Journal of Environmental Management 205 (2018) 9–17

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Assessing the effect of pruning and thinning on crown fire hazard in young Atlantic maritime pine forests

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ARTICLE INFO

Article history:
Received 2 May 2017
Received in revised form
12 September 2017
Accepted 18 September 2017
Available online 11 October 2017

Keywords:
Silviculture
Vertical canopy fuel distribution
Canopy bulk density
Canopy base height
Wildfires
Pinus pinaster

ABSTRACT

Management of fuel to minimize crown fire hazard is a key challenge in Atlantic forests, particularly for pine species. However, a better understanding of effectiveness of silvicultural treatments, especially forest pruning, for hazard reduction is required. Here we evaluate pruning and thinning as two essential silvicultural treatments for timber pine forests. Data came from a network of permanent plots of young maritime pine stands in northwestern Spain. Vertical profiles of canopy bulk density were estimated for field data and simulated scenarios of pruning and thinning using individual tree biomass equations. Analyses of variance were conducted to establish the influence of each silvicultural treatment on canopy fuel variables. Results confirm the important role of both pruning and thinning in the mitigation of crown fire hazard, and that the effectiveness of the treatments is related to their intensity. Finally, models to directly estimate the vertical profile of canopy bulk density (*CBD*) were fitted using the Weibull probability density function and usual stand variables as regressors. The models developed include variables sensitive to pruning and thinning interventions and provide useful information to prevent extreme fire behavior through effective silviculture.

1. Introduction

The risk of wildfires in temperate southwestern European forest is expected to increase as a result of severe weather conditions and the high accumulation of flammable fuels (EEA, 2016). Changes in traditional forests practices (Pérez, 1990) and land-use activities have changed forest composition, structure and stocking density (Gómez-Vázquez et al., 2013). Fuels reduction treatments help lessen the risk of high intensity and severe wildfires by decreasing both quantity and continuity of forest fuels (Agee and Skinner, 2005; Chiono et al., 2012). Silvicultural interventions such as pruning and thinning not only improve wood quality, but also break up the continuity of fuels. Specifically, pruning affects canopy base height and thus reduces vertical fuel continuity (e.g. Scott and Reinhardt, 2007), while thinning alters canopy bulk density and decreases the horizontal fuel continuity (e.g. Hevia et al., 2016b; Prichard et al., 2010). This fuel modification hinders the vertical development of surface fires burning through treated stands and reduces the probability of canopy fuels ignition (Graham et al., 2004), hence limiting the potential for high intensity crown fires (Cruz et al., 2008).

Crown fires are the most intense type of fire, they spread fast and are thus difficult and dangerous to contain (Ruiz-González and Álvarez-González, 2011; Scott and Reinhardt, 2001). Moreover, in managed forests, they cause severe damage (Alexander and Cruz, 2011; Ruiz-González and Álvarez-González, 2011) in terms of economic value and forest productivity (Rodríguez y Silva et al., 2012), as well as the ecology of the forest (Turner et al., 1999), wildlife habitat, recreational use, and human health through the effects of smoke (Dale et al., 2001). For these reasons, there is great interest in silviculture interventions to reduce forest susceptibility to crown fires (e.g. Reinhardt et al., 2006; Ruiz-González and Álvarez-González, 2011).

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https://doi.org/10.1016/j.jenvman.2017.09.051
0301-4797/

Two key variables that influence the initiation and spread of crown fires are canopy base height (*CBH*) and canopy bulk density (*CBD*) (Van Wagner, 1977). The quantification of these canopy fuel variables is therefore necessary in fire behavior simulation systems for modelling crown fire (Reinhardt et al., 2006). Measurements of many canopy fuel characteristics, such as *CBH* and *CBD* are not possible by direct methods (e.g. Carey and Schumann, 2003; Cruz et al., 2003; Hevia et al., 2016b; Reinhardt et al., 2006) and most indirect methods proposed (e.g. Gómez-Vázquez et al., 2013; Jiménez et al., 2013; Ruiz-González and Álvarez-González, 2011) require the determination of the available fuel which might be consumed in an active crown fire (Hevia et al., 2016b). In this respect, although there is some disagreement over what exactly constitutes available fuel, or the best way to estimate *CBH* and *CBD* (Fernández-Alonso et al., 2013), the use of data from destructive sampling and the development of biomass equations has been described as the most accurate method for estimating canopy fuel variables related to crown fire (Fulé et al., 2004; Reinhardt et al., 2006).

In the Atlantic region (northwestern Spain and Portugal) wildfires are the most destructive type of forest disturbance (e.g. Gómez-Vázquez et al., 2013, 2014) and maritime pine (*Pinus pinaster* Aiton) has historically been one of the species most prone to crown fire (Jiménez et al., 2013) due to its flammability (Fernandes and Rigolot, 2007), particularly when pruning and thinning are not applied, and forests carry high surface fuel loads (Cruz et al., 2008; Fernandes, 2009; Pinto and Fernandes, 2014). Indeed, in Atlantic forests it is possible to find high levels of fuel build-up which are probably not reached in temperate pine stands elsewhere (Vega, 2001), making fuel management to minimize fire risk a key challenge.

Recent studies for the main Atlantic conifer species have demonstrated that a better understanding of canopy fuel complex characteristics in forests and their relation to crowning potential can be obtained by combining classic forest inventory data with models which estimate those fuel characteristics. To date, however, most work in the Atlantic region has not considered the influence of silviculture (e.g. Fernández-Alonso et al., 2013; Gómez-Vázquez et al., 2013; Jiménez et al., 2013; Ruiz-González and Álvarez-González, 2011), while those that do have principally only taken into account thinning interventions (e.g. Crecente-Campo et al., 2009; Gómez-Vázquez et al., 2014; Hevia et al., 2016b; Ruiz-González et al., 2015) and studies focused on pruning or its combination with thinning remain scarce.

The first goal of this research is, therefore, to evaluate the effect of pruning and thinning on the potential initiation and propagation of crown fire in managed Atlantic maritime pine forests using a data set from permanent plots of this species in northwestern Spain. In addition to field data for pruning interventions, four simulated scenarios were considered: (1) untreated (control); (2) pruning only; (3) thinning only; and (4) pruning combined with thinning. Field data and simulated scenarios were used to estimate *CBH* and *CBD* as well as changes (%) in both canopy fuel variables.

The second aim is to develop equations for predicting the canopy fuel profile from easily measurable stand descriptors, using classic inventory data and variables related to silvicultural treatments. Field data from the permanent maritime pine plots and pruning interventions were considered in this respect.

2. Material and methods

2.1. Study area

The study area encompasses the western region of Asturias, Spain (Fig. 1) where pure and even-aged maritime pine forests abound. This area has an Atlantic climate with mild temperatures (annual average 12–14 °C) and abundant rainfall (930–1500 mm) throughout the year. The network of experimental plots used in the present study was chosen because they represent the range of forest conditions occurring within young maritime pine Atlantic forests which are suitable for silviculture. Mean elevation of the plots ranges between 101 and 536 m above sea level, soils are acid

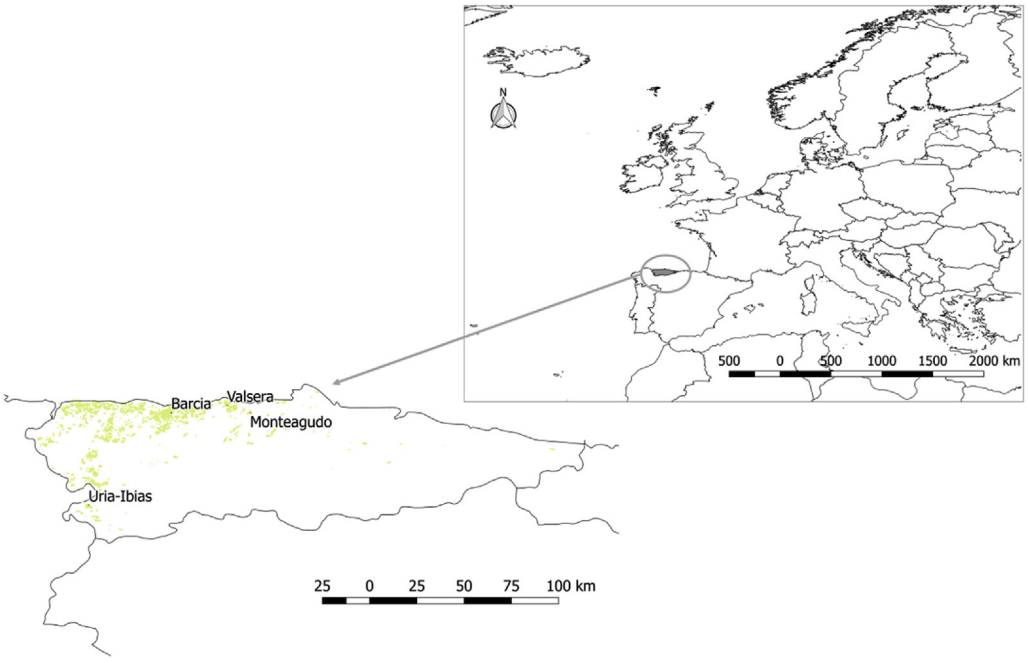

Fig. 1. Location of the study area within Europe (top right) and distribution map of *P. pinaster* (green) showing location of the network of research plots used to obtain the canopy fuel data (below, location names cross the centroid of each individual plot studied). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).