Forest Ecology and Management 368 (2016) 207–221

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Evaluating alternative fuel treatment strategies to reduce wildfire losses in a Mediterranean area

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ARTICLE INFO

Article history:
Received 11 October 2015
Received in revised form 1 March 2016
Accepted 3 March 2016
Available online 18 March 2016

Keywords:
Fuel treatment strategies
Burn probability
MTT algorithm
Mediterranean basin
Wildfire exposure
Wildfire risk mitigation

ABSTRACT

The goal of this work is to evaluate by a modeling approach the effectiveness of alternative fuel treatment strategies to reduce potential losses from wildfires in Mediterranean areas. We compared strategic fuel treatments located near specific human values vs random locations, and treated 3, 9 and 15% of a 68,000 ha study area located in Sardinia, Italy. The effectiveness of each fuel treatment was assessed by simulating 25,000 wildfires using the MTT fire spread algorithm. The simulations replicated severe wildfires observed around the study area, using historic weather and fuel moisture conditions (97th percentile). Wildfire exposure profiles for the study area as a whole and for locations with specific values of interest were analyzed. Results indicated significant variations in wildfire exposure among and within the fuel management strategies and treatment intensities. The simulated mitigation strategies substantially decreased the average wildfire exposure with respect to the untreated condition, and this effect was unequivocal for all strategies. Increasing the percentage of land treated improved the effectiveness of all fuel treatment strategies. The strategy based on road protection provided the highest performances for several wildfire exposure indicators. The methodology presented in this work can be applied to facilitate the design of fuel management programs and support policy decisions to address growing wildfire risk in the region. This work is one of the first applications of fire simulation modeling to evaluate fuel management effectiveness on wildfire risk mitigation in the Mediterranean areas.

1. Introduction

Wildfires represent a substantial threat to Southern European forests and ecosystems and every year cause extensive losses to anthropic infrastructures and values (Bassi et al., 2008; San-Miguel-Ayanz et al., 2013; Schmuck et al., 2014). Although the economic investments in fire suppression and fire crews training and preparation have progressively increased during the last decades, large wildfires still overwhelm suppression capabilities, spread for large distances and burn thousands of hectares (Costa Alcubierre et al., 2011; Alcasena et al., 2015b). Wildfire spread during these events represents the primary contributor to wildfire losses and area burned (Ganteaume and Jappiot, 2013; Salis et al., 2013). Mega-fires usually occur under extreme weather conditions, such as strong winds, low relative humidity and prolonged drought (Trigo et al., 2006; Viegas et al., 2009; Koutsias et al., 2012; Pausas and Fernandez-Munoz, 2012; Cardil et al., 2013, 2014; Salis et al., 2014).

Humans play a key role on influencing fire regimes, by means of anthropic fire ignitions, implementation of socio-economic policies and land uses, and fire suppression activities (Moreira et al., 2011). In the Mediterranean Basin, more than 90% of fire ignitions are human-caused and follow complex spatio-temporal patterns related to anthropic and biophysical variables (Koutsias et al., 2010; Lovreglio et al., 2012; Oliveira et al., 2012; Meddour-Sahar et al., 2013; Ager et al., 2014; Salis et al., 2015). In recent years, the increase and densification of anthropic activities and population in main towns, as well as in coastal zones,

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http://dx.doi.org/10.1016/j.foreco.2016.03.009
0378-1127/

has contributed to an increase in fire ignition sources in such areas (Martínez et al., 2009; Chas-Amil et al., 2013). In addition, rural exodus and land abandonment during the last decades prompted a rapid natural succession of vegetation in areas previously exploited for livestock and agro-forestry activities. These changes in land use brought about a large expansion in shrubby, thicket fuels on previously marginal and rural lands, as well as the development of understory vegetation and ladder fuels in previous timber production areas (Pausas, 2004; Bonet and Pausas, 2007; Ruiz-Mirazo et al., 2012). The result was a transition from mosaic-managed type landscapes to a high fuel load, continuous and highly hazardous vegetation complexes (Mazzoleni et al., 2004; Palahi et al., 2008; Fernandes et al., 2014). Furthermore, fire exclusion policies have also played a role on fuel load accumulation and the growing incidence of intense and large wildfires (Badia et al., 2002; Pinol et al., 2005; Xanthopoulos et al., 2006; Curt et al., 2013). Moreover, a substantial increase in fire suppression costs in the last decade has limited investments in fuel management and fire prevention (Calkin et al., 2005; Stephens and Ruth, 2005; Prestemon et al., 2008; Hand et al., 2014). For these reasons, fire managers and policy makers need to adopt the best compromise between fire control and fuel management approaches for the future, while considering that the complete exclusion of wildfires is not a feasible and reasonable strategy in the long term (Keane et al., 2008; Moritz et al., 2014). In the Mediterranean Basin, fire restoration and management are a challenging proposition since many houses and values intermingle with wilderness and unmanaged lands, and thus managing wildfires for fuel management poses unacceptable risks (Lampin-Maillet et al., 2010; Pellizzaro et al., 2012; Moritz et al., 2014). Fuel management strategies employ a combination of surface fuel loading, depth and continuity reduction treatments (e.g., prescribed burns and mastication), silvicultural practices to change tree crown structure (e.g., thinning and low-pruning), and the creation of infrastructures and safety areas to facilitate fire suppression activities (e.g., road networks and water points) (e.g.: Bovio, 2002; Leone and Signorile, 1997; Fernandes and Botelho, 2003; Xanthopoulos et al., 2006; Molina et al., 2011; Bovio and Ascoli, 2013; Zagas et al., 2013; Corona et al., 2015). Risk mitigation is strongly linked to landscape fuel management and may involve a range of primary targets, strategies and spatial patterns depending on fire management and protection objectives, land use laws, social and physical constraints, and budget (Parisien et al., 2007; Reinhardt et al., 2008; Ager et al., 2013; Hand et al., 2014; Corona et al., 2015; Valor et al., 2015). Designing feasible strategies is a complicated problem and a number of recent studies have explored appropriate spatial and temporal strategies and the effects of various constraints on their performance in reducing wildfire exposure and risk (Finney, 2001; Agee, 2002; Duguy et al., 2007; Finney et al., 2007; Wei et al., 2008; Ager et al., 2010; Elia et al., 2014; Chung, 2015; Vogler et al., 2015). Most studies examining fuel management strategies have applied probabilistic approaches based on fire spread simulators, and quantified the capabilities of fuel treatments in reducing losses from fires for specific targets as measured by burn probability and flame length. Such approach has been successfully implemented in many areas of the US and Canada (e.g.: Finney, 2001, 2006; Finney et al., 2007; Ager et al., 2007, 2010, 2013; Miller et al., 2008; Moghaddas et al., 2010; Liu et al., 2013; Scott et al., 2013), while for the Mediterranean Basin this methodology is still unexplored.

In Sardinia, new regional programs for rural development and fire management planning emphasize the crucial role of fire prevention by fuel and land management to reduce losses from wildfires under both current conditions and those expected in the future under climate change (Sardinia Regional Government, 2014a, 2014b, 2014c). As part of a larger effort to develop scientific basis for landscape fuel treatment programs in fire-prone Mediterranean ecosystems and in order to evaluate the effectiveness of competing fuel treatment strategies in reducing losses from wildfires, we applied wildfire simulation and geospatial modeling approach to test alternative strategies on a 68,000 ha study area located in North-east Sardinia, Italy. We defined three fuel treatment strategies and objectives, and simulated fuel-type-specific modifications in load and height for measured portions of the landscape. We then analyzed how these different strategies affected burn probability, wildfire intensity and size, and other aspects of wildfire exposure. The work is the first application of spatially explicit fire spread and behavior modeling in Sardinia, and one of the first in the Mediterranean area, to evaluate the potential effects of competing fuel treatment strategies on wildfire exposure and risk.

2. Material and methods

2.1. Study area

The study area is located in Northeastern Sardinia, Italy, and has nearly 68,000 ha of land (Fig. 1). About 20% of the study area is classified as European Site of Community Importance (EU 92/43/EEC Directive). The territory is mainly characterized by the granitic mountain complex of Monte Limbara, with orientation SW–NE, and by the Coghinas lake, the largest one of North Sardinia. The elevation of the study area ranges from about 45 m a.s.l. to the highest point of Punta Balistreri (about 1350 m a.s.l.). Overall, the area has a complex topography, and about 25% of the land is above 600 m a.s.l. (Fig. 1).

The climate is Mediterranean, with hot and dry summers and cold and wet winters, and intermediate conditions in spring and autumn. The average annual precipitation is about 650 mm in the plains, but peaks of more than 1000 mm are common at the highest elevations. In July, the average maximum and minimum temperatures range from 28.5 °C and 17.4 °C, while in January from 9.2 °C to 3.8 °C, with some relevant gradients moving from the plains to the top of the mountains (Chessa and Delitala, 1997; http://www.sar.sardegna.it/pubblicazioni/notetecniche/nota2/index.asp). Following the Pavari phytoclimatic classification (Arrigoni, 1968), the study area is mostly represented by Lauretum cold areas, and by Castanetum warm zones in north facing slopes and at elevation above 1000 m a.s.l..

The natural vegetation is mostly characterized by *Quercus ilex* and *Quercus suber* L. woods, as well as high and dense Mediterranean maquis. In the hilly and mountainous areas of Monte Limbara, the most representative shrub types are *Erica arborea* L. and *Arbutus unedo* L., while *Cistus monspeliensis* L. and low shrubs cover the south facing slopes and the most degraded areas. The conifer woods occupy limited areas, and are mainly represented by artificial plantations of *Pinus pinea* L., *Pinus pinaster* Aiton, and *Pinus nigra* ssp. *laricio* Poir. On the whole, shrublands and forests occupy about 46,000 ha of the study area, which corresponds to about 69% of the territory (Fig. 2). Anthropic areas cover approximately 850 ha of land, being the town and the industrial area of Tempio Pausania the most relevant anthropic zone of the study site. Fruit-bearing areas are mostly represented by sparse and family-farm vineyards and olive groves and cover about 2300 ha of land; these land types are largely concentrated in flat areas and nearby the town of Tempio Pausania. Grasslands and agricultural areas are mainly devoted to herbaceous and horticultural productions and characterize about 20% of the study area, particularly in the plains (Fig. 2).