# Creating fire-smart forests and landscapes

by Paulo M. FERNANDES

## Introduction

Land use mosaics and the intensity of biomass use in the Mediterranean Basin have constrained fire incidence in the past. Forests have expanded in the last decades and in parallel their management has generally decreased, increasing stand-level fuel accumulation and landscape-scale fuel connectivity. Contemporary fire management policies rely heavily on fire suppression and do not sufficiently address the root of the problem, i.e. the socio-economical and land management issues behind the inception and spread of fires. The effectiveness of fire fighting operations is greatly reduced when unfavourable weather conditions coincide with fuel accumulation (Figure 1). In fact, because successful fire suppression implies fuel build up, it can contribute to larger and more severe fires in the future.

It is now recognized that short-term and reactive fire control policies should be replaced by "longer-term policies aimed at acting on the structural causes of fires and integrating fire and forest management strategies" (EFI 2010). In order to support integrated fire management, a stronger research effort is required in regards to landscape-scale fire spread, mitigation of immediate fire effects (fire severity) in forest stands, and the resilience of different forest types in relation to variation in the fire regime. Climate change projections make these topics even more relevant, because the expected increase in fire danger will raise burned area and $CO_2$ emissions (THONICKE *et al.* 2010).

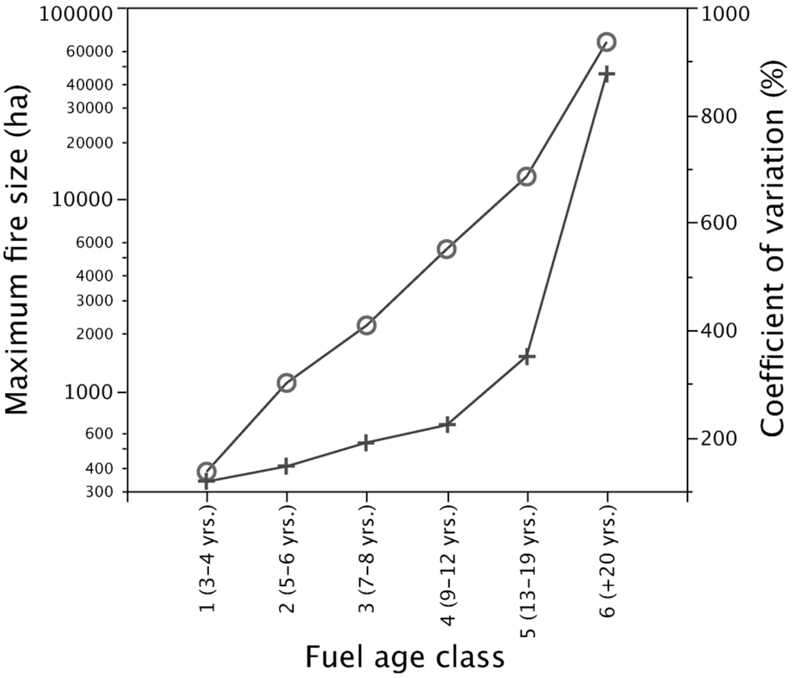

**Fig. 1:** Size of burn patches in Portugal (1998-2008) as a function of the fuel age mosaic: maximum observed (circles) and coefficient of variation (crosses). Drawn from data in FERNANDES *et al.* (2010a).

Mediterranean forests will adapt to climate change with difficulty and their protection from wildfire will be important, including large-scale fuel management through prescribed burning (PARRY *et al.* 2007).

Proactive forest management towards higher resistance to fire spread and increased fire resilience, i.e. the achievement of fire-smart forests and landscapes (HIRSCH *et al.* 2004), comprehends two complementary approaches, respectively the treatment of fuels in fire prone vegetation types and vegetation type conversion. This paper overviews the state of the art on these subjects as it relates to Mediterranean Europe.

## Goals, strategies and know-how

The ultimate goal of fire management is to modify the fire regime, which results from the interaction between ignitions and the fire environment, i.e. topography, weather and fuels. By modifying fuels, fire-smart forest management is ultimately expected to delay fire spread and expand the weather scenarios under which wildfire control is possible, hence leading to less area burned. An additional goal — often more relevant or realistic (REINHARDT *et al.* 2008) — is to increase tree resistance to fire and decrease fire severity, thus diminishing damage and increasing the ability to recover from the disturbance. Differentiation between fuel management strategies considers fuel isolation (fuel-breaks), fuel modification and fuel type conversion (PYNE *et al.* 1996). Fuel isolation and fuel modification can be viewed respectively as linear and area-wide options for treating fuels and presuppose different expectations, respectively fire containment and fire modification. Consequently, linear treatments will be of limited (or null) value if they fail to hinder fire spread, whereas area treatments will be beneficial as long as fire severity mitigation is apparent.

Current guidelines and practices to manage stands to decrease fire hazard — usually termed “preventive silviculture” — are quantitatively incipient. Some published recommendations even oppose empirical evidence and inference from fire behaviour models, especially in regards to stand density. Learning with wildfires, experimenting with fire or using simulation tools are the three basic approaches that are available to refine fire-smart prescriptions. However, the capacity to develop sound prescriptions remains limited: wildfire case studies are scarce and provide anecdotal data, fire experimentation involving modification of the tree canopy is practically non-existent, and fire modelling is not reliable enough, e.g. CRUZ & ALEXANDER (2010).

## Assessing the effectiveness of fuel treatments

The relative role of fuel and weather in shaping the fire regime differs by vegetation type. If the role of fuel in controlling wildfire incidence is minor then the rationale for investing in fuel management programs is weak. Weather is generally viewed as the prevailing driver of the high-intensity fire regimes that characterize Mediterranean environments (e.g. KEELEY & ZEDLER 2009). Fire frequency analysis for Portugal (FERNANDES *et al.* 2010a) indicates a relatively short fire-free interval (12-16 years) but fire hazard, the probability of reburn, grows exponentially with time since fire, as the aging of fuels results in fuel accumulation and higher flammability. Furthermore it seems that this time-dependency of fire incidence is only marginally affected by extreme weather, increasing the likelihood of effective fuel treatment performance under unfavourable weather scenarios. Fire size and maximum fire size tend respectively to be more variable and higher in older fuels (Fig. 1). Hence, the control of fuels over landscape fire spread occurs on a relatively short-term scale but is effective, which lends support to a prominent role of fuel treatments in fire management. The more fragmented and human-influenced landscape might be involved in explaining the more pronounced role of fuel in burn probability in comparison with other shrub-dominated Mediterranean regions.

Linear fuel treatments are the most common option in Mediterranean Europe, but their performance in the face of fire is uncertain. In their analysis of the 2003 wildfires in southern France, PERCHAT & RIGOLOT (2005) found out that most fuel breaks were crossed or transposed by high-intensity fire. Still, they note that headfire growth was delayed and that lateral (flank) fire spread was generally restrained. The width, placement and maintenance of fuel breaks, together with the potential for spotting and the resources available for fire fighting are critical factors in the success of a fuel management strategy based on isolation.

Fire-smart silviculture modifies the fire environment in ways that can frustrate the treatment objective (GRAHAM *et al.* 2004). Removing or modifying the fuels resulting from pruning and thinning is mandatory, or the decrease in crown fire potential will be outweighed by the increase in surface fire intensity. Although research in this topic is surprisingly scarce, raising the tree canopy and decreasing its density creates a drier and windier environment. In NW Spain, RUIZ (2007) measured a 2-3% absolute decrease in dead fuel moisture content when comparing unthinned (36 $m^2$ $ha^{-1}$) and thinned (22 $m^2$ $ha^{-1}$) *Pinus pinaster* stands.

Fire modelling allows simulation of fire characteristics for different fuel and stand management scenarios (e.g. CRUZ *et al.* 2008), as well as landscape-level analysis of fire-spread potential in response to variation in fuels and other factors (e.g. LOUREIRO *et al.* 2006). Expert knowledge can be analyzed to relate fire hazard with stand and fuel structure (GONZALES *et al.* 2007). However, evidence of differences in fire behaviour and severity between alternative fuel treatments or in treated versus untreated stands can be obtained only by actually observing fires and their effects. Although valuable — e.g. MCARTHUR (1962) reported a decrease by a factor of 3 in fire spread rate from unpruned *Pinus radiata* to pruned *P. pinaster* stands — the conclusions that can be drawn from wildfire data are usually limited in scope. Sound guidelines for treatments are more likely to be inferred from fire-resistant forest stands, i.e. where fire-induced tree mortality or fire severity is mitigated to some degree. Abundant documentation exists on the interaction between fire severity and stand structure in North-American continental and mediterranean conifer forests (e.g. AGEE & SKINNER 2005), and similar patterns seem to occur in the Iberian Peninsula, where mature and uneven-aged *Pinus nigra* (FULÉ *et al.* 2008) and *P. pinaster* (VEGA 2000) stands persist under a regime of low to moderate fire severity. Fire-resilient *P. pinaster* patches in northern Portugal (Picture 1) are open, vertically discontinuous and coincide with frequent low-intensity fires (VEGA *et al.* 2010).

Experimental studies of fire behaviour and effects in relation to fuel treatments have been extremely scarce worldwide. In SW Australia, GOULD *et al.* (2007) related fire behaviour in eucalypt forest with time since prescribed burning. In Portugal, a drastic change in fire behaviour — from crowning to relatively mild surface fire — was observed


**Picture 1:**
Fire-resistant *Pinus pinaster* stand near Murça, NE Portugal. Tree density = 250 $ha^{-1}$, basal area = 11 $m^2$ $ha^{-1}$ and median fire return interval = 6 years
*Photo P.F.*

**Picture 2:**
Fire self-extinction
in a *Betula alba* stand,
Mezio, NW Portugal.
*Photo P.F.*

when an experimental summer fire moved from an untreated 28-year old stand to areas that had been prescribed burnt 2-3 years before (Fernandes *et al.* 2004). Differences in fire characteristics between 13- and 28-year old fuels could not be proven, but in a related study (Fernandes 2009a) surface fire intensity was lower in prescribed burnt plots for at least 10 years after treatment.

## Assessing how different forest types burn and recover from fire

Forests that differ in their specific composition can represent distinct fire potentials, due to differences in the nature, quantity and arrangement of fuels, which provides the rationale for cover type conversion. Conventional wisdom assumes that some forest types, namely deciduous broadleaves, are effective at modifying fire behaviour and disrupting landscape fire spread. Fire modelling (Fernandes 2009b) and fire selectivity (Moreira *et al.* 2009) studies support such hypothesis. In NE Spain, Diaz-Delgado *et al.* (2004) report less fire incidence from pine to evergreen broadleaved to deciduous broadleaved forests, and Gonzales *et al.* (2006) found that hardwoods (*Quercus robur, Q. ilex*) and short-needled mountain pines were less fire prone than the more flammable pine species. The fire behaviour gradient corresponding to the transition of one vegetation type to another, e.g. from shrubland to *Quercus rotundifolia* (Azevedo *et al.* 2009), can be modelled by taking into account the spatial variation in fuels and stand structure. Local weather (fuel moisture, wind speed) and the fuel-complex are both affected by stand structure. Consequently, stand characteristics can minimize or offset the cover type effect, as in the simulation study of Fernandes (2009b), where the range in fire hazard was similar between and within forest types.

The fire severity implications of changes in cover type are expected to correlate with fire incidence but have been poorly quantified. In northern Portugal, Fernandes *et al.* (2010b) compared fire severity between adjacent stands of *P. pinaster* and of other species (deciduous and evergreen broadleaves and short-needled conifers). Fire intensity was highest in *P. pinaster*, followed by deciduous broadleaved and short-needled conifer forest. In addition to cover type, fire severity was explained by stand characteristics (height, density, basal area), terrain aspect, fire spread pattern and distance to the edge between *P. pinaster* and the contiguous cover type. A faster decline in fire severity was observed in deciduous broadleaves (Picture 2), and fire severity tended to decrease with stand maturity and in moister aspects. Implicit in these results is the fact that different cover types will not be different just in their fuel complexes. Simultaneous measurements of micrometeorological variables and fuel moisture contents should highlight weather-related differences in the fire environment between forest types, provided that the stands are contiguous and do not differ in aspect and slope.

Fire resilience is determined by the interaction between fire severity and species traits related with post fire response. Consequently, research on post fire tree mortality patterns is an important supplement to fire severity studies. The description and prediction of fire-induced mortality to southern Europe tree species has recently gained momentum, covering the entire fire severity range and addressing both conifers (*P. pinaster, P. nigra*) and broadleaves (*Quercus* spp., *Castanea sativa, Eucalyptus globulus*) (Moreira *et al.* 2007, Fernandes *et al.* 2008, Catry *et al.* 2010, Vega *et al.* 2010). The most fire-resilient types are those that recover quickly from high-intensity fire — species able to sprout from the crown, i.e. *Quercus suber* (Picture 3) and *Pinus canariensis* — and those associated to low flammability environments (deciduous broadleaves and mountain conifers), provided that their fire-resistance traits (namely bark thickness) are sufficiently developed to assure tree survival.

## Conclusion

Fire policies in Mediterranean countries are centred on fire suppression, which makes them unsustainable and often counterproductive. Fuel management, including the planned use of fire, deserves a more prominent role in fire management. Furthermore, and as the Mediterranean environment becomes more fire prone, the management of unplanned fires will have to be considered, especially in more remote areas, and both as a fuel treatment and an ecological process.

Fire-smart landscapes are obtained by area-wide fuel treatments and by fuel type conversion, rather than by fuel isolation. The spatial features of fuel management are critical, as random patterns can locally mitigate the effects of wildfire but have no impact on its growth. Proactive management should concentrate on expanding (i) less flammable forest types, and (ii) vegetation types that are resilient regardless of flammability, the later being the preferred option in a climate change context (Stephens *et al.* 2010). Both will require minimal treatment, in contrast to highly flammable forest plantations in fire-prone regions where costly fuel treatments are mandatory. However, it is important to note that climate change will likely reduce the prospects for type conversion into more mesic forests, and will favour open dry forests, where resistance and resilience to fire can be promoted through relatively undemanding fuel modifications.

**P. M.F.**

**Picture 3:**
Flammable but fire-resilient: *Quercus suber* woodland 11 years post fire in Romeu, NE Portugal.
*Photo P.F.*

## References

Agee, J., & C. Skinner. 2005. Basic principles of forest fuel reduction treatments. *Forest Ecology and Management,* 211, 83-96.

Azevedo, J., A. Possacos, R. Dias, A. Saraiva, C. Loureiro, & P. Fernandes. 2009. Survival of holm oak woodlands in fire prone landscapes in north-eastern Portugal. In Proc. Latin American IALE Conference, Campos do Jordão, Brasil.

Catry, F., F. Rego, F. Moreira, P. Fernandes, & J. Pausas. 2010. Post-fire tree mortality in mixed forests of central Portugal. *Forest Ecology and Management* (in press).

Cruz, M., & M. Alexander. 2010. Assessing crown fire potential in coniferous forests of western North America: a critique of current approaches and recent simulation studies. *International Journal of Wildland Fire,* 19, 377–398.

Cruz, M., M. Alexander, & P. Fernandes. 2008. Development of a model system to predict wildfire behaviour in pine plantations. *Australian Forestry,* 71, 113-121.

EFI. 2010. A Mediterranean Forest Research Agenda – MFRA. European Forest Institute, Joensuu.

Fernandes, P. 2009a. Examining fuel treatment longevity through experimental and simulated surface fire behaviour: a maritime pine case study. *Canadian Journal of Forest Research,* 39, 2529-2535.

Fernandes, P. 2009b. Combining forest structure data and fuel modelling to assess fire hazard in Portugal. *Annals of Forest Science,* 66, 415p1-415p9.

Fernandes, P., C. Loureiro, & H. Botelho. 2004. Fire behaviour and severity in a maritime pine stand under differing fuel conditions. *Annals of Forest Science,* 61, 537-544.

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Fernandes, P., J. Vega, E. Jiménez, & E. Rigolot. 2008. Fire resistance of European pines. *Forest Ecology and Management,* 256, 246-255.

Fernandes, P., C. Loureiro, M. Magalhães & P. Ferreira. 2010a. Testing the fire paradox: is fire incidence in Portugal affected by fuel age? In Proc. IUFRO Landscape Ecology International Conference, Bragança, Portugal (in press).

Fernandes, P., A. Luz & C. Loureiro. 2010b. Changes in wildfire severity from maritime pine woodland to contiguous forest types in the mountains of northwestern Portugal. *Forest Ecology and Management*, 260, 883-892.

Fulé, P., M. Ribas, E. Gutiérrez, R. Vallejo & M. Kaye. 2008. Forest structure and fire history in an old *Pinus nigra* forest, eastern Spain. *Forest Ecology and Management,* 255, 1234-1242.

González, J., M. Palahi, A. Trasobares & T. Pukalla. 2006. A fire probability model for forest stands in Catalonia (north-east Spain). *Annals of Forest Science,* 63, 169-176.

González, J., O. Kolehmainen & T. Pukalla. 2007. Using expert knowledge to model forest stand vulnerability to fire. *Computers and Electronics in Agriculture,* 55, 107-114.

Gould, J., L. McCaw, P. Cheney, P. Ellis, I. Knight & A. Sullivan. 2007. Project Vesta – Fire in dry eucalypt forest: fuel structure, fuel dynamics and fire behaviour. Ensis-CSIRO and Department of Environment and Conservation, Canberra, ACT, and Perth, WA.

Graham, R., S. McCaffrey & T. Jain (tech. eds.). 2004. Science Basis for Changing Forest Structure to Modify Wildfire Behavior and Severity. Gen. Tech. Rep. RMRS-GTR-120. Fort Collins: USDA Forest Service.

Hirsch, K., V. Kafka & B. Todd. 2004. Using forest management techniques to alter forest fuels and reduce wildfire size: an exploratory analysis. Pp. 175–184 In R.T. Engstrom, K.E.M. Galley & W.J. de Groot (eds.). Proceedings of the 22nd Tall Timbers Fire Ecology Conference: Fire in Temperate, Boreal, and Montane Ecosystems. Tall Timbers Research Station, Tallahassee, FL.

Keeley, J. & P. Zedler. 2009. Large, high-intensity fire events in southern California shrublands: debunking the fine-grain age patch model. *Ecological Applications,* 19, 69-94.

Loureiro, C., P. Fernandes, H. Botelho & P. Mateus. 2006. A simulation-based test of a landscape fuel management project in the Marão range of northern Portugal. In D.X. Viegas (ed.). Proc. 5th Int. Conf. Forest Fire Research, Elsevier B.V., Amsterdam. CD-ROM.

McArthur, A. 1962. Fire behaviour characteristics of the Longford fire. Leaflet No. 91, O.D.C. 43, Forestry and Timber Bureau, Department of National Development, Commonwealth of Austrália.

Moreira, F., L. Duarte, F. Catry & V. Acácio. 2007. Cork extraction as a key factor determining postfire cork oak survival in a mountain region of southern Portugal. *Forest Ecology and Management*, 253, 30-37.

Moreira, F., P. Vaz, F. Catry & J. Silva. 2009. Regional variations in wildfire susceptibility of landcover types in Portugal: implications for landscape management to minimize fire hazard. *International Journal of Wildland Fire,* 18, 563–574.

Parry, M., O. Canziani, J. Palutikof, P. van der Linden & C. Hanson. (eds). 2007. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Perchat, S. & E. Rigolot. 2005. Comportement au feu et utilisation par les forces de lutte des coupures de combustible touches par les grands incendies de la saison 2003. Morières: Ed. De la Cardère Morières.

Pyne, S., P. Andrews & R. Laven. 1996. Introduction to Wildland Fire. 2nd ed. John Wiley & Sons, New York.

Reinhardt, E., R. Kean, D. Calkin & J. Cohen. 2008. Objectives and considerations for wildland fuel treatment in forested ecosystems of the interior western United States. *Forest Ecology and Management,* 256, 1997-2006.

Ruiz, A. 2007. Efecto de las claras sobre la humedad de los combustibles muertos. In Proc. Wildfire 2007 - 4th International Wildland Fire Conference, 13-17 May, Seville, Spain.

Thonicke, K., A. Rammig & M. Gumpenberger. 2010. Changes in managed fires and wildfires under climate and land use change and the role of prescribed burning to reduce fire hazard under future climate conditions. Deliverable D4.2-1c / D4.2-4 of the Integrated project “Fire Paradox”, Project no. FP6-018505, European Commission.

Vega, J. 2000. Resistencia vegetativa ante el fuego a través de la historia de los incendios. Pp. 4.66-4.85 In La Defensa Contra Incendios Forestales: Fundamentos y Experiencias, McGraw-Hill, Madrid.

Vega, J., P. Fernandes, G. Defossé, M. Conedera, S. Bravo, N. Cassagne, J-L. Dupuy, M. Fernandes, E. Jiménez, L. Lucini, M., Leiva, E. Rigolot, C. Loureiro, C. Kunst, J-C. Valette, G. Pezzatti, H. Botelho, D. Portier, J. Pérez, P. Petit, R. Ledesma, J. Maréchal, J. Godoy, F. Pimont & V. Navarrete. 2010. Tree resistance to fire: final results. Deliverable D3.2-6 of the Integrated project “Fire Paradox”, Project no. FP6-018505, European Commission.

Stephens, S., C. Millar & B. Collins. 2010. Operational approaches to managing forests of the future in Mediterranean regions within a context of changing climates. *Environmental Research Letters*, 5, 024003.