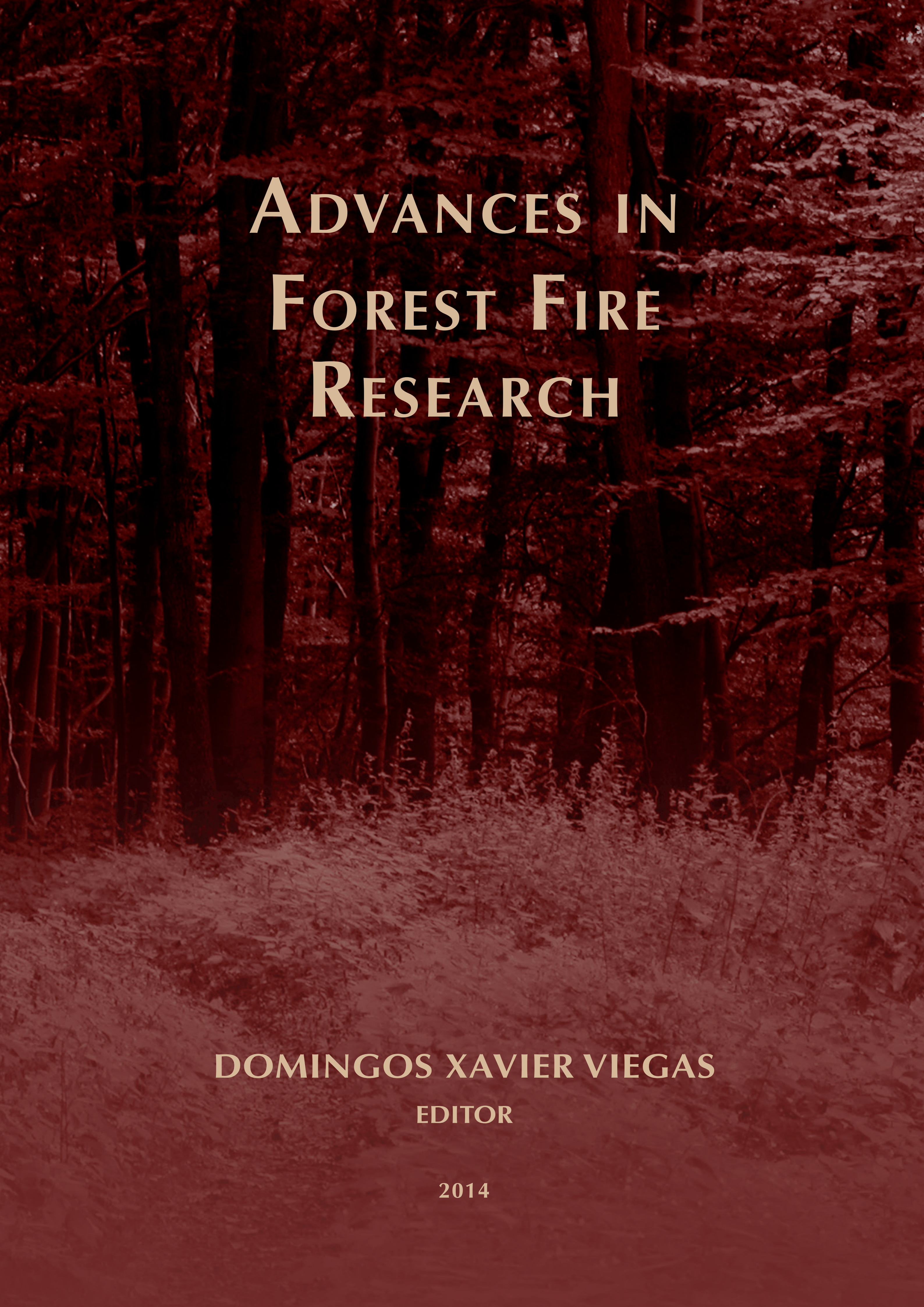

Advances in Forest Fire Research

DOMINGOS XAVIER VIEGAS
EDITOR

2014

Characterization of custom fuel models for supporting fire modeling-based optimization of prescribed fire planning in relation to wildfire prevention (southern Catalonia, Spain)

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Abstract
Prescribed fires are an important fuel management tool in Mediterranean fire-prone landscapes, but there is a lack of custom fuel models developed for Mediterranean-type ecosystems and, in particular, for describing ecosystems, which have been treated with a prescribed fire. Such custom fuel models would allow using fire modeling-based approaches for assessing the efficiency of real prescribed fires in relation to fire control at the landscape scale, but also for exploring the efficiency of alternative prescribed fire scenarios under climate change. Pre-burn field-collected vegetation data for shrublands under a *Pinus halepensis* canopy in a semi-arid Mediterranean study area located in southern Catalonia (Northeastern Spain) are presented and compared to values of vegetation parameters published in previous works and commonly used for fuel models characterization. The differences found at the species- and community-levels support the need of developing custom fuel models for improving future fire projections.

Keywords*: prescribed fire, custom fuel models, fire modeling, Mediterranean ecosystems, Aleppo pine*

1. Introduction

Wildfires are a major cause of environmental degradation in northern Mediterranean countries. The magnitude of the problem will likely be enhanced by climatic change, making necessary the implementation of landscape-level designed fire management strategies (Duguy *et al.* 2013).

Landscape-level fire prevention planning requires a better understanding of how ecosystems, and vegetation in particular, may respond to specific management actions. In recent years, prescribed fires have gained attention as an interesting fuel management alternative to mechanical or chemical tools and livestock grazing, both from economical and ecological points of view (Fernandes 2002, Fernandes and Botelho 2003, Goldammer and Bruce 2004, Rigolot 2005, Cassagne *et al.* 2011). However, while wildfire effects on Mediterranean ecosystems have been comprehensively treated in the literature (Trabaud *et al*. 1985a, 1985b, Pausas *et al*. 1999; Delitti *et al.* 2005; Baeza and Vallejo 2008; Duguy and Vallejo 2008), prescribed fire effects are not so well documented and require further attention before this tool may be extensively applied (Montiel and Kraus 2013).

Short and medium-term effects of prescribed fire are currently being evaluated for shrublands under *Pinus halepensis* canopy within the framework of the ForBurn-Land project funded by the Spanish Ministry of Science and Innovation (AGL2012-40098-C03-02). The focus is on the understory of Aleppo pine stands because almost 367,000 ha of such forests were planted or seeded in Spain between 1940 and 1980, increasing the existing extension of almost 674,000 ha of naturally regenerated *Pinus*

halepensis forests. An additional surface of 786,000 ha, resulting from the secondary succession on abandoned crops, had to be added after 1980.
In general, Aleppo pine forests contribute to the high fire-proneness of Mediterranean landscapes and fire usually plays a major role in the regeneration and dynamics of this pioneer plant community (EEA 2006). The crown structure and the morphology of the pine needles allow ample radiation to reach the soil, so a dense and flammable evergreen sclerophyllous shrub layer (with garrigue to maquis‑like physiognomies; EEA 2006), which may cause extreme fire intensities (Martins-Fernandes 2001), is often well developed. Moreover, in the past two decades, the lack of the required preventive silvicultural treatments has resulted in very hazardous stand structures unfavorable for management (Vega-Garcia and Chuvieco 2006). Consequently, we study here the effects of prescribed understory fires under *Pinus halepensis*. Prescribed crown fires are not considered, as they are not allowed in current fuel management planning in Spain (Decreto 312/2006, de 25 de julio in Catalonia and RCARA, de 11 de enero de 2013 in Asturias).
Spatially-explicit fire models, such as FARSITE (Finney 1998), have shown to correctly project fire growth and behavior of hypothetical fires through Mediterranean landscapes (Arca *et al.* 2007, Duguy *et al.* 2007). The reliability of their predictions strongly depends, however, on the accuracy of the fuel-related inputs (Arca *et al.* 2007). Seeking to improve fire simulation options, some scientific precedents in Mediterranean environments have tried to develop new fuel model types (i.e. Prometheus), but few have been based on extensive field measurements; e.g. the UCO40 system developed in Andalucia by Rodriguez y Silva and Molina-Martínez (2012), and most have been limited by scale and budget (Arroyo *et al.* 2008).
The purpose generally stated in previous works is the improvement of fire behavior modeling (Papió and Trabaud 1991; Pereira *et al.* 1995; Bochet *et al.* 2000; Dimitrakopoulos 2001; Viegas *et al.* 2001; Cohen *et al.* 2003; Baeza *et al.* 2006; Pellizzaro *et al.* 2007a; Cassagne *et al.* 2011; Santana *et al.* 2011)., but the evaluation of fuel management alternatives is not explicitly commented.
In that sense, there is still a lack of custom fuel models (CFM, hereafter) developed for Mediterranean ecosystems and, in particular, for describing ecosystems which have been treated with a prescribed fire. Such CFMs would allow using fire modeling-based approaches for assessing the efficiency of real prescribed fires in relation to fire control at the landscape scale, but also for exploring the efficiency of alternative prescribed fire scenarios under climate change.
Consequently, we intend to customize fuel models for pre- and a post-prescribed fire situations in shrublands under a *Pinus halepensis* canopy in a representative study area located in southern Catalonia (Northeastern Spain). The characterization and use of such CFMs are expected to provide more reliable fire modeling projections and, thus, foster the use of fire models as supportive tools for optimizing the landscape-scale planning of prescribed burnings in relation to wildfire prevention. Given that this project is still ongoing, only the pre-fire situation will be presented at this time.

2. Methods

2.1. Study area

The study area (Figure 1) is located in El Perelló (Southern Catalonia, Spain; UTM Zone 31N; x: 304762, y: 4530927; 250 m a.s.l.). The area is characterized by a semi-arid Mediterranean climate with mild winters and dry and warm summers in which water deficit may reach 300-400 mm. The mean annual precipitation is around 550 mm and mean annual temperature around 17 ºC (POUM Perelló, 2010). Stony Lithic Xerorthents and Lithic Haploxerolls developed over limestones and dolomites (Soil Survey Staff 1999) sustain a forest of *Pinus halepensis Miller* (Vigo *et al.*, 2006) with a canopy cover around 80%. The dominant shrub species in the understory are *Pistacia lentiscus*, *Quercus coccifera*, *Ulex parviflorus*, *Rosmarinus officinalis*, and *Erica multiflora*. *Rhamnus alaternus*, *Olea europaea* and *Chamaerops humilis* are other common woody species.

The pine stands were planted in 1970 on old crops (cereal, almond and olive groves) that were abandoned in the 1950s. A mechanical treatment was applied in 1998 to reduce the biomass of the understory.

2.2. Methods

Three plots (10x10 m) were installed in the study area. The vegetation samplings were carried out in February 2013 and March 2014, before and after, respectively, a prescribed burning for fuel hazard reduction that was conducted over 2.1 ha in May 2013 and that only affected the understory. The three plots were divided in a hundred 1m^2 quadrats for inventory of specific composition (list of species) and vegetation structure. The minimum and maximum height (of shrub layer and highest individuals among dominant shrubs), the minimum and maximum crown diameters, and the cover percentages (shrub and herbaceous layers) were measured.

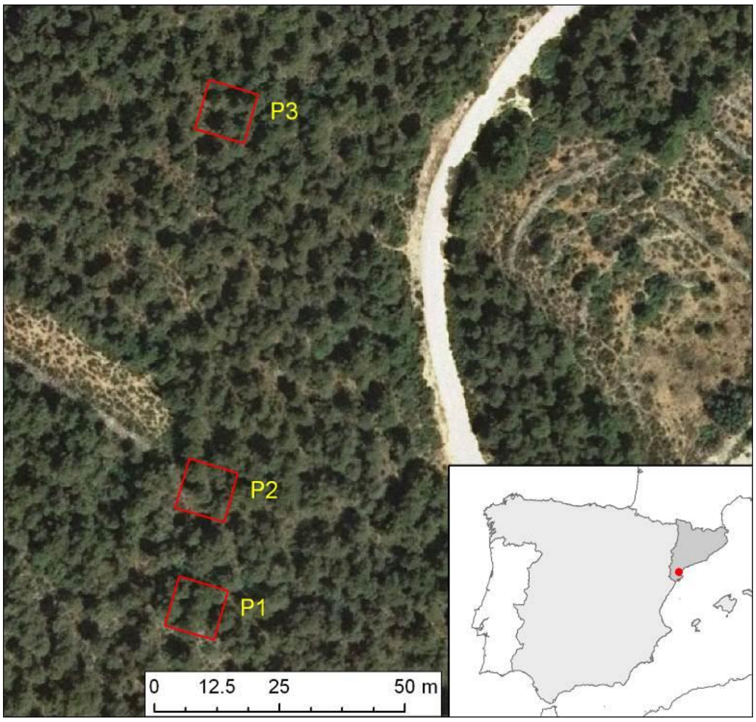

Figure 1. Location of study area and of the three sampling plots. Source: PNOA ordered by © Instituto Geográfico Nacional de España

Outside the plots, 20 individuals of each of the five dominant shrub species (*Rosmarinus officinalis*, *Pistacia lentiscus*, *Quercus coccifera*, *Ulex parviflorus* and *Erica multiflora*) were selected taking into account the dimensional range of each species in the site. Individuals were measured (minimum and maximum crown height and crown diameter), cut, weighted in the field, and reweighted after removing the fine live fraction (diameter < 6 mm) in order to develop allometric relations between the estimated volume and aerial phytomass. The data were processed in order to obtain fuel loads for the description of a CFM. The values of those parameters were then compared to the ranges found in the literature for the same species and similar Mediterranean plant communities. Additionally, those values were also compared to those of analogous fuel model types in the classifications by Scott and Burgan (2005), Anderson (1982) and the UCO40 system by Rodriguez y Silva and Molina-Martínez (2012).
Also, fine live (woody, herbaceous) and dead (fine, coarse) fuel moisture contents were sampled four times along the fire season in 2013 (June, July, August and September). Ten samples were taken by

fuel category and species, sealed, weighted (fresh weight), oven dried (80ºC) during 48h and reweighted afterwards (dry weight). Moisture content was estimated as a dry weight percentage.

3. Results

The values collected in the field for a set of fuel-related relevant characteristics and for the five sampled shrub species are presented in Table 1 along with the values found in the literature. Under the label "Proxy fuel load variables", the variables used for establishing allometric relationships are presented in the first six rows for our target species. They are followed by four woody fuel load fractions estimated based on those allometries. Below, available direct measurements of fuel load fractions obtained by destructive field sampling are recorded (Live Woody Fuel Load only), followed by total values (added fractions) obtained by any of these procedures (Aerial Phytomass).
Under the label "Custom fuel model input set" are listed some variables that are usually considered for fire modeling under semi-physical models based on Rothermel's (1972) equations, such as FARSITE (Finney 1998). Finally, moisture content data are presented, and the references are provided. In order to facilitate comparisons with fuels described in other studies, data compiled in the table are not restricted only to fuel loads.

Table 1. Fuel-related variables at the species level. The data presented in brackets correspond to FORBURN field data and the rest is bibliographic data. RO: Rosmarinus officinalis; PL: Pistacia lentiscus; QC: Quercus coccifera; UP: Ulex parviflorus; EM: Erica multiflora; (-): not available; H: height; D: diameter.

SPECIES TABLE		NAME	RO	PL	QC	UP	EM
		BIOLOGIC FORM	Nanophanerophyte	Nanophanerophyte	Nanophanerophyte	Nanophanerophyte	Nanophanerophyte
PROXY FUEL LOAD VARIABLES	ALLOMETRIC VARIABLES	Hmax crown (cm)	50-117 (10-110)	106-120 (10-150)	60-75 (10-80)	(10-85)	(15-120)
		Hmin crown (cm)	(0-70)	(0-130)	(0-40)	(0-40)	(0-70)
		Dmax crown (cm)	33.70-165 (5-150)	47.50-146.50 (5-144)	(5-100)	(10-80)	(5-120)
		Dmin crown (cm)	50-124 (3-110)	(5-110)	(5-100)	(5-50)	(5-100)
		Standing necromass length (cm)	-	-	-	-	-
		Basal diameter (cm)	9-112	-	-	-	-
	WOODY FUEL LOAD	Live Woody Fine Fuel Load (t ha-1)	-	-	-	3.89-4.9	-
		Live Woody Coarse Fuel Load (t ha-1)	-	-	-	0.27-17.6	-
		Standing Dead Woody Fine Fuel Load (t ha-1)	-	-	-	0.26-15.8	-
		Standing Dead Woody Coarse Fuel Load (t ha-1)	-	-	-	0-1.46	-
	LOAD FROM DESTRUCTIVE SAMPLING ON THE FIELD	Live Woody Fuel Load (t.ha-1)	0.33-1.30	-	-	1.94-6.36	-

	AERIAL PHYTOMASS	Total Aerial Weight (t.ha-1)	0.76-2.66 (1.69)	(10.72)	(0.90)	5.15-43.08 (0.07)	(1.78)
	ESTIMATED PHYTOVOLUME	PhytoVol_Conic (dm3)	30.80-416 (0.13-280.77)	237.80-3447.60 (0.07-287.90)	(0.07-83.77)	(0.13-62.83)	(0.03-172.79)
		PhytoVol_Cilin (dm3)	(0.39-843.3)	(0.20-864)	(0.20-251.33)	(0.39-188.5)	(0.10-518.36)
	FUEL PARTICLE DENSITY	Density_Vol_Conic (kg m-3)	410-693	530	820-930	614	-
CUSTOM FUEL MODEL INPUT SET	FUEL LOAD BY CATEGORY AND PARTICLE SIZE CLASS	Live Woody Fuel Load (t ha-1)	15-50	2.90-4.5	-	-	-
	SURFACE AREA TO VOLUME RATIO	Live Woody SAV (cm-1)	11.10-55	10.13-70.3	1.30-62.22	40.30-50	-
	EMC	Dead Fuel Moisture of Extinction (%)	-	80-85	>80	-	-
	FUEL PARTICLE PROPERTIES	Live Fuel Heat Content (kJ kg-1)	20.40-24.8	18.90-20.30	18.20-21.1	20-21	-
		Dead Fuel Heat Content (kJ kg-1)	-	-	-	-	-
MOISTURE CONTENT	MEAN DAILY WEATHER CONDITIONS (SAMPLING DAY AND THE 7 PREVIOUS DAYS)	Tmax (ºC)	(24.07-30.3)	(24.07-30.3)	(24.07-30.3)	(24.70-30.3)	-
		Precipitation (mm)	(0-1.84)	(0-1.84)	(0-1.84)	(0-1.84)	-
		Relative Humidity (%)	42-57.3 (64.5-68)	(64.50-68)	(64.50-68)	10-93 (64.50-68)	-
	MOISTURE CONTENT	Standing necromass	(6.36-58.73)	(6.36-58.73)	(6.36-58.73)	(6.36-58.73)	-
		Live Fine fuel	4.40-219 (52.42-194.27)	9.10-119 (81.45-150.48)	65-145 (52.5-85.09)	17.96-85 (52.77-124.86)	-
SOURCE			Bochet *et al.* 2000; Santana *et al.* 2011; Viegas *et al.* 2001; Cohen *et al.* 2003; Baeza *et al.* 2006; Pellizzaro *et al.* 2007a; Pellizzaro *et al.* 2007b; Cassagne *et al.* 2011; Curt 2014 (Unpublished data)	Papió and Trabaud 1991; Dimitrakopoulos 2001; Dimitrakopoulos and Panov 2001; Dimitrakopoulos and Papaioannou 2001; Cohen *et al.* 2003; Pellizzaro *et al.* 2007a; Pellizzaro *et al.* 2007b; GENCAT 2014	Dimitrakopoulos 2001; Dimitrakopoulos and Panov 2001; Dimitrakopoulos and Papaioannou 2001; Viegas *et al.* 2001; Cohen *et al.* 2003; Cassagne *et al.* 2011; GENCAT 2014	Pereira *et al.* 1995; Baeza *et al.* 2002; Cohen *et al.* 2003; Baeza *et al.* 2006; Santana *et al.* 2011; GENCAT 2014	-

For most variables, values are not available for all the species dominating the plant communities of our study area (Table 1). Those species are among the most common species that can be found in shrubland ecosystems of Western Mediterranean basin, though. This lack of data highlights the fact that many fuel-related parameters have not been sufficiently studied in previous work and shows the need of further field-based research on those variables.

The values of fuel-related relevant characteristics for some Mediterranean plant communities similar to the shrublands that have been sampled in the study area are presented in Table 2, as well as the data obtained in our site.
First rows describe the composition and cover variables of the plant communities, followed by fuel fractions estimated through destructive sampling in the field. Total values (added fractions) obtained by any of these procedures are below (Total Shrub Load).
Variables usually considered for fire modeling under semi-physical models based on Rothermel's (1972) equations are listed afterwards and shadowed in grey. Last rows provide fuel moisture data and bibliographic sources of values. Again, in order to facilitate comparisons with communities in other studies, data compiled in the table are not restricted only to fuel loads, but other variables are included.

Table 2. Fuel-related variables at the plant community level. AA: Arbutus andrachne; AU: Arbutus unedo; BR: Brachypodium retusum; BS: Buxus sempervirens; CA: Cistus albidus; CC: Cistus creticus; CH: Chamaerops humilis; CM: Crataegus monogyna; CS: Ceratonia siliqua; EA: Erica arborea; EM: Erica multiflora; FE: Festuca sp.; JC: Juniperus communis; JO: Juniperus oxycedrus; OE: Olea europaea; PA: Phillyrea latifolia; PB: Pinus brutia; PF: Phlomis fruticosa; PH: Pinus halepensis; PL: Pistacia lentiscus; PM: Phyllyrea media; PP: Pinus pinea; QC: Quercus coccifera; QI: Quercus ilex; RA: Rhamnus alaternus; RO: Rosmarinus officinalis; SS: Sarcopoterium spinoum; ST: Stipa sp.; UP: Ulex parviflorus; TV: Thymus vulgaris; (-): not available

PLANT COMMUNITY	SPECIES COMPOSITION	UP, RO, PL, EM, QC	RO, UP, CA	RO, UP, CA	PL, AA, QC, PL, CC, CS, CM, RA	QC, SS, AA, PL	UP, RO, QC, BR	UP, BR, CA, RO	QC, QI, PL, AU, EA	PB, PL, QC, AU, PM
	Species OVER 60% in cover	PL	RO	RO	PL	QC	UP	UP	QC	PB
	OTHER SPECIES	UP, RO, EM, QC	UP, CA	UP, CA	AA, QC, PL, CC, CS, CM, RA	SS, AA, PL	RO, QC, BR	CA, RO	QI, PL, AU, EA	PL, QC, AU, PM
COVER	Dead 1-hr (%)	-	37.80	46.3-90.1	-	-	-	-	-	-
	Live Herbaceous (%)	54	1.30	13.2-31.3	-	-	-	-	-	-
	Specfic Cover (%)	UP 3.8%, RO 18%, QC 16.34%, PL 50.38, EM 10 %	-	-	-	-		UP (>50), CA (1.5)	-	-
	Shrub_Cover (%)	46.7	10.40	59.5-76	-	-	-	-	-	-
	Total Cover(%)	100	-	-		65 - 90	-	-	-	-
LOAD FROM DESTRUCTIVE SAMPLING ON THE FIELD	Live Woody Fine Fuel Load (tn.ha-1)	-	-	-	11.80-21.70	9.50 – 14.50	-	-	-	-
	Live Woody Coarse Fuel Load (tn.ha-1)	-	-	-	-	2.30 – 19.20	-	-	-	-
	Standing Dead Fuel Load Woody (tn.ha-1)	-	-	-	-	4.60 – 8.20	-	-	-	-
SHRUB_LOAD	Total Shrub_Load (tn.ha-1)	(15.24)	-	-	24.70-51.30	19.30 – 36.80	5.00-35.00	-	-	-
FUEL LOAD BY CATEGORY AND PARTICLE SIZE CLASS	Dead Fine Fuel Load 1h (t ha-1)	-	-	-	-	-	-	9.24-18.96	7.39	8.48
	Dead Fuel Load 10h (t ha-1)	-	-	-	-	-	-	-	6.80	3.58
	Dead Fuel Load 100h (t ha-1)	-	-	-	-	-	-	-	3.58	1.80
	Live Fuel Load Herbaceous (t ha-1)	-	-	-	-	-	-	1.87-4.15	-	0.10
	Live Fuel Load Woody (t ha-1)	-	-	-	-	-	-	10.57-20.08	7.68	3.26
SURFACE AREA TO VOLUME RATIO	1hSAV (cm-1)	-	-	-	-	-	-	105.20	24.60	49.21
	10hSAV (cm-1)	-	-	-	-	-	-	-	59.06	59.06
	100hSAV (cm-1)	-	-	-	-	-	-	-	52.49	24.61
	Live Herbaceous SAV (cm-1)	-	-	-	-	-	-	82.02	-	-

	Live Woody SAV (cm-1)	(0.24)	-	-	-	-	-	49.21	-	-
FD	Fuelbed Depth (cm)	-	-	-	-	-	-	-	111.86	24.99
EMC	Dead Fuel Moisture of Extinction (%)	-	-	-	-	-	-	-	14.00	25.00
FUEL PARTICLE PROPERTIES	Dead Fuel Heat Content (kJ kg-1)	-	-	-	-	-	-	21050	-	-
	Live Fuel Heat Content (kJ kg-1)	-	-	-	-	-	-	19500	-	-
MEAN DAILY WEATHER CONDITIONS	Tmax (ºC)	(13.7)	-	-	-	22.50-29.30	-	-	-	-
	Relative Humidity (%)	(49.87)	-	-	-	50-77	-	67-93	-	-
MOISTURE CONTENT	Dead Fuel 1h	-	-	-	13.30-67.60	-	-	52-60	-	-
	Dead Fuel 10h	-	-	-	-	-	-	-	-	-
	Dead Fuel 100h	-	-	-	-	-	-	-	-	-
	Live Fine Fuel	-	-	-	60.30-164	28.20-50.70	-	85-174	-	-
	Live Herbaceous	-	-	-	-	-	-	103-133	-	-
SOURCE		FORBURN	Santana *et al.* 2012	Santana *et al.* 2012	Saglam *et al.* 2008	Bilgili and Saglam 2003	Duguy *et al.* 2007	De Luis *et al.* 2004; Baeza and Vallejo 2008	Kalabokidis *et al.* 2013	Kalabokidis *et al.* 2013

Once more, the compilation of available data presented in the table shows the need of further research for implementing better structural descriptions of some very common Mediterranean plant communities. This lack of reliable data for most fuel-related relevant vegetation parameters makes very difficult an appropriate structural characterization of the corresponding plant communities and, thus, a good description of the derived custom fuel models.

As for our FORBURN data, we found that before the prescribed burning, the total herbaceous cover in the three sampled plots was 50, 61 and 51%, respectively, while the total shrub cover was 58, 41 and 40%, respectively. Among shrubs, *Pistacia lentiscus* was the species with the largest covers (36.6 - 69%) and estimated phytovolumes (in % of total phytovolume of shrub understorey in the community, 33.3 - 73.5%), followed by *Rosmarinus officinalis* (6.5 – 35%, for cover, and 6.1 - 41.7% respectively), *Quercus coccifera* (4.9 - 37.1% cover and 2.3 - 26%), *Erica multiflora* (2.3 - 17.3% cover and 1.5 - 17.8%) and *Ulex parviflorus* (2.2 - 6.4% cover and 1.7 - 4.3% total phytovolume of shrub understorey).

Other species present (*Rhamnus lycioides, Rhamnus alaternus, Chamaerops humilis, Thymus vulgaris* and *Genista sp.*) had very low cover values (always less than 1.8%) and were not considered for our fuel model description purposes. Given the generally rather low percentage covers reached by *Ulex parviflorus* in the studied shrubland, the standing dead woody fuel loads of that species were not considered either.

Over the three plots, shrubs height did not exceed 150 cm. Species averaged heights were weighted by cover (Martins-Fernandes 2001) to provide an integrated site value of 0.68 m. The mean total shrub biomass in the pre-burn situation reached on average 15.25 tn.ha-1. This aerial weight of shrubs or live woody fuel load (LWFL) was lower than those found in Saglam *et al*. (2008) and Bilgili and Saglam (2003), within the range in Duguy *et al*. (2007), De Luis *et al*. (2004) and Baeza and Vallejo (2008), and higher than in Kalabokidis *et al*. (2013). This value is also higher than the total fuel load values provided by Anderson (1982) for shrub-type models 6 and 7 (14.8 and 12.1 t.ha-1, respectively), by Scott and Burgan (2005) for shrub-type model SH2 (12.9 t.ha-1), and by Rodriguez y Silva and Molina-Martínez (2012) for M5, HPM4 and HPM5 models (10.55, 11.13 and 10.74 t.ha-1, respectively). It is smaller than the total fuel load value provided by Anderson (1982) for shrub-type model 4 (32.1 t ha-1), although this fuel load amount includes a large value of dead fuel load (12.4 t ha-1). Our plant community value is also smaller than the fuel load value provided by Scott and Burgan (2005) for shrub-type model SH5 (16.09 t ha-1). This latter fuel model appears, nevertheless, as the

most appropriate standard fuel model that might be attributed to the studied community. SH5 is described as a shrubland with a heavy shrub load, in which the shrub layer height may range from 120 to 180 cm (Scott and Burgan 2005).
Those results are indicative of the wide margin for error that may exist when using for fire modeling fuel models that have not been developed in a customized way, i.e. based on local vegetation structural data collected on the field. They also confirm the need of new CFMs.
An aspect that sometimes makes difficult the appropriate understanding or selection of both standard and custom fuel models, as well as the comparisons between them, is the use of different units by the authors. We have presented all the variables shown in our tables using international system units in order to make those tables more useful for future evaluations and decision processes.

4. Discussion and management implications.

When considering individual species, Aleppo pine stands in our study site appear to be characterized by a shrub understory with smaller total fuel loads than those found in other Mediterranean ecosystems analyzed in the literature. The dimensional values found for the main shrubs present in our site are similar to those appearing in published works, but their aerial phytomasses and phytovolumes per unit area appear to be smaller. In our site, the understory is dominated in cover, volume and biomass by *Pistacia lentiscus*, although with smaller biomass values (10.72 t.ha-1) than those found by other authors, ranging from 14.19 to 158.20 t.ha-1 (Papió and Trabaud 1991; Dimitrakopoulos 2001; Dimitrakopoulos and Panov 2001; Dimitrakopoulos and Papaioannou 2001; Cohen *et al*. 2003; Pellizzaro *et al*. 2007a; Pellizzaro *et al.* 2007b). The differences may be explained by different conditions in these studies in terms of climatic variables, but also species composition and tree cover. The study by Papió and Trabaud (1991) was placed in a location with a mixed garrigue of *Quercus coccifera* with 919 mm of annual precipitation and no tree cover, while Pellizzaro *et al*. (2007a) and Pellizzaro *et al.* (2007b) worked in maquis and garrigue in a site with about 600 mm and without tree cover. Data in Dimitrakopoulos (2001), Dimitrakopoulos and Panov (2001) and Dimitrakopoulos and Papaioannou (2001) comes from general phrygana and maquis formations, but no climatic data is provided. For Cohen *et al*. (2003) only general locations are referred. Comparability among results is complicated by the lack of descriptions in these cases, but clearly studies in locations with a tree cover are lacking, which justifies our work.
For comparisons at the community level, a lower total shrub biomass in the pre-burn situation was in agreement with the fact that the mean annual rainfall in our study area is lower (300 - 400 mm, with a quite significant water deficit spanning 3-5 months with semiarid conditions, POUM Perello, 2010) than in other studies in which mean annual precipitation ranges between 450 and 700 mm (Lesvos, Greece, Kalabokidis *et al*. 2013), 466 and 700 mm (Valencia Region, Spain, De Luis *et al*. 2004; Duguy *et al*. 2007; Baeza and Vallejo 2008; Santana *et al*. 2012), or even 805 mm and 1200 mm (Turkey, Bilgili and Saglam 2003; Saglam *et al*. 2003). A lower biomass value resulting from more adverse ecological site conditions may be the major causative factor.
However, differences in the procedures followed by different authors for estimating the apparent phytovolumes and other proxy or intermediate variables may certainly have had also an impact on biomass estimations.
Both species and community FORBURN fuel load data estimates highlight the difficulty of carrying out comparative studies considering Mediterranean-type shrublands that may cover a wide range of ecological and land use history situations, and also the crucial need of standardizing the experimental protocols for the characterization of such plant communities in relation to the description of a larger number of custom fuel models. This also applies to other important variables, such as the fuel moisture, which is currently estimated with drying protocols varying from 24 h at 105 ºC (Viegas *et al*. 2001; Saglam *et al*. 2008) to 48 h at 60 ºC (Rodríguez y Silva and Molina-Martinez 2012), for instance.

The fact that in our pine stands the understory is dominated in cover, volume and biomass by *Pistacia lentiscus* raises questions regarding past silvicultural treatments implemented in those stands, but also about future stand treatments. The mechanical fuel reduction treatment applied in 1998 may have favored this species and controlled, on the contrary, the presence of some seeder shrubs (Baeza *et al.* 2003).

Unless excessively tall and thus producing ladder fuels in the pine stands that would increase the risk of crown fires, *Pistacia lentiscus* is a resprouter species, which is usually considered for ecological restoration purposes in Mediterranean fire-prone ecosystems, since its presence gives resilience to those systems (CEAM 2009).

On the contrary, *Ulex parviflorus (gorse)* and *Rosmarinus officinalis* are obligate seeders, which tend to accumulate large amounts of fine dead fuels and need to be controlled (Duguy and Baeza 2009). In gorse communities, in particular, the standing necromass incrases strongly with age, promoting conditions conducive to high intensity fires (Baeza *et al.* 2006). It has been recommended, therefore, to apply a combination of treatments, such as mechanical fuel reduction actions combined with repeated prescribed burnings in order to decrease fuel loads in such communities (Baeza and Duguy 2009).

A single prescribed fire conducted in 2010 in a similar pine stand adjacent to our site seems to have generated this reduction effect over *Ulex parviflorus* cover (M. Castellnou, personal communication, October 2012).

In any case, fuel reduction treatments must be designed taking into account the characteristics and ecological requirements of the species within the target ecosystems (Baeza 2004) and, particularly, the reproductive biology of the key species (Baeza and Duguy 2009). Within a climate change context, treatments strategies should also consider the need of an increased resilience of ecosystems to fire, conservation and promotion of biodiversity, carbon budgets and desertification issues (Hurteau *et al.* 2008).

As this project is still ongoing, post-fire data are not presented at this time, but if those data show that the structural characteristics of the plant community have not been significantly modified by the prescribed fire, the description of a different custom fuel model for the post-fire situation will not be justified. This would, of course, mean that the executed burning has not been an efficient tool in relation to fuel control and, therefore, fire prevention. Prescribed burning may have modified, however, the species composition of the *Pinus halepensis* forest understory. Such changes would require a further analysis, if they happen.

The comparison of total fuel load values (total shrub aerial biomass) of the studied community with those given for existing fuel model types under different classification systems, which are often used in Mediterranean ecosystems, leads to consider that significant errors can be made when using those latter fuel models for fire modeling in our region. It clearly shows the need of describing local custom fuel models for shrublands developed under an Aleppo pine canopy in semi-arid Mediterranean conditions.

5. Acknowledgements

We gratefully acknowledge funding from the Spanish Ministry of Science and Innovation to the ForBurn-Land project (AGL2012-40098-C03-02), and the field work and literature search tasks by Eduardo Collado, Laura Fuentes López, Jesús Godoy Puertas, Milena Prendin Navarro, Joaquim Garcia Codina and Adrián Cardil.

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