



**ADVANCES IN  
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RESEARCH**

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# Soil temperatures and fuel consumption in different species during three experimental fires as a fire severity measure

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## Abstract

Forest fires are a recurrent disturbance in Mediterranean ecosystems, and the effect on the structure and dynamics of vegetation may depend largely on fire severity. Our knowledge of how fuel consumption in different species can be an indicator of fire severity is limited, and very few studies have covered this aspect. Our initial work hypothesis is based on the existence of different ecological severities according to each species' structural characteristics. The work aims to determine degree of severity by assessing biomass of different species consumed during a fire. Three experimental fires in Ayora (eastern Iberian Peninsula) were conducted, and subplots dominated by *Rosmarinus officinalis*, *Quercus coccifera*, *Erica multiflora* and *Juniperus oxycedrus* were selected. The soil temperature during fire was measured using thermocouples in each subplot. Average fuel consumption per species was determined by measuring the minimum diameter of the branches burned in each subplot. Our results indicate fire severity variability between species. The fuel consumption values within the subplots differed significantly between species. The largest were found for *E. multiflora* and *R. officinalis* if compared to *Q. coccifera* and *J. oxycedrus*. The temperature residence time above 40°C was very important for all species, but the longest occurred in *E. multiflora* and *J. oxycedrus*. Soil temperature and its duration were related to fuel type. The results show that fuel accumulation and its spatial distribution in the plant architecture, associated with reproductive strategy, are one of the most important traits in determining fuel consumption and soil temperature and can, therefore, play a key role in fire severity terms. These results indicate the importance of considering fuel structure and flammability of species as potential drivers of new fire regimes.

**Keywords:** *consumed biomass, fire ecology, fuel type, flammability, Mediterranean shrubland, severity degree*

## 1. Introduction

Fire is a recurrent natural disturbance in Mediterranean ecosystems which drives the dynamics of many plant communities (Naveh, 1975; Trabaud, 1980; Gill *et al.*, 1981; Pyne, 1995; Baeza *et al.*, 2006; Santana *et al.*, 2011). However, the level of severity affecting an area depends on the parameters defining the fire regime, such as: extent, frequency, recurrence period, seasonality and intensity of fires. These parameters have been discussed in several papers, but very few have attempted to relate the effects of fire on vegetation by taking into account fire severity (Pérez and Moreno, 1998; Key and Benson, 2005; Lentile *et al.*, 2006; Keely, 2009).

The effects of fire variability on the ecosystem may depend on canopy's dominant species; in particular, the structural characteristics of fuels can modulate the effects on the ecosystem. Availability of fire-prone fuel is determined by its flammability; this property varies from one species to another, and is determined by the interaction of different structural attributes (Cornelissen *et al.*, 2003; Alessio *et al.*, 2008). Differences in dead twigs retention (Zedler, 1995; Schwilk, 2003; de Luis *et al.*, 2004; Bond and Keeley, 2005), a property that changes with time (Baeza *et al.*, 2011), and structural differences in the arrangement of leaves and stems (van Wilgen *et al.*, 1990), affect the temperatures reached during the fire and the heat they emit.

Some research has suggested that differences in fuel structural attributes between different species

induce variability in soil temperature and fuel consumption (Pérez and Moreno, 1998; Molina and Llinares, 2001; Santana *et al.*, 2011). Other studies have shown relationships between post-fire regeneration strategies (seeders or resprouters) and flammability traits (Zedler *et al.*, 1983; Lloret *et al.*, 2003; Bond and Keeley, 2005; Saura-Mas *et al.*, 2010). Therefore, further studies are required to clarify the effects of the fuel characteristics of different functional groups in relation to fire severity. This study focused on fire severity, and specifically on the relationships between two related proxies: fuel consumption and soil temperatures. These relationships were assessed in species with different functional attributes (seeders or resprouters). Our aim was to know how fuel consumption in different species can act as a fire severity indicator.

## 2. Methods

This work was conducted in Ayora, eastern Iberian Peninsula (39 ° 05'-40 ° 15 'N, 0 ° 51'-1 ° 59' W). In April 2009, three plots of 33x33 m were burned. The areas were previously delimited by a 4-metre-wide fire break in which vegetation was eliminated through mechanical brushing. Experimental burnings were carried out under strict safety conditions and were monitored by forest services. Vegetation was a shrubland dominated by seeders such as *Rosmarinus officinalis* and *Ulex parviflorus*. The resprouting species, these being *Erica multiflora*, *Quercus coccifera* and *Juniperus oxycedrus*, appeared between the seeder species distributed in a mosaic. This vegetation came from the regeneration of the pine forests burned in the 1979 Ayora fire, which means a vegetation age of 30. Thirty-six subplots of 50x50 cm were randomly selected prior to the fire. A thermocouple connected to a datalogger was placed in the centre of each subplot on the soil surface, which recorded the temperature every 10 seconds. After the fires, the diameter of burned twig tips were measured for the different species in each subplot following the methodology of Moreno and Oechel (1989). Furthermore, the average fuel consumption for each species was determined using allometric equations, which were applied to the diameters of the burned twig tips. The differences between the amounts of consumed biomass among the various species were analysed by one-way ANOVA. The residence time of temperature above 40°C was related using regressions with the terminal burned twigs diameter and consumed biomass.

## 3. Results

Biomass consumption differed among the three fires. Fire 3, with a maximum temperature of 710°C was the severest, followed by Fire 2 and Fire 1 with 676°C and 670°C, respectively. The variability in fire severity among the different species was also observed. The highest consumptions were observed for *E. multiflora* and *R. officinalis* rather than for *Q. coccifera* and *J. oxycedrus* (Figure 1).

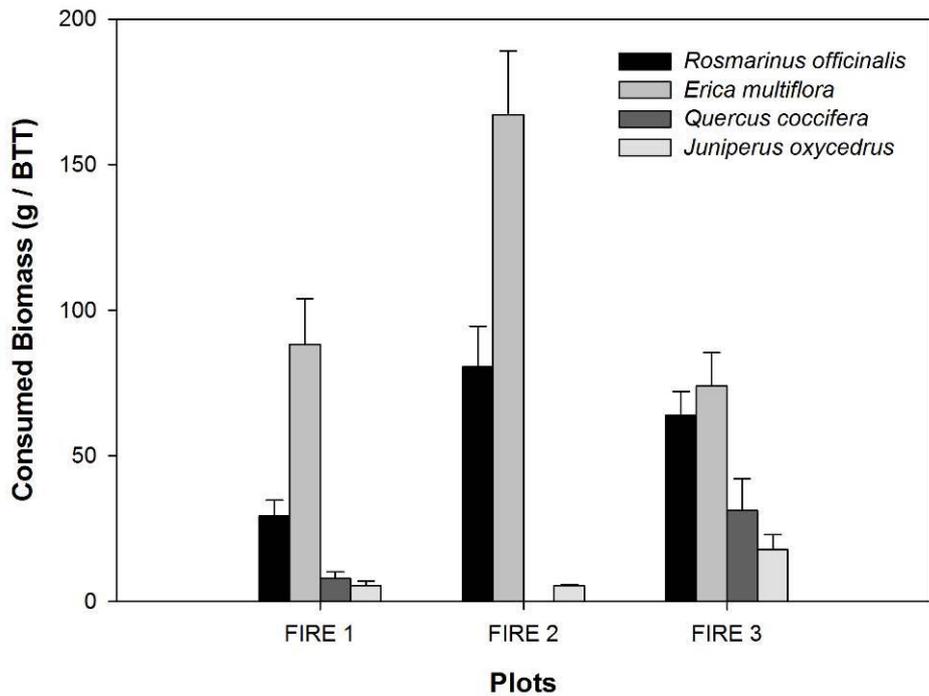


Figure 1. Consumed biomass (mean  $\pm$  standard error) for the different species during each fire. (BTT: Burned Twig Tips)

The residence time of temperature above 40°C was high for all the species, and ranged between 74 and 92 minutes, but longer durations were recorded for *E. multiflora* and *J. oxycedrus* (Figure 2). Temperatures above 60°C and 80°C were of intermediate duration, and residence time was longer for *Q. coccifera*. For temperatures above 400°C, duration was relatively low (under 5 minutes) for all the species.

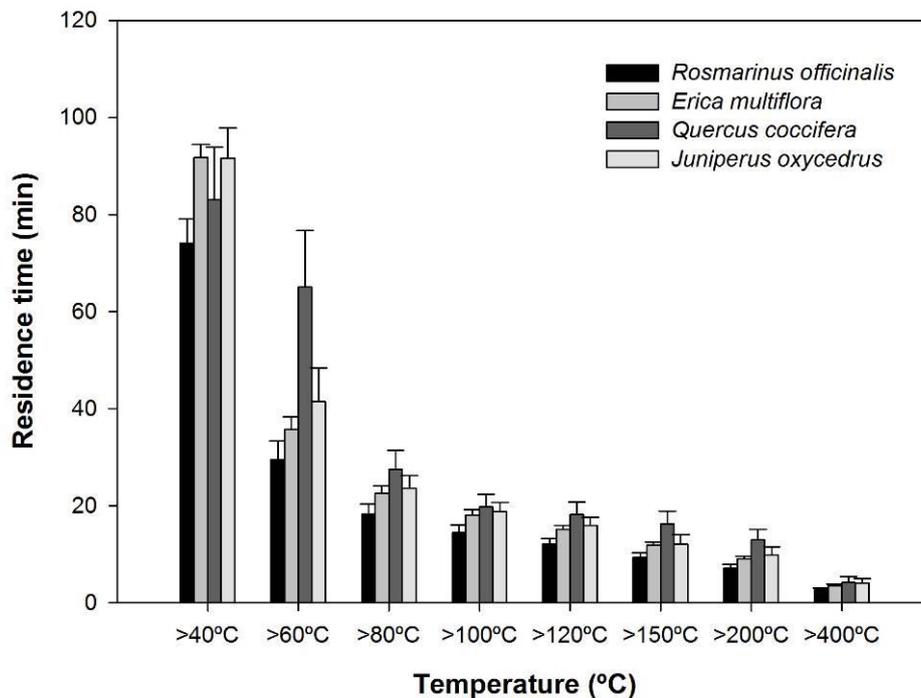


Figure 2. Residence time of temperatures at ground level (0 cm) for the different species (mean  $\pm$  standard error)

The diameters of the burned twig tips and consumed biomass correlated positively with residence times of above 40°C for *R. officinalis* and *J. oxycedrus* ( $P < 0.01$ ; Table 1). Furthermore, the consumed biomass of *R. officinalis* correlated significantly with the residence times above 100°C and 120°C, while this effect was not observed for the consumed biomass and the diameters of terminal tips of *Q. coccifera* and *E. multiflora*.

*Table 1. Correlation between the temperature residence time and the diameters of burned twig tips and biomass consumption (\*  $P < 0.05$ , \*\*  $P < 0.01$ ); (CB: Consumed biomass, DTT: Diameters of twig tips)*

Temperature residence time (min)	<i>Rosmarinus</i>		<i>Quercus</i>		<i>Erica</i>		<i>Juniperus</i>	
	CB (g)	DTT (mm)	CB (g)	DTT (mm)	CB (g)	DTT (mm)	CB (g)	DTT (mm)
>40°C	<b>0.2146**</b>	<b>0.2084**</b>	0.1751	0.1363	0.0000939	0.1309	<b>0.509**</b>	<b>0.5175**</b>
>60°C	0.0929	0.0821	0.2917	0.2437	0.0126	0.0988	0.1102	0.2437
>80°C	0.1275	0.083	0.2339	0.1857	0.011	0.083	0.0689	0.0422
>100°C	<b>0.1364*</b>	0.0806	0.3515	0.271	0.005	0.0043	0.129	0.0857
>120°C	<b>0.1306*</b>	0.1144	0.3575	0.2719	0.0019	0.0031	0.1686	0.1064
>150°C	0.109	0.103	0.4373	0.3351	0.000021	0.0009	0.1273	0.0746
>200°C	0.1035	0.0983	0.4905	0.3792	0	0.0002	0.1491	0.1015
>400°C	0.1071	0.1221	0.2625	0.2041	0.0079	0.0202	0.1864	0.1707

#### 4. Discussion

The present study reveals the existence of variability in fire severity between our experimental fires, even though they took place at the same time, in similar communities and under similar climatic conditions. This fact has been pointed out in other communities (Baeza, 2001). It has also been suggested that variation in vegetation moisture might be responsible for these differences (Johnson and Miyanishi, 1995). Fuel moisture content is the main factor to control the fire spread rate in controlled burnings applied to young and mature Mediterranean gorse (dominated by *Ulex parviflorus*; Baeza *et al.*, 2002b). This variability is also due to the fuel characteristics of the component species and may, thus, depend on the assembly of different compositions in each plot. In fact, specific vegetation composition seems to play a decisive role in the temperatures recorded during a controlled burning in Mediterranean shrublands (De Luis *et al.*, 2004).

Our study reveals that seeder species *R. officinalis* was the most flammable species in contrast to resprouter species. One exception was *E. multiflora*, which also showed high flammability. In line with this, some previous studies have correlated flammability characteristics with post-fire regeneration strategies in plants (Bond and Keeley 2005; Ojeda *et al.*, 2010; Saura-Mas *et al.*, 2010). Mediterranean Basin seeders grow much faster and allocate more biomass on leaves than resprouters. Seeders are mainly non-sclerophyllous and are associated with early succession stages, whereas resprouters are mainly sclerophyllous and are associated with late succession stages (Keeley, 1998; Pausas, 1999; Verdú, 2000). In fact seeders need lower temperatures to produce flame and exhibit fast combustion (Saura-Mas *et al.*, 2010, Santana *et al.*, 2011). However, the higher temperatures required by resprouters to initiate combustion, together their large fuel loads, can make fires not easily to extinguish (Andrews and Bevins, 2003). These preliminary results suggest that the ecosystems dominated by seeders are more prone to fire and burn more severely than those dominated by resprouting species.

Moreover, fire behaviour and its impact potential are related to the amount of accumulated fuel which, in turn, depends on the time elapsed since the last fire (Baeza *et al.*, 2011). In fact, the differences observed between each species' consumed biomass are attributable to not only the structural

differences between species, but also to the retention of dead branches (Schwilk, 2003; Bond and Keeley, 2005). Our results indicate that shrub species such as *E. multiflora* and *R. officinalis* obtain much higher consumed biomass values if compared to tree or semi-tree species such as *Q. coccifera* and *J. oxycedrus*. Baeza *et al.* (2011) suggested that in advanced succession stages, shrub species like *E. multiflora* obtain higher percentages of dead fuel and dead thin twigs than other tree species such as *Q. coccifera* and *J. oxycedrus*. This suggests that the plant communities dominated by these shrub species are more likely to burn.

The fuel structure differences between species are significant in soil temperatures modulation and temperature residence times. In our study, *R. officinalis* displayed shorter temperature residence times despite its greater fuel consumption. This can be explained by its fast combustion due to a more dispersed fuel load in its structure. In contrast, the residence time was longer for resprouters with thicker fuels and larger amounts of fuel. These species require higher temperatures and longer times for the combustion of their biomass.

Indeed as has been widely documented in other fire-prone shrublands with similar fuel loads, the maximum soil temperatures and the longest residence times are significantly higher and longer, respectively, for fuels of lower height and higher bulk density (Molina and Llinares, 2001; Wright and Clarke, 2008). These results agree with other studies in conducted Mediterranean shrublands (Bradstock *et al.*, 1992, 1993; Savadogo *et al.*, 2006; Baeza *et al.*, 2002a; Santana *et al.*, 2011).

Our results show that differences in fuel accumulation among species with a different reproductive strategy, as well as their spatial distribution in the plant architecture, represent one of the most important structure features that determine fuel consumption and soil temperature. Consequently, it may play a key role in fire severity determination.

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