FUEL MODELS FOR MEDITERRANEAN WILDLAND-URBAN INTERFACES IN SOUTHERN ITALY

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Over the last decades, wildfire management programs have become an emerging issue in wildland-urban interfaces (WUIs) across the Mediterranean landscapes of Europe. Fuels can be aptly reduced to limit wildfire severity and consequently prevent damages. To this end, we have customized four fuel models for wildland-urban interfaces in southern Italy, starting from forest classes of land-cover use and using a hierarchical clustering approach. Furthermore, we assessed a prediction of the potential fire behavior of our customized fuel models using FlamMap 5 under different extreme weather conditions (85th and 95th percentiles). The simulated potential fire behavior for each fuel model in the study included surface rate of spread, fireline intensity, flame length, and heat per unit area. The results suggest that fuel model IIIP (Mediterranean maquis) has the most severe fire potential for the 95th percentile weather conditions and the least severe potential fire behavior for the 85th percentile weather conditions. This achievement has broad implications for land managers, particularly forest managers of the Mediterranean landscape, an ecosystem that is susceptible to wildfires and, at the same time, to the increasing human population and man-made infrastructures. Therefore, this study will be of great practical significance in Mediterranean Basin and it will corroborate prior research and future analysis in this field since our fuel models are more adapted to local conditions than those developed by Anderson (1982) and Scott and Burgan (2005) often used in similar researches.

Keywords: fuel model, fuel treatment, landscape management, wildland-urban interface (WUI), wildland fire.
Parole chiave: modello di combustibile, gestione selvicolturale, interfaccia urbano-foresta (WUI), incendi forestali.

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1. Introduction

Over the last few decades, the massive agricultural abandonment of rural lands and the reduced pressure on the use of forests and pastures have determined a pronounced woodland and shrubland re-colonization in many areas. These new landscape conditions, together with the increase in of the wildland-urban interface, have led to increasing wildfire hazard in many countries under Mediterranean environments (Moreira *et al*., 2011).

The territory-scale approach of integrated fire management is the "*fire smart management of forest landscapes*" (Fernandes, 2013) which aims to control the fire regime by intervening on vegetation (fuel) to foster more fire-resistant (less flammable) and/or fire-resilient environments. It is an improvement of the "*fire safe forest*" concept (Agee and Lolley, 2006) based, at stand scale, on fuel conditions that limit surface fireline intensity.

To this end, site-specific information concerning fuel load characteristics (e.g., canopy cover, forest stand structure, loading, etc.) and their effects on wildfire behavior across WUIs are needed to support wildfire management interventions and programs (Brown *et al*., 1981; Burgan, 1987; Keane *et al*., 2001; Reich *et al*., 2004; Piñol *et al*., 2007; Miller *et al.,* 2009).

A variety of studies have described the physical characteristics of fuels across different regions worldwide (Dimitrakopoulos, 2002; Dymond *et al*. 2004; Riccardi *et al*., 2007; Cheyette *et al*., 2008; Wu *et al*., 2011) and classified forest fuels into fuel models defined as "*a mathematical representation of surface fuels and a complete set of fuel inputs for mathematical fire behavior spread models"* (Rothermel, 1972; Deeming *et al*., 1978).

These studies have developed different standard fuel model systems. Dimitrakopoulos (2002) developed the PROMETHEUS system starting from various vegetation types of Mediterranean ecosystems in Greece. Dymond *et al.* (2004) provided a template of fuel characteristics from fuel classification systems in Indonesia and gathered data from the literature and the field. Eight fuel models were identified and then used to assess fire behaviour and guide fuel management. Other examples of fuel model systems are those developed by Scott and Burgan (2005) and by Ottmar *et al.* (2007) (Fuel Characteristic Classification System, FCCS), which are often used to describe fuels and assess fire behavior. However, most of these models are site-specific and cannot be easily generalized in other regions and/or landscape contexts (e.g. WUI). In particular, there is still a lack of knowledge on forest fuel models in southern Europe despite the fact that the extent of wildfires has increased dramatically over the past few years (San-Miguel-Ayanz *et al*., 2013).

We propose customized fuel models that are specific for wildland-urban interfaces (WUIs) in the Mediterranean landscape of Europe. We developed these fuel models by focusing on WUIs located in the Apulia region (southern Italy). We assessed the potential fire behavior of our customized fuel models under different weather conditions, using FlamMap 5 (Fire Behavior Mapping and Analysis Program, Finney 2006).Classifying forest fuels into customized fuel models is an essential step in assessing fire behavior and hazard in WUIs, especially in the context of a broader wildfire management risk analysis (Spyratos *et al*., 2007; Lutes *et al.,* 2009; Verde and Zêzere, 2010; Gorte and Bracmort, 2012).

2. Material and methods

2.1 Study area

The Apulia region is the easternmost region in Italy and is located at a latitude of 39°50'-41°50' N and a longitude of 15°50'-18°50' E (Fig 1). Its climate is characterized by mild rainy winters, dry hot summers, and a remarkable water deficit from June until September. The vegetation in Apulia is affected by both physical factors and a long history of human pressures (e.g., fires, grazing, urbanization, agriculture) as is also in the rest of the south Italy. Woodlands and forests in Apulia are mainly represented (52%) by *Quercus ilex* L., *Q. pubescens* Willd, *Q. cerris* L., and *Q. coccifera* L. Pine plantations of *Pinu shalepensis* L. and *P. pinea* L. (10%) are present mainly along the coast and cover most of the Ionian arc in the South-West. The Mediterranean maquis occupies 31% of woodlands (*Phillyrea spp*., *Ruscu saculeatus* L., *Pistacia lentiscus* L., *Asparagus acutifolius* L., *Cistus monspeliensis* L., *C. incanus* L., *C. salvifolius* L., *Fraxinus ornus* L., *Prunus spinosa* L., and *Paliurus spinachristi* Mill.).

2.2 Field inventory protocol

To characterize the landscape of the study area, we employed vectorized land-cover data collected by the regional government (http://www.sit.puglia.it) on a scale of 1:50,000. The most detailed level of these land-cover data defines the landscape according to 62 classes. Forest-cover layers were extracted, and for each forest-cover class (i.e., maquis, conifer, broad-leaved, and mixed forest) field data were collected. The proportion of forest-cover types was estimated within 300-m buffers (WUI) from the nearest urban areas.

According to this estimation, we selected the first 20 municipalities of the Apulia region, since they hold 60% of the entire amount of WUI forest cover in the region.

Sampling of fuels was conducted in-field according to the method by Brown *et al.* (1981) with some modifications to render it more suitable to the area landscape under investigation. Firstly, the procedure identified the sampling area using a global positioning system (GPS) and took into account the sensitivity and error (5-15 meters) of GPS. A total of 72 plots (13-m radius) were randomly located and sampled in September 2013 and the field inventory protocol is illustrated in figure 2.

2.3 Data sampling

The fuel characteristics and loadings were collected according to the fire model input requirements. Live canopy fuel data were collected on the 13-m radius plot: data include diameter at breast height (cm), canopy height (m), canopy base height (m), and number of trees per hectare (Fig. 2). We used the Vertex IV hypsometer for measuring canopy height (m) and canopy base height (m), whereas canopy cover was visually estimated with reference tables and recorded in percentage categories from 10% to 100% in steps of 10. By using these measures we estimated the average canopy height and average canopy base height for each plot. Further, the average canopy bulk density for each plot was estimated using the equations developed by Cruz *et al.* (2003).

Shrub parameters were estimated on the two (1 m radius) subplots, and fuel loadings in each subplot were calculated using equations developed by the U.S. Fish & Wildlife Service (AA.VV., 1992) and in the “Fire Paradox” Project (AA. VV., 2008).

From the rectangular subplots a sample of cut grass and litter was obtained. The contents of the sealed bags were brought to the laboratory and placed in an oven. In this manner, it was possible to evaluate the dry mass of the herbaceous component and litter present on each of the four surfaces delineated by the plots during the in-field procedure.

We also calculated the fuel loadings and surface area-to-volume ratio (SA/V) employing the methods and equations developed by the U.S. Fish & Wildlife Service (AA. VV., 1992) and in the “Fire Paradox” Project (AA. VV., 2008). The number of woody pieces on the ground that intersected the measuring tape were recorded on the data sheet and subdivided by time-lag class: the diameter, measured by the caliper at the point of intersection with the transept, discriminates the time-lag class in which each single piece falls. The pieces whose central axes did not coincide with the transept were not counted (quite a singular event), whereas for the transepts that intersected a curved piece in more than one point each intersection was counted, according to the method by Brown *et al.* (1981).

The 1-h time-lag fuels (0- to 0.65-cm diameter class) included needles, leaves, small twigs, cured herbaceous plants and fine dead stems of plants. The 10- and 100-h time-lag fuels (0.65- to 2.5- and 2.5- to 7.5-c diameter classes, respectively) were small- to medium-size branches and large branches.

3. Results

Hierarchical cluster analysis with relative Squared Euclidean distances and Ward’s method was employed in order to develop customized fuel models by clustering all fuel plot parameters collected in the study area (Poulos *et al.*, 2007; Wu *et al.*, 2011) (Tab. 1).

This approach allows to classify fuel attributes, thus avoiding errors stemming from vegetation-type-based classification, and takes into account fuel parameter variations caused by different agents such as logging, insects, disease, etc. It does not require determining the number of clusters in advance. The desired number of clusters can be achieved by 'cutting' the dendrogram at the level considered appropriate.

Despite these advantages the clustering approach could be sensitive to noise and outliers, especially if the data set is too large. Before running the cluster analysis we standardized the fuel parameters to z score to account for differences in means and variances.

Plots with similar fuel arrangements and topography were classified into different clusters according to our field knowledge; in fact, when automated classification ran counter to established field knowledge we manually reclassified the plots to the suitable clusters. Hierarchical cluster analysis was performed using the SPSS 20 statistical software package.

Following the analysis, each parameter of the fuel models represented the mean value of all the plots that were classified in the same cluster. The number of clusters (N= 172) were determined according to the literature, since four main forest ecosystems in the Apulia region can be recognized (e.g, conifer, mixed-forest, broad-leaved and Mediterranean maquis). Therefore, we grouped four clusters to develop the four fuel models for the WUI. Non-parametric Kruskal-Wallis tests were employed to assay the significant differences of forest fuel parameters in the customized fuel models (Poulos, 2009; Wu *et al*., 2011).

The potential fire behavior for each fuel model was simulated with FlamMap 5 (Fire Behavior Mapping and Analysis Program, Finney 2006). FlamMap 5 is a GIS-based model that describes potential fire behavior for constant environmental conditions (weather and fuel moisture) for each pixel within a certain landscape.

The main inputs for fire behavior simulation with FlamMap 5 were fuel models and their attributes (e.g, 1h, 10h, 100h fuels , 1h SA/V, live woody fuel load, live herbaceous fuel load, fuel moisture; see Tab. 2), terrain parameters (aspect, elevation, slope), and canopy cover. The simulated potential fire behavior for each fuel model included surface rate of spread (ROS, mmin^{-1}), fireline intensity (FLI, kWm^{-1}), flame length (FML, m), and heat per unit area (HUA kJm^{2}).

To facilitate comparisons of the potential fire behavior of the customized fuel models we employed two weather and fuel moisture scenarios to represent the burning conditions in the Apulia region (Burgan and Rothermel, 1984; Andrews *et al*., 2003).

We analyzed the frequency distribution of the extreme values of temperature, relative humidity and wind of the last 13 years (2000-2013 time period) in southern Italy and estimated the 95th and 85th percentiles (Tab. 1).

Four fuel models that differed significantly in forest fuel characteristics and local environmental conditions were identified across the Apulia region (Tab. 2-3). Figure 3 provides examples of fuel models in the WUI of Apulia where there is evidence of biomass accumulation (i.e., fuel load) due to lack of forest management. They do not correspond neither to the fuel models of Anderson (1982) nor to those of Scott and Burgan (2005).

In Table 4 we propose a qualitative comparison of our fuel models and some of the fuel models developed by Rothermel (Northern Fire Forest Laboratory, NFFL) and the ICONA project, which are frequently used in southern Europe. The difference between our fuel models and the others is more than evident. It suggests that there is a need to develop customized fuel models that are specific for WUIs in the Mediterranean landscapes of Europe.

Comparing fire behavior potential is essential to understand the flammability and combustibility of the four fuel models and the fire severity (Fig. 4). Using FlamMap 5, we computed ROS (m min^{-1}), FLI (kWm^{-1}), FML (m) and HUA (kJ m^{2}) for each of the four fuel models of the Apulia region (Fig. 4). The fuel model IIIP (Mediterranean maquis) had the most severe potential fire behavior for the 95th percentile weather conditions and least severe potential fire behavior for the 85th percentile weather conditions. The significant values of ROS, FLI and FML were also affected by lack of canopy cover (5%). The absence of trees allowed the wind to push the fire without any resistance. Moreover, the absence of trees increased the evapotranspiration of understory layers (live herbaceous and woody fuels), which causes loss of humidity and increased ignition probability (Pyne *et al*., 1996). Instead the fuel model IP had the highest severe potential fire behavior if compared to the other fuel models for the 85th percentile weather conditions.

These findings can be explained by the fact that the increased wind speed (up to 77 km/h for the 95th percentile weather conditions) mostly affected the fuel models with open canopy cover, such as fuel models IIP and IIIP (broad-leaved and Mediterranean maquis). Fuel model IIP recorded the second highest potential fire behavior; its primary carrier of fire was broad-leaved litter (1-h fuel load) and live woody fuel (Fig. 4). However, in forest conditions associated with fuel model IIP, high values of wind speed combined with high slope may actually cause higher ROS than predicted because of spotting caused by rolling and blowing leaves (Anderson, 1982).

Based on simulations, fuel model IVP presented the lowest ROS, FLI and FML values. Our findings suggested that fuel model IVP has the least severe fire potential compared to fuel model IP and the other two fuel models for both the 95th and 85th percentile weather conditions. In forest ecosystems of the Apulia region associated with fuel models IP and IVP, most wildfires are surface fires, but under severe hot and dry weather conditions crowning, spotting, and torching of individual trees may occur (Lovreglio *et al*., 2010).

4. Discussion

Vegetation and fuel types in southern Europe are frequently assigned to the NFFL fuel model or to the ICONA (1990) classification system.

This is understandable given the existence of ready-to-use technology, gaps in knowledge and expertise, and because fuel models are usually employed to assess possible or potential, rather than actual, fire situations (Fernandes *et al*., 2006).

Therefore, customized fuel models should be developed to describe site-specific conditions (e.g., for fuel hazard mapping or for research purposes) and to investigate the effects of fuel management practices (Fernandes and Botelho, 2004), i.e. the most appropriate prevention silvicultural practices to be applied to mitigate the hazard (i.e., the probability of fire occurrence and the difficulty to extinguish it, based on the current vegetation characteristics).

Fuel treatments are a key factor to decreasing wildfire risk (Omi and Martinson, 2002): they target different fuel components in order to achieve both forest structures and fuel characteristics which are able to reduce the likelihood of fire spread.

Fuel treatments are mainly aimed at eliminating the vertical and horizontal continuity of fuels, in order to disrupt the vertical progression of fire (passage from surface fuels to ladder fuels to canopy fuels), and its horizontal progression, especially from crown to crown (Scott and Reinhardt, 2001; Graham *et al*., 2004).

The range of possible treatments to modify forest fuels is rather wide, varying from pruning (Leone, 2002) to thinning, to mechanical thinning, to fuel mastication (Harrington, 2012) to prescribed fire (Leone *et al*., 1999; Fernandes and Botelho, 2004; Molina *et al*., 2010; Rego and Montiel, 2010; Ascoli *et al*., 2012) to grazing (Hart, 2001; Ruiz-Mirazo *et al*., 2009; Ruiz-Mirazo, 2011; Mancilla-Leytón and Martín Vicente, 2012).

In our study case critical severity simulated fires suggest interventions to reduce the fuel load through targeted silvicultural treatments:

- fuel model IP: thinning (mainly high thinning), together with prescribed burning, play the most important role in the silvicultural prevention of wildfires
- fuel model IIP: conversion of abandoned coppice trees and use of pasture together prescribed grazing system.
- fuel model IIIP: grazing is officially considered as a wildfire prevention tool in many countries such as Italy (article 3 of Law 47/1975, now repealed; many regional laws also include grazing by cattle, sheep and pig as appropriate preventive measures).
- fuel model IVP: thinning (mainly low thinning)the conifers to facilitate the process of re-naturalization of deciduous.

5. Conclusion

Programs for the assessment of fuel loads and characteristics at landscape scale represent an essential step in effective wildfire management.

Our study represents an appropriate starting point for fuel model development in the Mediterranean basin. We have identified four forest fuel models in southern Italy (Apulia region) by classifying fuel parameters using a hierarchical cluster analysis. Additionally, we have simulated the potential fire behavior of the fuel models using FlamMap 5. Employing detailed information about fuel models ad hoc and their fire behavior across the WUI landscape may contribute to fuel management decision-making processes in the context of a broader wildfire management risk analysis (Gorte and Bracmort, 2012). Although the aim of this study is to provide customized fuel models for Mediterranean WUIs in southern Italy, some specific limitations must be taken into consideration.

The number of sample plots was restricted in quantity due to wildland characteristics within urban interfaces in the Apulia region, where forested areas are rather small and fragmented. In addition, the study will corroborate prior research and future analyses in this field, since our fuel models are more adapted to local conditions than those developed by Rothermel (NFFL) and ICONA, which are often used in similar research. As for any modelling approach, however, further analyses are warranted.

Table 1. 95th and 85th percentile weather conditions used for fire behavior simulations.

Weather conditions	*95th percentile*	*85th percentile*
1-h moisture content (%)	3	4
10-h moisture content (%)	4	5
100-h moisture content (%)	5	6
Live herbaceous fuel moisture content (%)	40	57
Live shrub fuel moisture content (%)	70	87
Minimum temperature (°C)	20	19,1
Maximum temperature (°C)	40,7	40
Minumuim humidity (%)	23,6	29
Maximum humidity (%)	83,5	82
Maximum wind speed (km/h)	76,6	50,2
Precipitation (mm)	0	0

Table 2. Main features of the models of fuels identified.

Fuel model IP	*Fuel model IIP*	*Fuel model IIIP*	*Fuel model IVP*
Representative of coniferous forests characterized by heavily branched *P. halepensis, P. pinast*er, and *P. pinea.* Large amount of fuel loading in the dead woody fuel class (18.58 Mg/ha) with the highest value for 1-h fuel load (15.67 Mg/ha). Lowest fuel loading in the live woody fuel class with relatively low values of live herbaceous fuel load (up to 0.71 Mg/ha).	Representative of broad-leaved forests mainly dominated by *Q. ilex and Q. pubescens.* Highest value of woody fuel load (9.04 Mg/ha), most likely due to a slow transition process to Mediterranean maquis. Low presence of grassland, 0.77 Mg/ha)	Representative of the Mediterranean maquis. Showed the highest value of live fuel load (10.44 Mg/ha) due to the rich biodiversity of species including *P. lentiscus* (L.), *P. terebinthus* (L.), *Rosa canina* (L.), *Crataegus monogyna* (Jacq.), *Phillyrea spp.*, *Rhamnus alaternus* (L.), *Erica arborea* (L.), *Rubus ulmifolius* Schott.), *Smilax aspera* (L.), *Calycotome spinosa* (L.) and *Arbutus unedo* (L.). Abundant presence of live herbaceous fuel load (6.34 Mg/ha) together with low canopy cover (5%).	Presented the highest value in dead fuel load classes (25.37 Mg/ha) with the largest amount of both 10-h and 100-h fuel load (5 and 6.06 Mg/ha, respectively). As for fuel model IP, model IVP was characterized by dense and closed canopy cover (92%) and a high value of fuel bed depth (up to 60 cm)

Table 3. Customized fuel models and their characteristics: Mean values (±SE).

Forest fuel characteristics	*Fuel model*			
	IP	*IIP*	*IIIP*	*IVP*
Dead fuel load (Mg/ha)	18,58	13,5	9,08	25,37
- 1-h **	15,67 ± 0,79	11,54 ± 0,78	8,46 ± 0,86	14,31 ± 1,15
- 10-h **	2,20 ± 0,30	1,66 ± 0,34	0,51 ± 0,18	5,00 ± 0,33
- 100-h **	0,71 ± 0,20	0,30 ± 0,12	0,11 ± 0,07	6,06 ± 1,14
Live fuel load (Mg/ha)	4,39	9,81	10,44	5,97
- Herbaceous**	0,71 ± 0,32	0,77 ± 0,32	6,34 ± 1,10	0,46 ± 0,46
- Woody*	3,68 ± 0,89	9,04 ± 1,78	4,10 ± 1,18	5,51 ± 1,55
1-h SA/V**	5278,61 ± 166,32	4165,51 ± 359,64	2256,80 ± 133,59	4457,21 ± 463,36
Fuel bed depth (cm)*	41,21 ± 4,99	53,62 ± 3,21	50,80 ± 4,18	59,06 ± 4,57
Canopy cover (%)**	93 ± 2,20	59 ± 6,36	5 ± 3,90	92 ± 1,83
Canopy Height (m)**	13,03 ± 0,72	3,13 ± 0,89	0,00 ± 0,00	8,27 ± 1,51
Canopy Base Height (m)**	6,13 ± 0,46	1,37 ± 0,42	0,00 ± 0,00	3,79 ± 0,77
Canopy Bulk Density Kg/m^3)**	0,05 ± 0,01	0,01 ± 0,00	0,00 ± 0,00	0,03 ± 0,01
Slope (%)**	5,90 ± 1,37	11,29 ± 1,58	3,04 ± 0,99	10,68 ± 3,11
Aspect (°)	98,59 ± 15,10	155,87 ± 17,89	95,32 ± 31,98	104,06 ± 20,69
Elevation (m)*	139,96 ± 38,62	201,04 ± 30,20	74,92 ± 29,29	235,22 ± 89,88

Asterisks indicate significant differences between fuel models according to the Kruskal–Wallis test, with * indicating significance at the $P<0.05$, ** indicating significance at the $P<0.01$.
SA/V Surface area to volume ratio.

Table 4. A qualitative comparison between our fuel models and the corresponding fuel models developed by Rothermel (NFFL) and by the ICONA.

		Fuel model							
		7	*IP*	*10*	*IIP*	*4*	*IIIP*	*7*	*IVP*
Rotheremel-Albini (NEFL)	1 h (Mg/ha)	2,7	15,6	6,4	11,5	12,4	8,5	2,7	14,3
	10 h (Mg/ha)	4,7	2,2	5,5	1,6	9,9	0,5	4,7	5
	100 h (Mg/ha)	3,7	0,7	11,1	0,3	4,5	0,1	3,7	6
	Live (Mg/ha)	0,3	4,4	4,5	9,8	12,4	5,9	0,3	6
ICONA	1 h (Mg/ha)	2,5	15,6	6,7	11,5	11,2	8,5	2,5	14,3
	10 h (Mg/ha)	4,2	2,2	4,5	1,6	9	0,5	4,2	5
	100 h (Mg/ha)	3,4	0,7	11,2	0,3	4,5	0,1	3,4	6
	Live (Mg/ha)	0,8	4,4	4,5	9,8	11,2	5,9	0,8	6

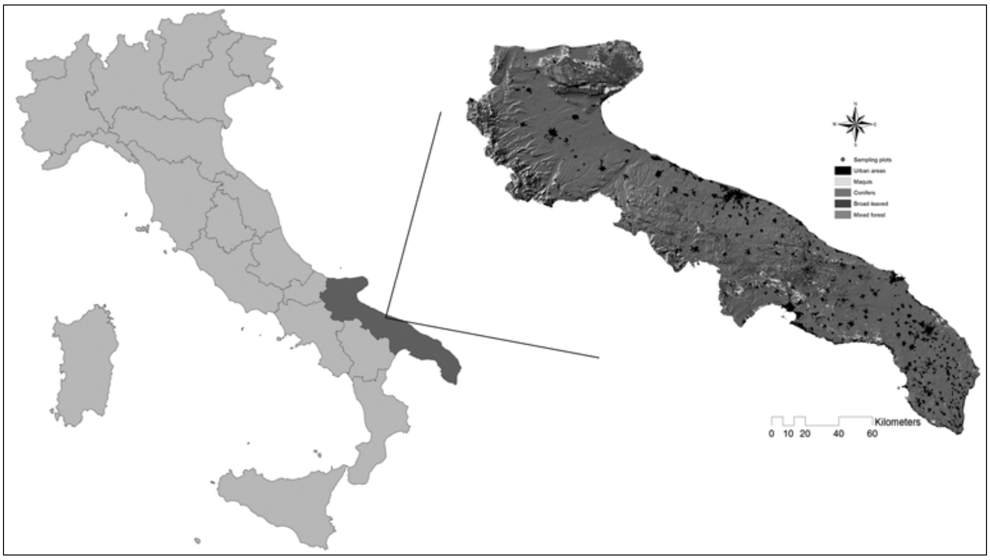

Figure 1. Map of the Apulia region in southern Italy. The position of 72 sample plots across the region is shown.

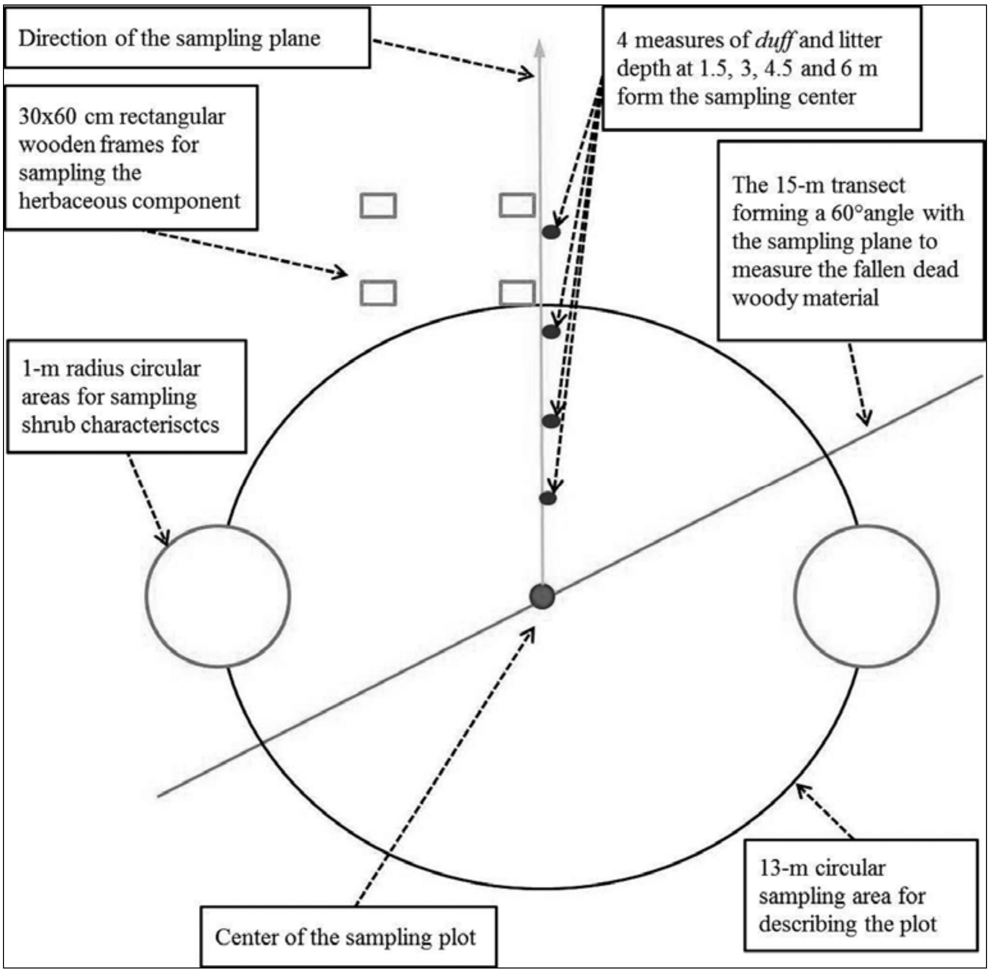

Figure 2. The field inventory plot is illustrated. Crown parameters were measured in the 13-m radius plot; 1-m radius circular areas were used for sampling woody shrubs characteristics; herbaceous and litter loadings were estimated within 30x60-cm rectangular frames; four measurements of duff and litter depth were taken at different distances from the center of the sampling plot; and fallen dead woody material was sampled along the 15-m transect.

Figure 3. Examples of fuel model types observed in the study area: (a) Fuel model IP, (b) Fuel model IIP, (c) Fuel model IIIP, and (d) Fuel model IVP. Biomass accumulation is evident due to lack of forest management.

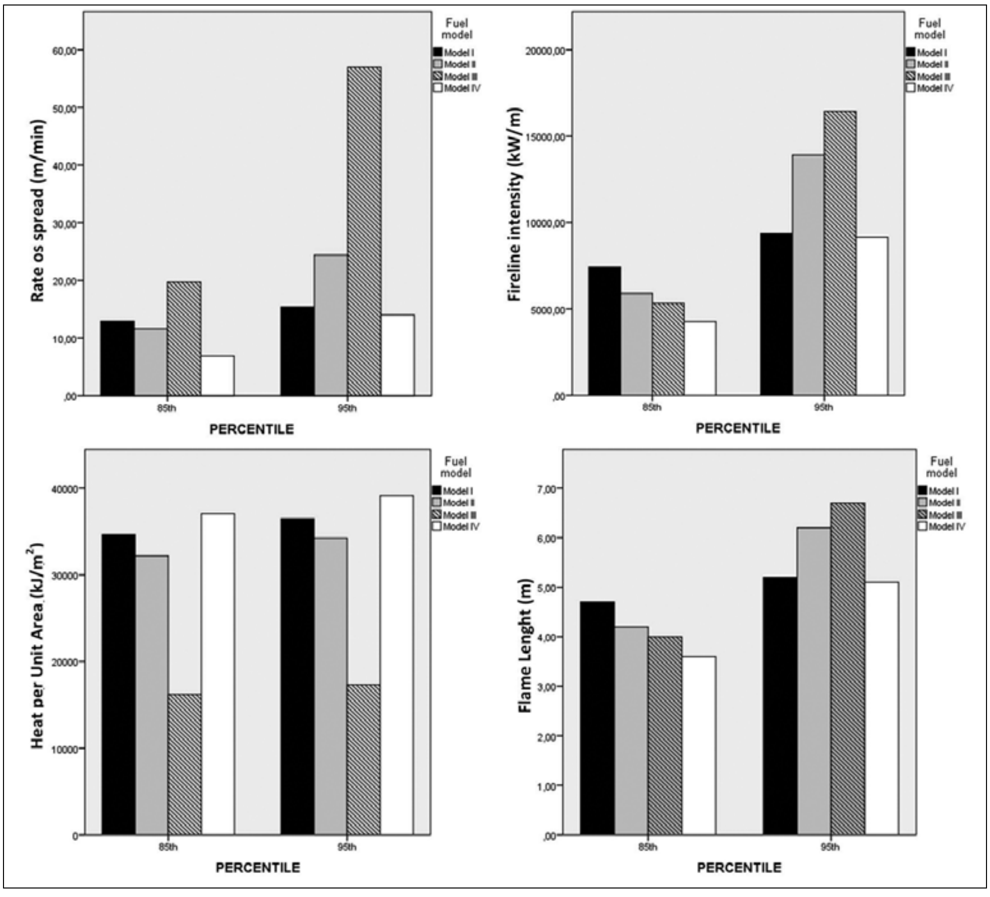

Figure 4. ROS (m min^{-1}) (a), FLI (kWm^{-1}) (b), HUA (kJ m^2) (c) and FML (m) (d) were computed for each of the four fuel models in the WUI landscape of the Apulia region under the 95th and 85th percentile weather conditions.

RIASSUNTO

Modelli di combustibile ad hoc per le aree di interfaccia urbano-foresta del sud Italia

La gestione integrata dei combustibili al fine di ridurre il rischio di incendi gioca un ruolo chiave soprattutto in aree densamente popolate poste in prossimità di territori forestali: le cosiddette aree di interfaccia urbano-foresta (wildland-urban interface, WUI). Il combustibile vegetale può essere opportunamente modificato per ridurre la probabilità di propagazione, contenere la severità degli incendi e prevenire danni a cose e persone. Lo studio ha previsto lo sviluppo di quattro modelli di combustibile ad hoc per le aree di interfaccia urbano-foresta del sud Italia (Puglia), utilizzando un approccio di “clustering” gerarchico che consente di raggruppare le caratteristiche del combustibile presente in specifici modelli per un dato paesaggio. Utilizzando FlamMap 5 è stato simulato il comportamento del fuoco potenziale in due differenti scenari climatici (85esimo e 95esimo percentile) per la stima della velocità del fronte di fiamma (ROS), intensità lineare (FLI), lunghezza del fronte di fiamma (FML) e calore per unità di superficie (HUA). I risultati hanno suggerito che il modello di combustibile IIIP (macchia mediterranea), presenta i valori più alti di ROS e FLI nel caso dello scenario al 95esimo percentile e valori leggermente meno elevati nel caso dello scenario all’85esimo percentile delle condizioni climatiche. Lo studio suggerisce possibili indicazioni di gestione del territorio forestale mediterraneo, molto suscettibile agli incendi boschivi e caratterizzato da un crescente processo di urbanizzazione in ambito di WUI. I modelli di combustibile, sviluppati ad hoc si adattano meglio agli ecosistemi forestali mediterranei rispetto a quelli standard spesso usati in ricerche analoghe.

BIBLIOGRAPHY

AA. VV., 1992 – *Fuel and Fire Effects Monitoring Guide*. U.S. Fish & Wildlife Service, pp.674.

AA. VV., 2008 – *Review of fuel description methods*. Deliverable D3.4-2 of the Integrated Project “Fire Paradox”, Project no. FP6-018505, European Commission, pp. 57.

Agee J.K., Lolley M.R., 2006 – *Thinning and prescribed fire effects on fuels and potenti*al *fire behaviour in an eastern Cascades Forest, Washington, USA*. Fire Ecology, 2: 3-19. http://dx.doi.org/10.4996/fireecology.0202003

Anderson H.E., 1982 – *Aids to determining fuel models for estimating fire Anderson behavior*. Ogden, UT: US Department of Agriculture, Forest Service, Intermountain Forest and Range Experimental Station, Gen. Tech. Rep. INT-122.

Andrews P.L., Loftsgaarden D.O., Bradshaw L.S., 2003 – *Evaluation of fire danger rating indexes using logistic regression and percentile analysis*. International Journal of Wildland Fire, 12: 213-226. http://dx.doi.org/10.1071/WF02059

Ascoli D., Catalanotti A., Valese E., Cabiddu S., Delogu G., Driussi M., Esposito A., Leone V., Lovreglio R., Marchi E., Mazzoleni S., Rutigliano F.A., Strumia S., Bovio G., 2012 – *Esperienze di fuoco prescritto in Italia: un approccio integrato per la prevenzione degli incendi boschivi*. Forest@- Journal of Silviculture & Forest Ecology, 9 (1): 20-38.

Birot Y., 2009 – *Living with wildfires: What science can tell us*. EFI Discussion paper 15/2009. European Forest Institute, Joensuu, Finland.

Brown J.K., Oberheu R.D., Johnston C.M., 1981 – *Handbook for inventorying surface fuels and biomass in the Interior West*. Ogden, UT: US Department of Agriculture, Forest Service, Intermountain Forest and Range Experimental Station, Gen. Tech. Rep. INT-129.

Burgan R.E., 1987 – *Concepts and interpreted examples in advanced fuel modeling*. USDA Forest Service Gen. Tech. Rep. INT-238.

Burgan R.E., Rothermel R.C., 1984 – *BEHAVE: Fire behavior prediction and fuel modeling system-FUEL subsystem*. USDA Forest Service Gen. Tech. Rep. INT-167

Cheyette D., Rupp S.T., Rodman S., 2008 – *Developing Fire Behavior Fuel Models for the Wildland-Urban Interface in Anchorage, Alaska*. West J Appl For., 23: 149-155.

Cruz M.G., Alexander M.E., Wakimoto R.H., 2003 – *Assessing canopy fuel stratum characteristics in crown fire prone fuel types of western North America.* International Journal of Wildland Fire, 12: 39-50. http://dx.doi.org/10.1071/WF02024

Deeming J.E., Burgan R.E., Cohen J.D., 1978 – *The National Fire-Danger Rating System*. USDA Forest Service Gen. Tech. Rep. INT-39.

Dimitrakopoulos A.P., 2002 – *Mediterranean fuel models and potential fire behavior in Greece*. International Journal of Wildland Fire, 11: 127-130. http://dx.doi.org/10.1071/WF02018

Dymond C.C., Roswintiarti O., Brady M., 2004 – *Characterizing and mapping fuels for Malaysia and western Indonesia*. International Journal of Wildland Fire, 13: 323-334. http://dx.doi.org/10.1071/WF03077

Fernandes P.M., Botelho H.S., 2003 – *A review of prescribed burning effectiveness in fire hazard reduction*. International Journal of Wildland Fire, 12: 117-128. http://dx.doi.org/10.1071/WF02042

Fernandes P., Botelho H., 2004 – *Analysis of the prescribed burning practice in the pine forest of northwestern Portugal.* Journal of Environmental Management, 70: 15-26. http://dx.doi.org/10.1016/j.jenvman.2003.10.001

Fernandes P., Luz A., Loureiro C., Ferreira-Godinho P., Botelho H., 2006 – *Fuel modelling and fire hazard assessment based on data from the Portuguese National Forest Inventory*. Forest Ecology and Management, 234S-S229. http://dx.doi.org/10.1016/j.foreco.2006.08.256

Fernandes P.M., 2013 – *Fire smart management of forest landscapes in the Mediterranean basin under global* *change*. Landscape and Urban Planning, 110: 175-182. http://dx.doi.org/10.1016/j.landurbplan.2012.10.014

Gorte R.W., Bracmort K., 2012 – *Wildfire protection in the wildland-urban interface*. CRS Report for Congress, Congressional Research Service, January 23, 2012

Graham R.T., McCaffrey S.M., Jain T.B., 2004 – *Science basis for changing forest structure to modify wildfire behavior and severity*. General Technical Report RMRS-GTR-120. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, pp. 43.

Hart S.P., 2001 – *Recent Perspectives in Using Goats for Vegetation Management in the USA*. J. Dairy Sci., 84 (E. Suppl.): 170-176. http://www.uky.edu/Ag/AnimalSciences/goats/pubs/s.hart%20overview%20veg.%20management.pdf accessed 11.27. 2012

Harrington T.B., 2012 – *Silvicultural Basis for Thinning Southern Pines: Concepts and Expected Responses*. Georgia Forestry Commission. http://www.gfc.state.ga.us/resources/publications/SilviculturalApproaches.pdf accessed 11.29. 2012

ICONA, 1987 e 1990 – *Clave fotografica para la identification de modelos de combustibile*. Istituto Nacional para la Conservacion de la Naturaleza (ICONA), Area de Defensa contra Incendios Forestales, Madrid. Vol. 2.

Keane R.E., Burgan R., Van Wagtendonk J., 2001 – *Mapping wildland fuels for fire management across multiple scales: integrating remote sensing, GIS, and biophysical modeling*. International Journal of Wildland Fire, 10: 301-319. http://dx.doi.org/10.1071/WF01028

Leone V., Signorile A., Gouma V., Pangas N., Chronopoulou-Sereli A., 1999 – *Obstacles in prescribed fire use in Mediterranean countries: early remarks and results of the Fire Torch project*. In: Proceedings of the "DELFI International Symposium. Forest Fires: Needs and Innovations". Athens (Greece), Nov. 18-19 1999: pp. 132-136.

Leone V., 2002 – *Forest management: pre and post fire practices*. In: Fire, Landscape and Biodiversity: An Appraisal of the Effects and Effectiveness. Pardini, G., Pintó, J. (Eds.). Diversitas, Universitat de Girona, pp. 117–141.

Lovreglio R., Leone V., Giaquinto P., Notarnicola A., 2010 – *Wildfire cause analysis: four case-studies in southern Italy*. iForest, 3: 8-15.

Lutes D.C., Keane R.E., Caratti J.F., 2009 – *A surface fuel classification For estimating fire effects*. International Journal of Wildland Fire, 18: 802-814. http://dx.doi.org/10.1071/WF08062

Mancilla-Leytón J.M., Martín Vicente A., 2012 – *Biological fire prevention method: Evaluating the effects of goat grazing on the fire-prone Mediterranean scrub*. Forest Systems, 21(2): 199-204. http://revistas.inia.es/index.php/fs/article/download/2289/1679 accessed 11.28.2012

Miller J.D., Safford H.D., Crimmins M., Thode A.E., 2009 – *Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA*. Ecosystem, 12: 16-32. http://dx.doi.org/10.1007/s10021-008-9201-9

Molina D., Castellnou M., García-Marco D., Salgueiro. A., 2010 – *Improving fire management success through fire behaviour specialists*. In: Towards Integrated Fire Management Outcomes of the European Project Fire Paradox (Silva JS, Rego F, Fernandes P, Rigolot E eds). Research Report 23, European Forest Institute, Joensuu, Finland, pp. 105-119. http://www.efi.int/portal/virtual_library/publications/research_reports/23 accessed 11.27.2012

Moreira F., Viedma O., Arianoutsou M., Curt T., Koutsias N., Rigolot E., Barbati A., Corona P., Vaz P., Xanthopoulos G., Mouillot F., Bilgili E., 2011 – *Landscape-wildfire interaction in southern Europe: Implications for landscape management.* Journal of Environmental Management, 92: 2389-2402. http://dx.doi.org/10.1016/j.jenvman.2011.06.028

Omi P.N., Martinson E.J., 2002 – *Effects of fuels treatment on wildfire severity*. Final report submitted to the Joint Fire Science Program Governing Board. March 25, 2002. Western Forest Fire Research Center, Colorado State University. Fort Collins, CO. http://www.ntc.blm.gov/krc/uploads/399/Effects%20of%20Fuels%20Treatment%20on%20Wildfire%20Severity.pdf. (Last accessed 11.27. 2012).

Ottmar R.D., Sandberg D.V., Riccardi C.L., Prichard S.J., 2007 – *An overview of the fuel characteristic classification system-quantifying, classifying, and creating fuelbeds for resource planning*. Canadian Journal of Forest Research, 37: 2383-2393. http://dx.doi.org/10.1139/X07-077

Piñol J., Castellnou M., Beven K.J., 2007 – *Conditioning uncertainty in ecological models: Assessing the impact of fire management strategies*. Ecological Modelling, 207: 34-44. http://dx.doi.org/10.1016/j.ecolmodel.2007.03.020

Poulos H.M., 2009 – *Mapping fuels in the Chihuahuan Desert borderlands using remote sensing, geographic information systems, and biophysical modeling*. Canadian Journal of Forest Research, 39: 1917-1927. http://dx.doi.org/10.1139/X09-100

Poulos H.M., Camp A.E., Gatewood R.G., Loomis L., 2007 – *A hierarchical approach for scaling forest inventory and fuels data from local to landscape scales in the Davis Mountains, Texas,USA*. Forest Ecology and Management, 244: 1-15. http://dx.doi.org/10.1016/j.foreco.2007.03.033

Pyne S.J., Andrews P.L., Laven R.D., 1996 – *Introduction to wildland fire*. 2nd edn. Wiley, New York

Rego F., Montiel C., 2010 – *Lessons Learned and the Way Ahead. In: Best practices of fire use - prescribed burning and suppression fire programmes in selected case-study regions in Europe.* In: Research Report 24. European Forest Research Institute. Montiel C, Krauss D eds. Joensuu, Finland, pp. 165-169. http://www.efi.int/portal/virtual_library/publications/research_reports/24/ accessed 11.27. 2012

Reich R.M., Lundquist J.E., Bravo V.A., 2004 – *Spatial models for estimating fuel loads in the Black Hills, South Dakota*, USA. Int J Wildland Fire, 13:119-129.

Riccardi C.L., Ottmar R.D., Sandberg D.V., Andreu A., Elman E., Kopper K., Long J., 2007 – *The fuelbed: a key element of the fuel characteristic classification system.* Canadian Journal of Forest Research, 37: 2394-2412. http://dx.doi.org/10.1139/X07-143

Rothermel R.C., 1972 – *A mathematical model for predicting fire spread in wildland fuels*. Ogden, UT: US Department of Agriculture, Forest Service, Intermountain Forest and Range Experimental Station, Gen. Tech. Rep. INT-115

Ruiz-Mirazo J., Robles A.B., González-Rebollar J.L., 2009 – *Pastoralism in natural parks of Andalucía (Spain): a tool for fire prevention and the naturalization of ecosystems*. In: Changes in sheep and goat farming systems at the beginning of the 21st century. Pacheco F. and Morand-Fehr P. (Eds.). Zaragoza. Options Méditerranéennes, Série A, Séminaires Méditerranéens 91: 141-14.
http://digital.csic.es/bitstream/10261/42929/1/OPTIONS_pontedelima_descargado.pdf accessed 11.27. 2012

Ruiz-Mirazo J., 2011 – *Environmental benefits of extensive livestock farming: wildfire prevention and beyond*. Options Méditerranéennes, 100: 75-82.
http://ressources.ciheam.org/om/pdf/a100/00801486.pdf (Last accessed 11.29. 2012).

San-Miguel-Ayanz J., Moreno J.M., Camia A., 2013 – *Analysis of large fires in European Mediterranean landscapes: Lessons learned and perspectives*. Forest Ecology and Management, 294:11-22.

Scott J.H., Reinhardt E.D., 2001 – *Assessing crown fire potential by linking models of surface and crown fire behavior*. USDA Forest Service Rocky Mountain Research Station Research Paper RMRS-RP-29. Fort Collins, CO.
http://www.treesearch.fs.fed.us/pubs/4623
Accessed 11.27. 2012

Scott J.H., Burgan R.E., 2005 – *Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model*. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Spyratos V., Bourgeron P.S., Ghil M., 2007 – *Development at the wildland-urban interface and the mitigation of forest-fire risk*. Proceedings of the National Academy of Sciences of the United States of America, 104: 14272-14276.
http://dx.doi.org/10.1073/pnas.0704488104

Verde J.C., Zêzere J.L., 2010 – *Assessment and validation of wildfire susceptibility and hazard in Portugal*. Natural Hazards and Earth System Sciences, 10: 485-497.
http://dx.doi.org/10.5194/nhess-10-485-2010

Wu Z.W., He H.S., Chang Y., Liu Z.H., Chen H.W., 2011 – *Development of Customized Fire Behavior Fuel Models for Boreal Forests of Northeastern China*. Environmental Management, 48: 1148-1157. http://dx.doi.org/10.1007/s00267-011-9707-3