Pinus pinaster Ait. tree mortality following wildfire in Spain

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A R T I C L E   I N F O

A B S T R A C T

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.

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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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