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Pinus pinaster Ait. tree mortality following wildfire in Spain

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ABSTRACT

Maritime pine (*Pinus pinaster* Ait.) is the tree species most affected by wildfire in the Iberian Peninsula. Prediction of the probability of fire-injured tree mortality is critical for management of burned areas, evaluation of the ecological and economic impact of wildfire and prescribed fire planning and application. Pine bark beetles (Scolytidae) frequently attack burned maritime pine stands and cause extensive post-fire mortality throughout the Iberian Peninsula. In the present study, maritime pine trees were monitored for three years following 14 wildfires in four ecotypes in Spain (11 fires in Galicia (Galician ecotype – NW Spain), one fire in Portillo (Meseta-Castellana ecotype – Central Spain), one fire in Rodenal (Rodenal ecotype – Central Spain), and one fire in Genalguacil (Sierra Bermeja ecotype – SW Spain)). Data on tree attributes, crown and bole injury, ground fire severity, *Ips* sp. presence and tree survival were obtained by examining 3085 trees. Logistic regression models for predicting the probability of delayed maritime pine mortality were developed by use of generalized estimated equations (GEE). An ample range of response to fire damage in mortality was evident among the four ecotypes and different models were fitted for each. The most important variables for predicting tree mortality were total crown volume damaged, presence of *Ips* sp. attack and cambium kill rating. The results highlight the extensive presence of *Ips* sp. in burned maritime pine forests and its importance in tree mortality process, the ample range of response of *P. pinaster*, in terms of post-fire mortality, as well as the need to develop site specific mortality models for the different ecotypes of this species following fire.

1. Introduction

Pinus pinaster Ait., the tree species most affected by wildfire in the Iberian Peninsula, shows life history attributes interpreted as evolved adaptations to fire (Vega, 2000; Tapias et al., 2004; Fernandes and Rigolot, 2007). Some of these fire-related traits such as thick bark, self-pruning, large buds protected by thick scales and long and thick needles, may play a decisive role in post-fire survival of this species. The comparative resistance of *P. pinaster* to fire has not yet been completely clarified. Fernandes et al. (2008) considered maritime pine as a species with appreciable fire resistance similar to that of *Pinus pinea* and with a comparatively high survival rate relative to most other European pines species. However, Catry et al. (2010) have reported marked differences in mortality between *P. pinaster* and *P. pinea*. Hence, more information on post-fire maritime pine survival is imperative because of its ample diversity, as well as the large spectrum of habitat conditions (Baradat and Marpeau, 1988; Alía et al., 1997; Salvador et al., 2000) and associated traits, which presumably confer different levels of resistance. Moreover, the apparent response may be obscured by delayed mortality caused by bark beetle attack, mainly by *Ips* spp. and *Tomicus* spp. (Lombardero, 1994; Fernández, 2006; Sánchez et al., 2008) which are frequent in maritime pine burned stands, and can kill trees already weakened by fire. This response is similar to that exhibited by other pine species such as ponderosa pine (Ryan and Amman, 1996; McHugh et al., 2003; Wallin et al., 2003; Sieg et al., 2006) and may substantially change the evaluation of post-fire mortality in maritime pine.

Better prediction of post-fire tree survival is critical for improving burning prescriptions, application of post-fire restoration in coniferous forests (Stephens and Finney, 2002; Fulé et al., 2004) and management of affected stands, especially as regards decisions on salvage logging.

Post-fire tree mortality is the result of complex processes in which many factors are involved. The level of severity and type of tree tissue damaged (foliage, buds, cambium, or roots), fire resistance characteristic of the species, tree age and vigor, fire season, post-fire environment and insect and fungal attacks are some relevant factors that affect tree mortality following wildfire.

Extensive research has been conducted in pine tree mortality prediction, following wildfire, prescribed burning and experimentally fire-damaged trees, mainly in the western North

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Fig. 1. Location of the maritime pine ecotypes under study. Gray points, fires used for model development. Black points, fires used for validation.

America (Peterson and Arbaugh, 1986; Ryan and Reinhardt, 1988; Regelbrugge and Conard, 1993; Stephens and Finney, 2002; Beverly and Martell, 2003; McHugh and Kolb, 2003; van Mantgem and Schwartz, 2003; Fowler and Sieg, 2004; Kobziar et al., 2006; Sieg et al., 2006; Breece et al., 2008; Battaglia et al., 2009; Hood et al., 2010). These studies consistently identified crown foliage damage as the best predictors of post-fire tree mortality followed by cambium damage, tree diameter and other tree attributes.

Information on mortality prediction in European conifers is comparatively scarce (Fernandes et al., 2008), particularly for *P. pinaster* (Botelho et al., 1998; Catry et al., 2010). However, given the notable variability in traits exhibited by the different ecotypes of this species, it is not known if these are widely applicable.

Moreover, few of the models available for predicting delayed post-fire tree mortality in conifer species consider the effect of beetle attack (Menges and Deyrup, 2001; McHugh et al., 2003; Sieg et al., 2006; Hood and Bentz, 2007; Hood et al., 2007; Breece et al., 2008; Fettig et al., 2008; Youngblood et al., 2009) and none of these apply to maritime pine. This gap in knowledge has a decisive effect on our current ability to predict the fate of fire-damaged stands and probably confounds post-fire management decision-making that is based on models that do not consider beetle attack as an explanatory variable.

The aim of the present study was to model delayed mortality following fire in several different *P. pinaster* ecotypes.

2. Methods

2.1. Study areas

Fires in stands four contrasting *P. pinaster* ecotypes were selected for the study (Fig. 1): in Galicia (Galician ecotype – NW Spain), Genalguacil (Sierra Bermeja ecotype – S Spain), Portillo (Meseta-Castellana ecotype – central Spain) and Rodenal (Rodenal ecotype – central Spain). The main characteristics of the study sites are summarized in the Table 1.

2.2. Sampling and measurements

Permanent plots were installed in each study site. Some plots were established a few months after the fire and an initial assessment of tree condition, particularly crown scorch, was made, although most plots were established in the summer after each fire. As a result of the timing of beetle emergence, establishment of plots and periodic re-measurements were conducted after mid July to ensure that flight and colonization stages had been completed. Plot size and the numbers within each fire varied among fires ranging from 0.10 to 0.30 ha and from 2 to 15 plots per fire, respectively, basically depending on the size of fire and the possibility of finding burned areas including a range of tree characteristics, crown and stem damage, ground fire severity and beetle attack. In each fire, a grid of between 200 and 1000 m was overlaid on a map of the burned area, and between 2 and 15 centers of each grid were randomly chosen to establish the corner of a rectangular plot with one of its sides oriented at random. When this point was situated in a stand affected by a crown fire or in a plot without trees, the nearest center of the grid situated on the right was selected. In each plot, all trees with dbh >7.5 cm were tagged. The number of trees per plot varied from 30 to 68. All trees were alive at the time of selection, and trees showing signs of beetle attack prior to the fire were not selected. Trees were classified as dead or alive according to the presence/absence of green foliage.

A set of twenty-five variables were measured for each tagged tree and used to reflect pre-fire tree characteristics and fire damage, which potentially influence post-fire mortality (Appendix A). Selection of the variables was based on factors that were significant in previous studies or suspected to be relevant for the processes analyzed.

The tree characteristics measured were diameter (dbh at 1.30 m), total height and pre-fire base crown height. Pre-fire live crown ratio (CCR) was determined as the proportion of total tree height occupied by the crown length. Crown position (3, dominant; 2, co-dominant; 1, intermediate; 0, suppressed) was also determined. Tree density in a circular subplot around each tree was estimated. The subplot radius was 10 m for stocked stands (density > 1000 trees/ha) and 15 m for open stands. Bark thickness (BT) was measured in the four quadrants of the stem at 0.5 m above ground. For each fire, between 80 and 100 trees were selected from nearby unburned areas and BT and dbh were measured in each tree. An equation relating BT and dbh was developed by regression, for each fire, and then used to estimate pre-fire bark thickness for that fire. High values of R^2 were obtained (0.88–0.96). A bark factor (BF) was calculated as $BF = 1 - \exp[-BT(\text{cm})]$, according to Ryan et al. (1994), to reflect the protective role of bark against heat