relevant to maintain pine stand processes, but it is also the most significant threat to forest stands in the Mediterranean Basin when fire regime changes (Barbéro *et al.*, 1998; Pausas & Fernandez-Muñoz, 2012). Forestry species (or populations) are usually adapted to a specific fire regime in each location. Fire ecology is fairly well known in many major forestry species: Fire ecology of most European pines species have been studied (Fernandes *et al.*, 2008; Fernandes & Rigolot, 2007). However, few references can be found and there is not much knowledge about the fire ecology of *Pinus uncinata* Ram. Lacking of the specific knowledge

on fire ecology for PU does not allow the best possible management of those stands (i.e., best fuel management). Few records of wildland fire occurrence are explicit in EGIF database (General Statistics on Wildland Fires) and most of them display small fire events in PU areas. Additionally, climate change trends might favor fire occurrence and a more extreme fire behavior (Cardil *et al.*, 2013; Cardil *et al.*, 2015; Gianakopoulos *et al.*, 2009).

Several severe wildfires occurred in the winter season in the Central Pyrenees (Huesca and Lleida provinces). These fires were very intense with high rate of spread and large flame length due to the physiological drought of the vegetation, the lack of snow cover, and the steep slopes. Little knowledge is in the literature about fire tolerance of PU and the fire effects in the species survival or enhances productions of seeds. This work is a first approximation to assess the effect of fire intensity, fire severity and influencing factors on PU mortality after a wildfire.

Methodology

Study case. Cabdella 2012 fire

Cabdella fire (20 February 2012), in Lleida province (Figure 1), is one of the several wildland fires occurred in 2012 (winter season) in the Central Pyrenees. Fire affected a large PU plantation located at 1.800-2,100 meters above the sea. This wildland fire account for 102 ha approximately and is a relevant case study because it burned under diverse fire behavior scenarios (flame length, rate of spread and residence time). In this way, we assess the species response under different fire behavior thresholds.

Local weather conditions from mobile weather stations (from firefighters) influenced fire behavior as

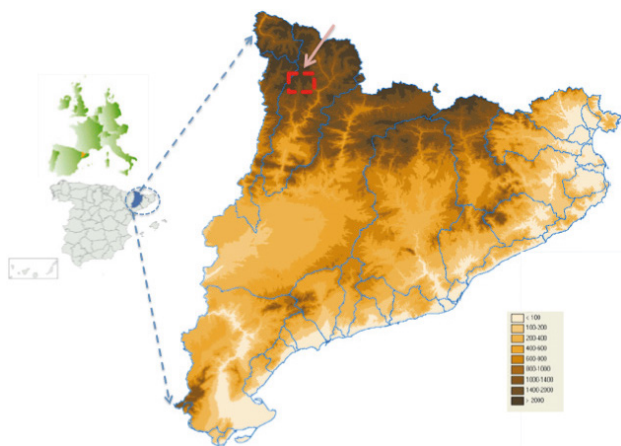


Figure 1. Geographic location of the study area in Catalonia (Spain) and digital elevation model of Catalonia (m).

usual. Fire spread was also influenced by the lack of snow. A severe physiological drought of the vegetation was also a key factor. Rainfall was significantly lower in relation to the climatic mean in February and previous months in winter. Repeated north synoptic episodes brought air masses with extremely low air humidity, increasing vegetation stress. In the fire day, 20 February 2012, the air relative humidity content was very low around 8 %. That day, a northward synoptic episode provided strong winds (45 km/h) that provided a window for dangerous fire behavior (from firefighting notes provided by co-authors Jordi Oliveres and Marc Castellnou who were part of the suppression forces).

In our study site, several forest stands were treated previously (i.e., pruning until 2 meters above the terrain). Therefore, a high dead and down fuel load covered the forest surface (2 or 3 years old pruning action) providing a fuel model 12 sensu Rothermel (1972). The stand structure was composed by a mean value of 440 trees per hectare with a mean diameter of 16.5 cm² and a basal area of 9.4 m²/ha. Topography (i.e., very steep slopes >45%) was also an important factor in fire propagation in several forest stands.

Fire behavior and analysis

We analyzed fire effects on vegetation following three levels of fireline intensity. Each portion was labeled as high, medium or low fire intensity following observations from firefighter's notes on fire behavior during suppression efforts (fire suppression agency from the Regional Government of Catalonia). The analysis started two months after the fire (3 April 2012) when we delimited plots' surface and marked trees. The second sampling was carried out eight months after the fire in October 2012 and the third sampling in November 2014, almost three years after the fire.

We accomplished two different analyses similar to other authors (Catry *et al.*, 2010; Rigolot, 2004): (1) effect of fireline intensity (high, medium and low) on tree mortality according to the analysis from firefighting services; (2) fire severity on tree mortality in the plots of medium fireline intensity.

(1) Fireline intensity effect on tree mortality: We have monitored 250 trees in each fireline intensity level with random transects following the contour lines in the plots 1, 2, 3 and 4 (Figure 2). Trees were classified "alive" or "dead" till reaching 250 in each fireline intensity level. Statistical analysis (logistic regression) was performed to assess if tree mortality (dependent and single variable) was different among the three fireline intensity levels (high, medium and low; independent, categorical and single variable) in November 2014.

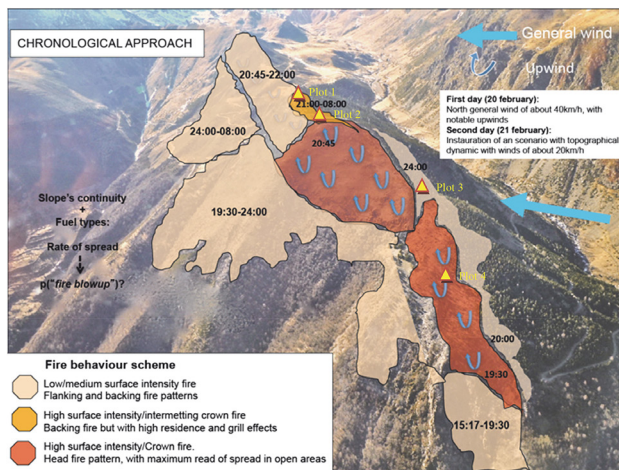


Figure 2. Fire behaviour scheme considering fire intensity and time fire spread. Yellow triangles (plots 1 and 2) mean plots located in medium fireline intensity areas to assess fire severity and tree characteristics effects on tree mortality.

(2) Fire severity effects on tree mortality in medium fireline intensity plots: We analyzed which factors could influence tree mortality, measuring trees and fire effects on them. We only performed this analysis in medium fireline intensity areas due to fire effects in both high and low fireline intensity levels were very conclusive before doing this analysis due to the mortality rate in both intensities (more than 90 % of mortality in high intensity and less than 5 % of mortality in low intensity). This work is a first scientific approximation to assess the effect of fire severity on PU mortality. We chose two different rectangular plots with 30 trees (700 m² approximately each one) in medium fireline intensity areas considering slope, exposure, in order to assess fire effects (Plots 1 and 2; Figure 2). In plot 1 with a less steep slope, fire spread was slower than in Plot 2 and both residence time and fireline intensity higher. Plot 1 exposure was northward while plot 2 was northeastward. We used several logistic regression analysis with single variables to identify which studied variables influenced tree mortality (independent variable) considering the first measures in April 2012. The measured variables were (dependent variables): tree height, tree diameter, bark thickness,

height to the lower green (alive) branch, maximum scorch height, percentage of scorched crown, minimum bark char height around the whole trunk perimeter, maximum bark char height around the whole trunk perimeter. A single independent variable in each logistic regression model was selected because the studied variables were correlated (correlation matrix). The method of maximum likelihood was used to perform the logistic regression, using Chi-square test. The model predicts continuous probabilities and we used a cut-off (0.5) to classify cases (0 or 1), maximizing the sum of sensitivity and specificity. The area under the ROC curve (AUC) was used to assess the model fit.

Results and discussion

PU mortality was very different according to fire intensity (p -value<0.001; logistic regression; Table 1). PU mortality was not high under low and moderate intensity fire events (5 % in low fire intensity and between 15 and 30 % in moderate fire intensity). In contrast, in high fire intensity areas, mortality rate was very high (more than 90 % of trees died two years after the fire). According to the logistic regression, the probabilities of tree mortality in medium and high fire intensity areas were respectively 8.08 (1.26 - 14.35; confidence level: 95 %) and 269.5 (125.93 - 576.74; confidence level: 95 %) times higher than those trees in low intensity areas. Comparing medium and high fire intensity areas, those trees located in high intensity areas had a probability of mortality 33.32 (18.98 - 58.49; confidence level: 95 %) times higher than in medium fire intensity areas.

In plots located in medium fire line intensity areas, two months after the fire (3 April 2012), some trees seemed to be in a critical state (20 % trees with more than 80 % of the crown scorched). However, 6 months later (20 October 2012), the average scorched crown decreased (Table 2) and new shoots (green branches) were present. Therefore, most trees increased their green foliage in this period. More than 2 years later (November 2014), around 30% of trees had died. We

Table 1. Logistic regression to assess the effect of fireline intensity (high, HI; medium, MI; and low, LI) on tree mortality and fire severity effects on tree mortality in medium fireline intensity plots.

Model	Logit	Independent variables	χ^2	AUC	% Correct (Cut-off=0.5)	P
Intensity N=750	$\ln(p/1-p)_{(dead)} = -0.42+3.03$ (HI) - 0.47 (MI)	Intensity	497.15	0.901	85.6	<0.001
Severity* N=60	$\ln(p/1-p)_{(dead)} = -4.08+0.052$ (SC) $\ln(p/1-p)_{(dead)} = -3.33+0.431$ (SH)	Scorched crown, SC (%) Scorched height, SH (%)	16.2 4.94	0.821 0.685	90.6 81.5	<0.001 0.026

* Only statistically significant models are shown in the table.

Table 2. Average characteristics of studied trees in several dates after the wildland fire. Plot number 1 and 2.

Date/ Variable	Tree height (m)	Basal diameter (cm)	Lower green (alive) branch (m)	Scorched height in lives trees (m)	Percentage of scorched crown volume in lives trees (%)	Minimum bark char height around the whole tree perimeter	Maximum bark char height around the whole tree perimeter
3 April 2012				3.9 ± 1.4	47.9 ± 28.5		
20 October 2012	6.8 ± 0.9	16.6 ± 3.1	1.9 ± 0.6	3.2 ± 0.9	19.5 ± 30.9	0.4 ± 0.2	1.7 ± 0.3
13 November 2014				2.6 ± 0.6	15.2 ± 25.5		

have studied the relationship between fire severity and PU mortality considering several variables. Both the percentage of scorched crown volume and scorched height were statically influencing variables on tree mortality (p -value <0.001 ; logistic regression; Table 1). The percentage of scorched crown was also an influencing factor regarding the probability of mortality in *Pinus halepensis* Mill. and *Pinus pinea* L. forests (Rigolot, 2004). The most effective indicator of crown injury appears to be the proportion of the crown scorched or killed by fire (Ryan et al. 1988, Ryan & Reinhardt, 1988). Comparing trees having a crown scorched over 66% of its volume versus less scorched trees, we found that the probability of tree mortality was 48 times higher in the most scorched crowns (4.66 – 1,263.21; confidence level: 95 %; p -value <0.01). Mean scorched crown volume was 72% in dead trees versus 40% in live trees. Not significant relationships were found in terms of tree mortality in medium fireline intensity plots in relation to the tree height (p -value=0.11), diameter (p -value=0.75), bark thickness (p -value=0.97), minimum scorched height and maximum bark char height around the whole trunk perimeter (p -value=0.98). Therefore, in low and moderate intensity levels, we can deduce that PU individuals did survive as well developed individuals (adult trees). This is a resistant strategy (i.e., after the disturbance, a tree persisted as adult individual) to low or moderate fireline intensity. By contrast, in the areas with high fire intensity, fire burned crowns (either as passive or active crown fire) and mortality was very high (i.e., 92.4%, 231 dead, 19 alive). Therefore, it seems that the species is not well adapted to high fireline intensity: It is clear that PU lacks of adaptations to intense fires as other species like *Pinus halepensis* (serotines cones), *Pinus canariensis* (resprouting) or *Quercus suber* (bark thickness and resprouting) (Fernandes *et al.*, 2008; Pausas, 1997). However, it could regenerate in the burned area from seeds from few individuals that survive inside the burned stand or from unburned islands or from PU populations outside the fire perimeter. This effect could be key because of it is a clearly stress tolerant species

to cold, blizzards, short growing seasons. In short, it is the fittest species to this stress dominated habitat.

There is still a lot of knowledge to be gain about fire ecology of PU. This understanding is critical to properly manage these forests and also to assess implications of climate change and changes in fire regime (Fernandes et al., 2013). Wildland fires with an intense fire behavior did not occur frequently in the past. Meteorological and climatic conditions could change this in the near future, decreasing the vitality of trees and providing more frequent and extreme wildland fires in the Pyrenees, causing an environmental damage if forest managers do not work on minimizing fuel load with prescribed burning and its subrogates.

We understand that it is possible to plan prescribed fires in PU areas due to the tolerance of the species under low and moderate fireline intensity fires. We can monitor fire behavior with low and medium fire line intensity. Additionally, prescribed burns allow treated surfaces and, therefore, we have a chance to control this emerging phenomenon of high intensity wildfires in high mountains (Conedera & Tinner, 2004; Allen et al., 2010).

Conclusions

Few references can be found about fire ecology of *Pinus uncinata* Ram. This work is a first scientific approximation to assess the effect of fire intensity and fire severity on PU mortality after a wildland fire. PU mortality were very different according to fire intensity. The species is tolerant to low and moderate fireline intensity fires but tree mortality is very high in high fireline intensity fires. Both the percentage of scorched crown volume and scorched height were statically influencing variables on tree mortality.

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