Designing landscape fuel treatments to mitigate impacts from large wildfires in Greece

Palaiologou P.[1*], Kalabokidis K.[2] and Ager A.[3]

[1] USDA Forest Service International Visitor Program, Oregon, USA.

[2] University of the Aegean, Department of Geography, University Hill, 81100 Mytilene, Lesvos Island, Greece.

[3] USDA Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory, 5775 US Highway 10W, Missoula MT 59808, USA.

*corresponding author:

e-mail: palaiologou.p@aegean.gr

Abstract.

The growing problem of catastrophic wildfires in Greece advocates a need to re-examine wildfire risk governance policies. Current fire protection planning is either non-existent or narrowly focused on specific parcels of land, compared to strategic, landscape approaches used in other fire prone regions of the globe. Specifically, fuel breaks are concentrated between developed and wildland areas, while ignoring the larger wildfire problem on the surrounding lands. For instance, about 20% of Lesvos Island, Greece, is covered by dense conifer forests, an important ecological, cultural and aesthetic resource, that are capable of spawning large wildfires. In this study, we used wildfire simulation methods to build a network of fire transmission among forests, developed areas and other land cover types (shrublands, olive cultivation and abandoned lands), and identify source-sink relationships. We then used spatial optimization methods to locate fuel treatments in specific land types to reduce large fire growth. The results demonstrated improved methodologies for fuel management planning that consider the connectivity of wildfire among different land types. They also illustrated that wildfire risk to individual communities is a function of land uses well beyond the current fuel break networks, thus contributing to a larger framework for building fire resilient landscapes and fire adapted communities.

Keywords: Fuel treatment optimization, Cross-boundary risk transmission, Minimum Travel Time simulations, Wildland-urban interface, FlamMap.

1. Introduction

The challenge of confronting large wildfire events in the future will require the adoption of holistic approaches, targeting in prevention and reduction of spread rates and intensity by modifying the fuel patterns at a landscape level. Managing the condition of the landscape and the spatial fuel structure is the only option humans have for pre-fire control (weather and topography cannot be changed), slowing overall fire growth and improving fire suppression. Successful application and experiences from North America and South Europe proved that investing more in prevention and pre-fire planning is the only way to deal with the upcoming challenges that emerge from global warming and the land abandonment effect on fuel patterns. Countries like Greece implement a minimalistic application of fuel treatments (limited in extent, size and efficiency) that require in addition "active" fire suppression for benefits to be realized (Finney, 2007). This approach is opposed to the "passive" fire management (Gill and Bradstock, 1998), where canopy and fuel treatments are combined to achieve a decrease in overall fire hazard, with treatments comparable to the size of the fire (Finney, 2001). The temporal scale of treatment effectiveness is usually ignored and the strategic allocation is narrowed only to fuel breaks without considering the dominant travel paths of wildfires in the landscape. Several alternative fuel treatment methods exist that can be applied as prescriptions in pre-selected units in the landscape, including silvicultural tending with mechanical means (e.g. thinning from below, pruning), prescribed burning and grazing for reducing surface and ladder fuels. Studies showed that reduction in large fire growth is obtainable through the collective effect of many units occurring on the landscape (Finney, 2001). Random treatment patterns are inefficient in changing large fire growth rates compared to strategic designs, because they permit fire to easily move laterally around treatments, unless large portions of the landscape are treated (Hayes *et al*., 2004). In this study, we applied a combination of the Minimum Travel Time (MTT) algorithm (Finney, 2002) and the Treatment Optimization Model (TOM) of FlamMap 5 software (Finney, 2006) to locate the optimum areas to apply fuel treatments on conifer stands in a heavily forested high risk area of Lesvos Island, Greece. The main research scenario was to apply fuel treatments to reduce wildfire spread rates and intensity on the 20% of the study area, which includes the removal of small trees and saplings by thinning from below, prescribed burnings that can clean the understory to achieve the change of fuel model and use of silvicultural tending (thinning from below, pruning) to increase tree canopy base height.

2. Materials and Methods

2.1. Study area

This study is focused in the central part of Lesvos Island, Greece, extending on an area of 47,000 ha that is covered by the largest continued pine (Pinus spp.) forest complex of all the Aegean Sea islands relatively to the island's size (21,000 ha). An important part is cultivated with olive trees (13,000 ha) and permanent crops (3,100 ha), with the remaining covered with grasslands (2,500 ha), chaparral (2,100 ha), shrubs (2,000 ha) and broadleaved trees (1,700 ha). Significant parts of the island face land abandonment with the subsequent reforestation, and since forests are mostly unmanaged and privately owned, no fuel management exists on these lands. Approximately 300 fire events have been recorded since 1974, resulting in about 6,000 ha of burned area. The largest fire ever recorded occurred in 1994 and burned 2,600 ha, followed by 1,500 ha in 1977, 700 ha in 1992 and 300 ha in 1984. The main forested complex was divided into three study sectors: north, central and south (Figure 1-A). Wildfires and human related activities such as grazing, resin collection, infrastructure constructions and farming influenced the development and conditions of each forest. Several field samplings were conducted to measure and estimate tree height, diameter at breast height (DBH), canopy base height (CBH) and crown bulk density (CBD), along with several other surface and canopy stand level attributes (Palaiologou *et al*., 2013). The north sector had one forest (Vouleri-Koukos) with 10 sampling sites. East and west of this forest, olive plantations are dominant, while at north, grasslands and shrubs prevail. The average conifer height was 10.6 m with 4.2 m CBH and moderate DBH (28.4 cm). The number of trees was high on both overstory and understory (1034 and 733 trees/ha respectively). Average canopy cover was 59% and over 90% of all recorded trees were conifers. Litter layer was thin (4 cm) and grazed, with dead fuel loadings less than 6.72 tonne/ha. Two forests comprise the central sector (Paspalas- Megali Limni and Axladeri). The first forest is located on a topographic smooth area dominated by young conifers mixed with chaparral and shrubs, resulted from repeated wildfires (1984 and 1992). Samplings on 10 sites revealed that the average tree height was 11 m with 5m CBH, forming stands with 60% canopy cover and low DBH (23.7 cm). A high number of trees were recorded on the overstory but with fewer on the understory (1,077 and 533 trees/ha, respectively). Litter loadings were 8.96 tonne/ha with 10 cm depth on average. The forest of Axladeri is located on the east side of the largest island's gulf of Kalloni, spanning on elevations from 40 to 350 m. Sampling on nine sites revealed the existence of either single story mature or young conifer stands. A moderate average number of trees were recorded on the overstory (790 trees/ha), with moderate on the understory (584 trees/ha). The average tree height was 11 m with 5 m CBH, 57% canopy cover and 28 cm DBH. Litter loadings were 5.82 tonne/ha with 4 cm depth on average, comprised mainly of needles and small shrubs. Forests on the south sector are comprised of higher elevation mature conifer stands (400-800 m), forming multistory mature stands with regeneration under canopy openings. Eight samplings were performed in Olympus-Ampeliko forest stands, with average tree height 13 m with 5.6 m CBH, 35 cm DBH and 58% canopy cover. Several trees on the most fertile soils on higher elevation sites had a DBH greater than 100 cm. The average litter loadings were high (18.83 tonne/ha) with 12 cm depth. Rogada forest is comprised of a mixture of mature single or multi story conifer stands and farming areas. Samplings were performed in eight sites, with a high average tree height and CBH (14.3 and 6.1 m), 35 cm DBH and 58% canopy cover. The number of trees is moderate on both overstory and understory (633 and 469 trees/ha respectively). Litter loadings were 8.51 tonne/ha with 5.5 cm depth on average. The last area on the south sector is the Vrisa-Vatera forest that extends until the coastline. Field samplings were performed on seven sites, either on young or mature multistory stands comprised of conifer trees, oak (*Quercus macrolepis*) and *Quercus coccifera*. The average tree height was 13 m with 5 m CBH, 33 cm DBH and 64% canopy cover. Litter loadings were 6.51 tonne/ha with 8 cm depth on average. This forest receives pressure from the urban development and touristic activities of the area, resulting in more than 40 fire incidents during the past 40 years but with low burned area for each incident (< 10 ha and only one with 100 ha). Finally, the southeast of the study area is dominated by a regenerated conifer forest resulted from the large fire of 1994. More than 30 field samplings were performed in sites with elevation from 450 to 810 m. On the north, two discrete large areas covered with chestnut trees and chaparral dominate the landscape, while on the west and south olive cultivations prevail. The average conifer tree height was 5.3 m with 2 m CBH, 9.2 cm DBH and 40% canopy cover. The average number of trees was 1,480 trees/ha, with a low of 400 and a high of 7,440 trees/ha. Young conifers are usually mixed with oak, chaparral, small shrubs and *Quercus coccifera*.

2.2. Methods

To estimate the fire behavior characteristics, we used wildfire simulations performed with the MTT algorithm. MTT computes the fastest travel routes of a wildfire in the landscape and suggests (but not applies) initial places for optimal placement of fuel treatments for delaying fire growth through the TOM. TOM requires a description of the current landscape situation with spatial raster data, called LCP, depicting information about topography, surface and canopy fuels. The required inputs for the study area were created on previous work (Palaiologou *et al*., 2013). The next most important input is the ideal landscape which represents post-treatment conditions, with treatments occurring wherever they are possible (not just desired). It is not the areas that will be treated, only the area that can be treated (and the fire behavior effects of those treatments) for every vegetated cell. In Table 1, information about the proposed treatments for each conifer stand type can be found, while in Figure 1-B, the treated pixels of canopy characteristics for the ideal LCP can be seen. For sparse conifer stands, the goal was to change the fuel model (FM) to TU1, reduce canopy cover and CBD for trees less than 5 m height, and increase CBH for trees >5 m height. Canopy treatments can extend to 1,300 ha out of the 4,250 ha, i.e. 30.5%. For dense conifer stands, the goal was to change FM to TL1, reduce CBD and canopy cover by 50% for areas with CBD values >0.2 kg/m^3, and increase low CBH sites to 4.4 m for areas with CBD >0.2 kg/m^3. Canopy treatments can extend to 8,300 ha out of the 24,900 ha, i.e. 33.3%. Finally, for young conifer and regeneration stands, the goal was to identify

Table 1. Proposed fuel treatments. Numbers in parenthesis denotes the current average values of each variable. N/t denotes that no treatments were proposed.

Vegetation	Fuel Model	Canopy Cover (CC - %)	CBD (kg/m^3)	Height (m)	CBH (m)
Sparse Conifer	TU1	If Height <5 m, reduce by 50% (**37.9**)	If Height <5 m, reduce by 50% (**0.16**)	n/t (**8.34**)	If <3.3 m and height > 5m, set to 3.3 m (**3.79**)
Young Conifer / Regeneration	TU4	If >50% reduce by 50% (**41.8**)	If CC >50%, reduce by 50% (**0.01**)	n/t (**5.05**)	If CC >50%, increase to 2 m (**1.04**)
Dense Conifer	TL1	If CBD >0.2, reduce by 50% (**50.3**)	If >0.2, reduce by 50% (**0.2**)	n/t (**10.7**)	If CBD >0.2 and < 4.4 m, increase to 4.4 m (**4.43**)

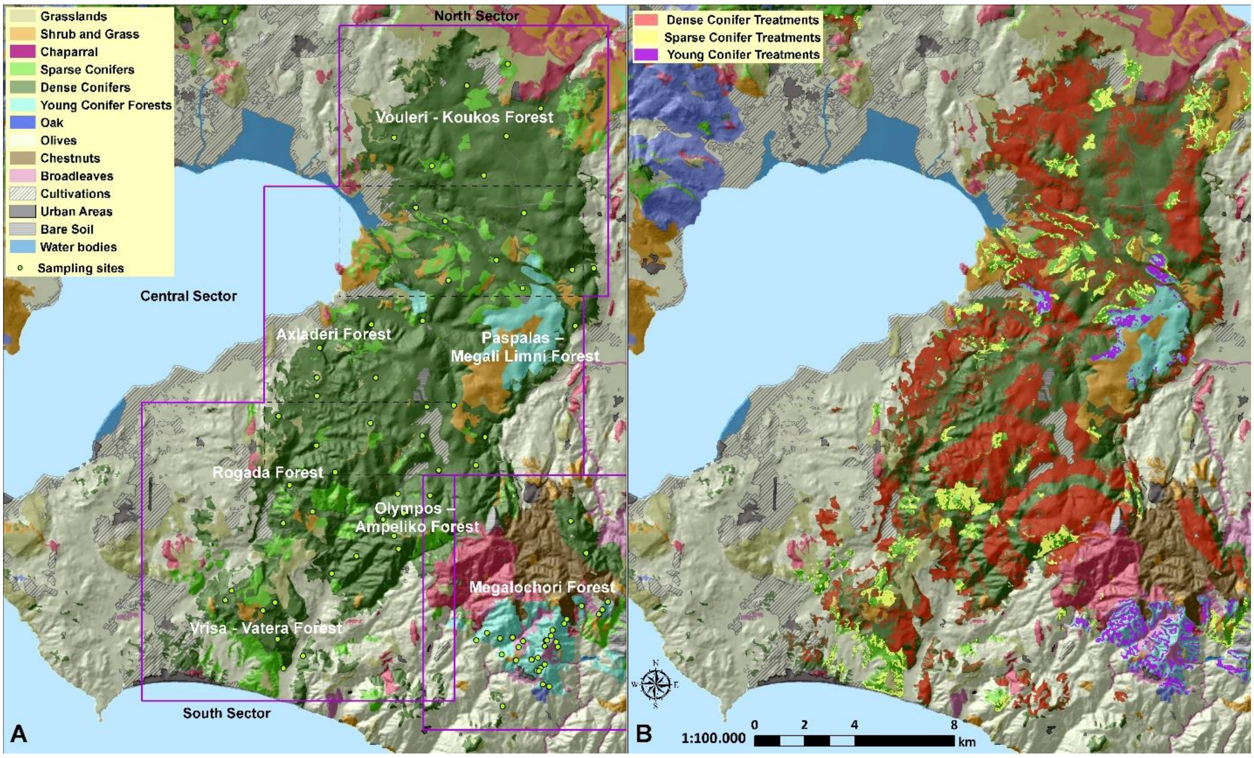

Figure 1. (A) Land cover types and forests of the study area and (B) modifications of canopy cover characteristics for generating the ideal landscape on dense, sparse and young conifer forests (red, yellow and purple areas, respectively)

areas with high canopy cover (>50%) and reduce it, along with CBD, by 50%, while increasing CBH to 2 m. Canopy treatments can extend to 630 ha out of the 1,900 ha, i.e. 33.2%.Weather inputs were derived from a Remote Automatic Weather Station (RAWS) installed on the south part of the study area (Palaiologou *et al*., 2011), setting NE as the dominant wind direction with 35 miles per hour wind speed for TOM calculations, using the WindNinja algorithm to compute spatial data for wind vectors and speed. Conditional period dates were set from the weather conditions occurring before and after a recent problem fire of 16 July 2014 in the north part of the study area. Fuel moisture was computed from the 10-hr sensor of RAWS as the average of the 06:00-21:00 time period of the conditional period dates (base values: 1-hr=5%, 10-hr=6%, 100-hr=7%). Each fuel model was set to be fuel moisture class specific based on the sunlight exposure; i.e. grass/shrub FM with no overstory had a reduction of 2% for each dead fuel moisture class (live moistures were set as LH=30%, LW=60%), chaparral FM was the same as base values and for timber FM we added 1% at each dead fuel moisture class (LH=60%, LW=90%). Foliar moisture content was set as 90%, while crown fires were estimated using the Scott and Reinhardt (2001) method. Stochastic fire simulations of 10,000 ignitions on both base and ideal landscapes were performed with FConstMTT version of MTT for three weather scenarios (300 min duration with 48 km/h from NE (70%), NW (20%) and SW (10%), estimating the differences of burn probabilities and conditional flame length between the two landscapes. Transmitted wildfire exposure was calculated by intersection of fire perimeters and ignition locations with the land cover layer (Ager *et al*., 2015, Ager *et al*., 2012). A networks graph was created comprised of nodes and edges, corresponding to land cover types and fire transmission, respectively.

3. Results

Simulation results revealed that the 19.7% of all fires burned inside dense conifer forests and received most fire from self-burning ignitions (33.8%), i.e. ignited and burn within its own boundaries, followed by olives (31.8%), grasslands (9.1%), chaparral (6.2%), sparse conifer forests (5.4%) and shrub/grass (5.1%) (Figure 2). Sparse conifer forests receive the 4.6% of all fires, most of which comes from dense conifers (25.5%), olives (25.1%), self-burning (11.6%), grasslands (11.2%), chaparral (10.2%), shrub/grass (7.8%) and cultivations (6.2%) (Figure 2). Finally, young conifer forests receive the 3.1% of all fires, with 30.8% self-burning, followed by dense conifers (17.4%), olives (16%), chaparral (13.8%) and shrub/grass (9.9%). For other land cover types, most fire activity occurs inside olive cultivations (42.7%), cultivations (9.9%) and grasslands (8.1%) (Figure 2). Red areas in Figure 3 show the results from TOM simulations, highlighting those areas inside conifer forests where both canopy and surface treatments can reduce wildfire activity (areas with only surface treatments, i.e. fuel model modification, were excluded). The proposed treatment areas span in 21,000 ha, with 16,500 ha located inside dense, 2,700 ha inside sparse and 1,800 ha inside young conifer forests. On the north and east parts of Vouleri-Koukos forest, we found the largest and most continuous treatments sites. Olympus-Ampeliko forest has also large candidate parts for fuel treatments.

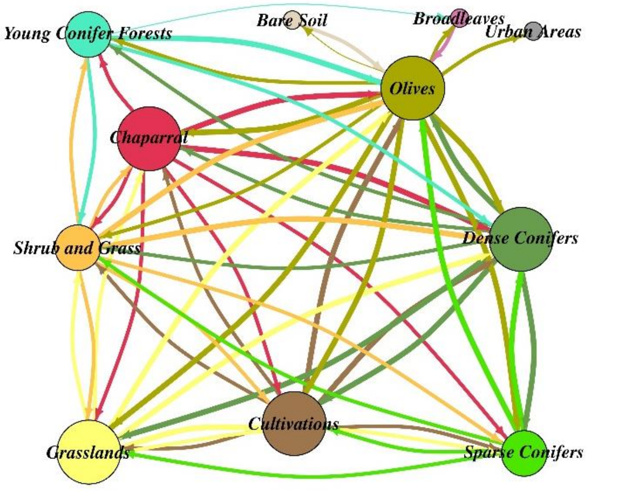

Figure 2. Wildfire transmission network among the land cover types. Network edges represent wildfire transmitted from one land tenure to another, as shown by the arrow and colored by its source. The size of each node corresponds to the amount of fire transmitted and received from that node.

Smaller treatment units can be established inside the Axladeri and Vrisa-Vatera forest, while the conifer forest on the east of chestnut forest in Megalochori forest has also a great potential for successful fuel treatment application.

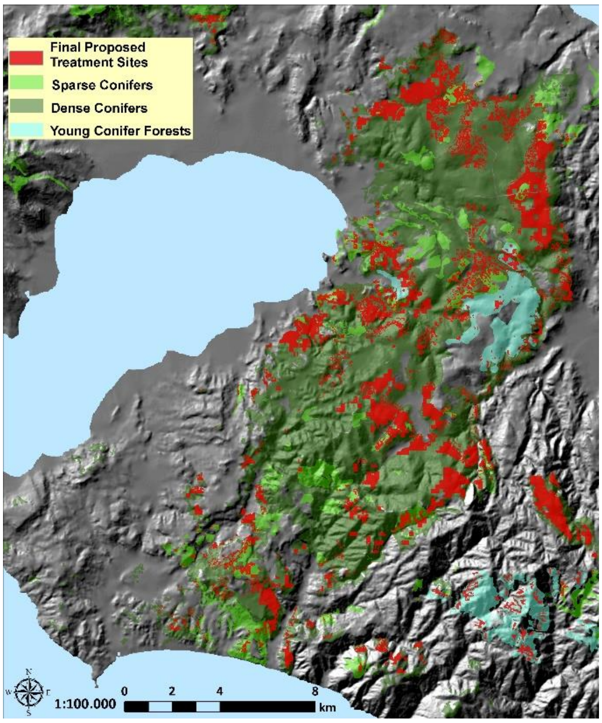

Figure 3. Optimum canopy and surface treatment areas for wildfire behavior reduction, as calculated with TOM.

Finally, in Figure 4-A the decrease in burn probability (BP) was greater in the south part of the study area and in parts of Olympus-Ampeliko and Axladeri forests, while conditional flame length (CFL) reduction was moderate for the most part of dense conifer forests and greater in parts of Olympus-Ampeliko and Vrisa-Vatera forests. Sparse conifer forests had an average reduction of 0.006 BP and 1.17 m CFL, dense conifer forests 0.005 BP and 1.47 m CFL and young conifer forests 0.002 BP and 0.08 m CFL.

4. Discussion / Conclusions

This study introduces a well-documented and tested approach for fuel reduction planning for Greek forests. Applied methods can be used to design alternative treatment plans and compare their ability to reduce fire severity relative to untreated forest. Results from different scenarios can vary substantially, and we can compare them to estimate the required size of treatment units to effectively reduce fire behavior and allow firefighter access for defense of Wildland-Urban Interface residences. The use of spatial data is essential to create maps that can help managers to decide where the proposed sites have not imposed constrains (e.g. protected lands) and reflect local objectives or restrictions on activities. The main priority of this study was to locate treatment areas that can protect the forest resources from future wildfires and not urban areas. Concluding, the areas we identified in the landscape significantly reduce wildfire behavior.

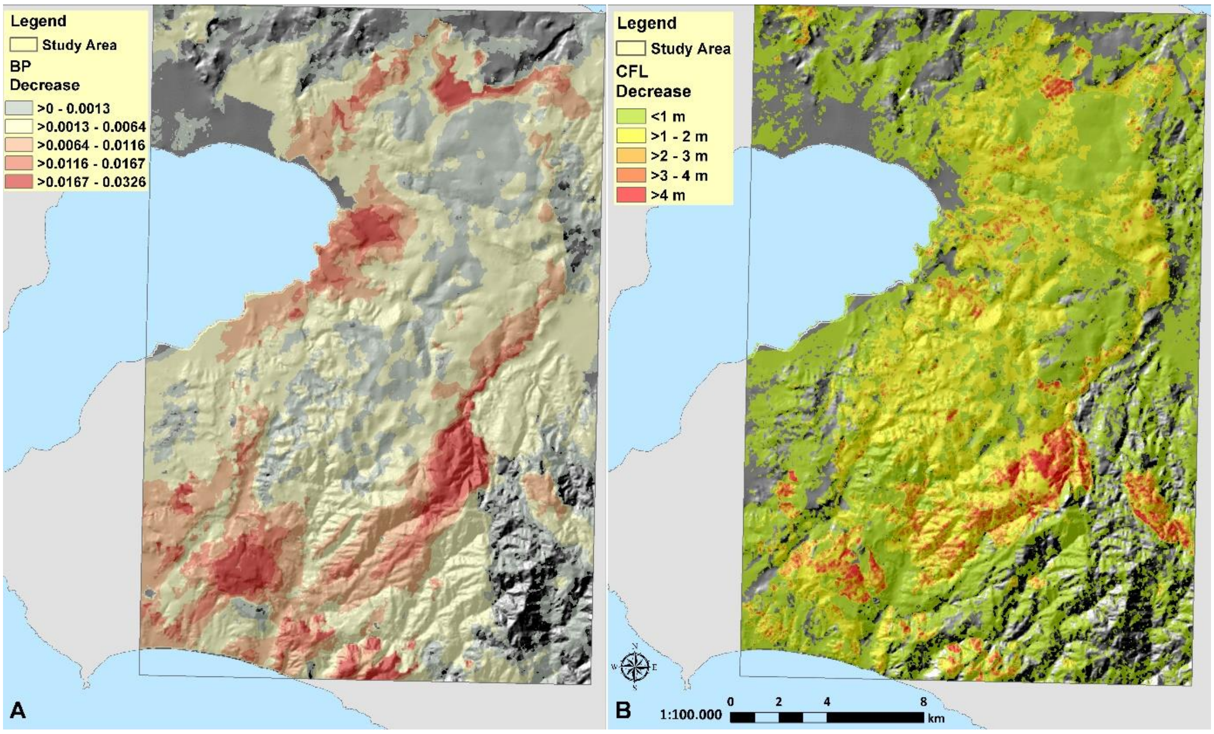

Figure 4. Decrease of (A) burn probability (BP) and (B) conditional flame length (CFL), as calculated by stochastic fire simulations with MTT.

References

AGER, A. A., BARROS, A. & DAY, M. A. 2015. Understanding the transmission of wildfire risk on a fire prone landscape: A case study from Central Oregon. *Geophysical Research Abstracts*, 17**,** EGU2015-15128.

AGER, A. A., FINNEY, M. A. & VAILLANT, N. M. 2012. Analyzing the spatial transmission of wildfire risk from large fires. *In:* SPANO, D., BACCIU, V., SALIS, M. & SIRCA, C. (eds.) *Modelling fire behaviour and risk.* Nuova StampColor.

FINNEY, M. A. 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. *Forest Science*, 47**,** 219-228.

FINNEY, M. A. 2002. Fire growth using minimum travel time methods. *Canadian Journal of Forest Research,* 32**,** 1420-1424.

FINNEY, M. A. 2006. An overview of FlamMap fire modeling capabilities. *In:* ANDREWS, P. L. & BUTLER, B. W., eds. Fuels Management-How to Measure Success. Proceedings RMRS-P-41, 28–30 March 2006 Fort Collins, CO. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station, 213-220.

FINNEY, M. A. 2007. A computational method for optimizing fuel treatment location. *International Journal of Wildland Fire,* 16**,** 702-711.

GILL, A. & BRADSTOCK, R. Prescribed burning: patterns and strategies. Proceedings of the 13th Conference on Fire and Forest Meteorology, 1998. 3-6.

HAYES, J. L., AGER, A. A. & BARBOUR, R. J. (eds.) 2004. *Methods for integrated modeling of landscape change: Interior Northwest Landscape Analysis System. General Technical Report PNW-GTR-610,* Portland, OR: USDA Forest Service, Pacific Northwest Research Station.

PALAIOLOGOU, P., KALABOKIDIS, K., HARALAMBOPOULOS, D., FEIDAS, H. & POLATIDIS, H. 2011. Wind characteristics and mapping for power production in the Island of Lesvos, Greece. *Computers & geosciences,* 37**,** 962-972.

PALAIOLOGOU, P., KALABOKIDIS, K. & KYRIAKIDIS, P. 2013. Forest mapping by geoinformatics for landscape fire behaviour modelling in coastal forests, Greece. *International journal of remote sensing,* 34**,** 4466-4490.

SCOTT, J. H. & REINHARDT, E. D. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station.