P1.16 INFLUENCE OF SEASONAL WEATHER VARIATIONS ON FUEL STATUS FOR SOME SHRUBS TYPICAL OF MEDITERRANEAN BASIN

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1. INTRODUCTION

The term flammability refers to the ability of a particular fuel to ignite and sustain fire. Although there is not an accepted standard for flammability vegetation measurement, most methods are based on measuring the "ignition delay time" (ID time) or time to ignition, which is the time required for the fuel to start ignition in presence of a constant heat source (Trabaud, 1976; Valette, 1990; Dimitrakopoulos and Papaioannou, 2001). Ignitability of living vegetation is influenced by several factors including structural properties, chemical properties and moisture content. The moisture content of living plant is a critical parameter affecting fire ignition (Van Wagner, 1977; Chandler et al., 1983; Carlson and Burgan, 2003). Depending on the moisture content, living vegetation may act as a heat source or a heat sink, either contributing to the energy of fire or retarding fire propagation and intensity (Pyne et al., 1996; Ralph and Nelson, 2001).

Evergreen sclerophyll shrubland is a prominent feature of Mediterranean Basin. Moreover, Mediterranean shrub species are an important component of the understorey vegetation that constitutes the surface fuels primarily responsible for the ignition and the spread of wildland fires in Mediterranean forests (Dimitrakopoulos and Bemmerzouk, 2003). In Mediterranean areas, where climate is characterized by variable winter precipitation and prolonged summer drought, vegetation has flammable structure and chemistry that allow live fuels to propagate wildfire. Moreover, a decrease in vegetation moisture, due to a seasonal decrease of soil water availability, can determine severe fire danger when combined with high meteorological risk (i.e. strong summer wind) (Dennison et al., 2003).

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Therefore, the knowledge of seasonal variation of ignitability and vegetation moisture content could contribute to identify critical periods of high fire risk in Mediterranean maquis ecosystems.

The main objectives of this work were (i) to describe the seasonal pattern of live fine fuel moisture content (LFMC) and ignitability values for some Mediterranean shrubs, and (ii) to evaluate the influence of weather seasonality, on LFMC variation.

2. MATERIALS AND METHODS

The study was carried out in a natural reserve located in North Western Sardinia, Italy (40° 36' N; 8° 09' E, 30 m a.s.l.). The climate is Mediterranean with a water deficit from May through September and precipitation mainly concentrated in autumn and winter. The mean annual rainfall is 640 mm and the mean annual air temperature is 16.8 °C. The soils are Luvi and Litosoils, neutral, with depth rarely exceeding 0.2-0.3 m. The study area is covered by Mediterranean maquis and gariga, developed after a fire event occurred in middle 1970s. A detailed site vegetation description has been reported in previous works (Pellizzaro et al., 2003).

ID time and LFMC were measured from October 2003 to October 2004, monthly or bi-monthly, on four dominant species of the study area that are very common in the Western Mediterranean Basin: *Cistus monspeliensis* L., *Phillyrea angustifolia* L., *Pistacia lentiscus* L., and *Rosmarinus officinalis* L.

Samples of live fine fuel, consisting of terminal portions of twigs were collected from outer crown. Phenological observations were made at the moment of sampling. Ignitability test was performed using a standard epiradiator of 500 W constant nominal power with a pilot flame located 0.04 m above the center of the disk, according to the methodology described by Valette (1990). For each species, a total of 45 samples were prepared. According to the method proposed by Valette (1990), species were classified as low or moderately flammable when ID time values were higher than 27 s, as flammable when ID time values ranged between 17 and 26, and very or extremely flammable when ID time values were smaller than 17 s.

Moreover, four samples of 5 grams were dried in a oven for 24 hours at 104 °C to determine live fine fuel moisture content (LFMC) for each species. LFMC was expressed as percentage of dry weight.

During the whole period of experimentation, meteorological variables were recorded by an automatic weather station located in the study site, and the soil moisture content at 0.2 m deep was monitored by TDR probes (Campbell, CS 615).

Cumulated values of the daily precipitation over different periods before sampling date (15, 30, 60, and 90 days) were calculated. In addition, a Canopy Drought Stress Index (CDSI) (Baldocchi, 1997) was calculated. CDSI is defined as the ratio between the cumulative precipitation (ΣP) and cumulative reference evapotranspiration (ΣETo) over a period of time. ETo was estimated using the Hargreaves equation (1975).

The results of the ignitability test were subjected to regression analysis in order to describe for each species the relations between time to ignition and seasonal variation of fuel moisture content. A one way ANOVAs with measured plant parameters (LFMC and ID time) as dependent variable, and date of sampling as independent factor, was performed to test the effect of season. Finally, correlation analysis was performed in order to test the significance of linear relationships between (i) LFMC and ΣP or CDSI, calculated over different period before sampling; (ii) between LFMC and soil moisture content values and (iii) between LFMC and the mean value of daily maximum air temperature calculated over 10 days before sampling.

3. RESULTS and DISCUSSION

Highly significant relations between LFMC and time to ignition were observed for all species and the moisture content variation accounted for most of the variance in the time to ignition values (table 1).

These results confirm what other authors reported about the relationship between live fine fuel moisture and ignitability in Mediterranean species (Trabaud, 1976; Bunting et al., 1983; Hernando Lara et al., 1994; Dimitrakopoulos and Papaioannou, 2001). Water must be vaporized before the fuel can be ignited, so that higher moisture content means a higher quantity of heat needed to reach the temperature of ignition (Pyne et al. 1996).

Table 1 – Regression statistics of ID time versus LFMC.

	Regression model $y = \alpha + \beta x$			
Species	α	β	R^2	Sign.
Cistus monspeliensis	8.70	0.09	0.73	**
Rosmarinus officinalis	5.61	0.13	0.85	***
Phillyrea angustifolia	1.52	0.17	0.72	**
Pistacia lentiscus	1.78	0.20	0.94	***

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

Although the seasonal behavior of time to ignition was very close to that one observed for fuel moisture content for all the studied species, the seasonal trend and the range of LFMC and ID time values were very different.

Cistus and *Rosmarinus* showed the highest seasonal variability on LFMC and ID time (Fig 1). The lower LFMC and ID time values were recorded in summer, whereas a clear increase of values was observed in autumn when rainfall occurred. The highest LFMC and ID time values were observed in winter and spring. *Cistus* and *Rosmarinus* LFMC values were highly correlated with ΣP or CDSI when period of 15, 30 or 60 days before sampling were considered (table 2). Significant correlations were also observed between LFMC and soil moisture content values or mean value of maximum air temperature calculated over 10 days before sampling (table 3). *Pistacia lentiscus* and *Phillyrea angustifolia* showed low LFMC and ID time seasonal variability (Fig. 1). These species showed values of LFMC and ID time almost constant during the cold period, whereas small decreases were observed in late summer. In late spring an increase of LFMC values was observed for *Phillyrea angustifolia* when the plants were in resprouting phase.

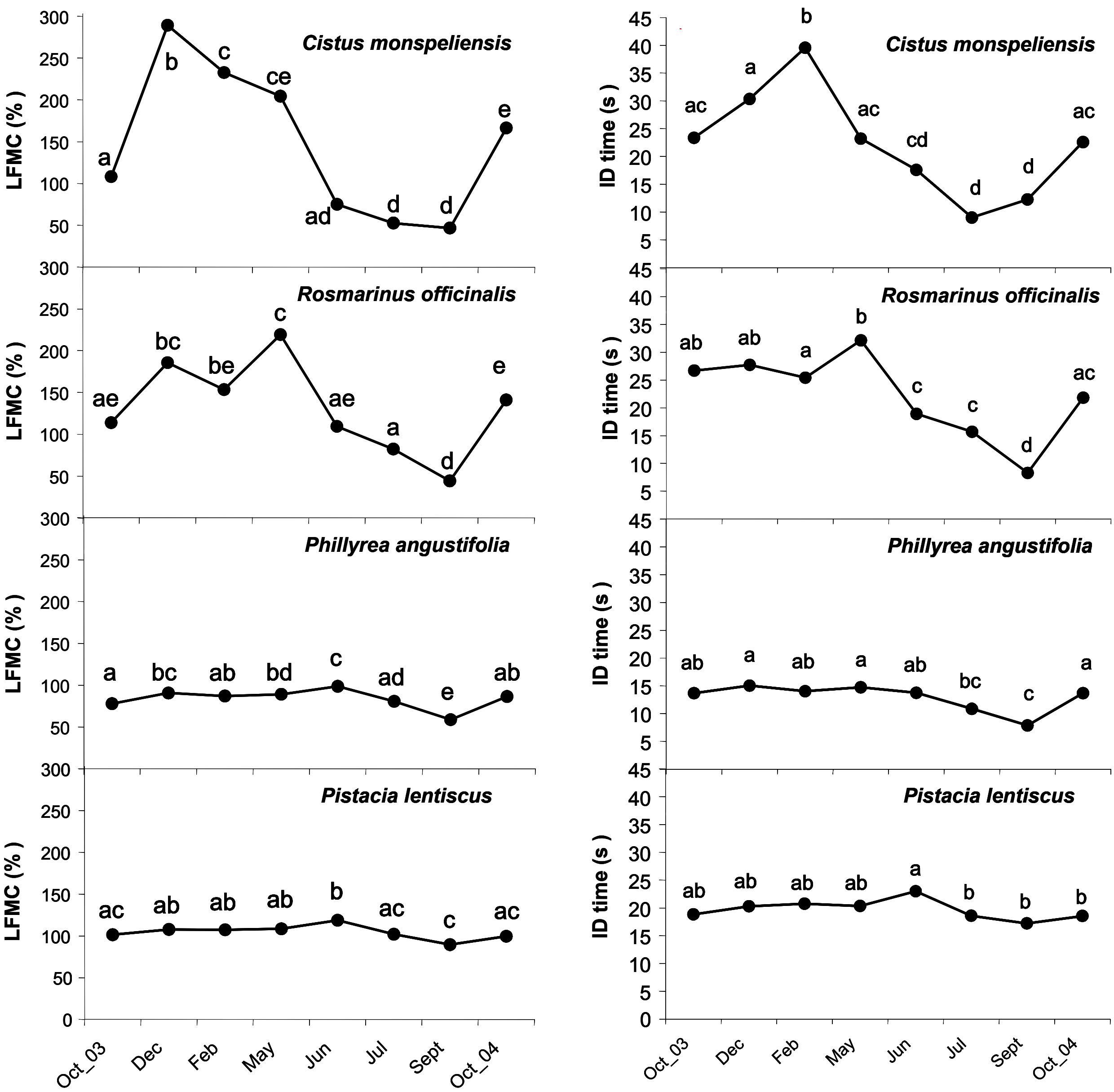

Figure 1. Average values of live fuel moisture content and time to ignition of the four different species studied. Mean values followed by the same letters are not significantly different for p≤0.01 by Duncan's test.

For *Pistacia* and *Phillyrea* significant correlation coefficients between LFMC and ΣP values were found only when ΣP was calculated considering 90 days before sampling. No significant relations were found for the other cases (tables 2 and 3).

According to our results, the species examined could be classified in two groups: (i) *Cistus* and *Rosmarinus* with LFMC, and consequently ID time values strongly sensitive to seasonal changes and well correlated with meteorological variables; (ii) *Pistacia* and *Phillyrea* with LFMC values that seemed to be independent on seasons. A small decrease of this variable was observed only in late summer when drought conditions were particularly severe.

These behaviours can be related to the functional types of the plants. In living fuels the moisture content of foliage and small twigs is governed by the relative rates of water uptake through the roots and of water loss by transpiration (Castro et al., 2003 ; Piñol et al.,1998). In Mediterranean species, both rates are controlled by different physiological and morphological adaptive strategies adopted by plants to cope summer drought season typical of Mediterranean climate.

Table 2. Significance of correlation coefficient between the LFMC and precipitation (ΣP) or Canopy Drought Index (CDSI) cumulated 15, 30, 60 and 90 days before sampling.

	15 days	30 days	60 days	90 days
species	Σ P			
Cistus monspeliensis	*	*	**	n.s
Rosmarinus officinalis	**	***	**	*
Phillyrea angustifolia	n.s.	n.s	n.s	*
Pistacia lentiscus	n.s.	n.s	n.s	*
	CDSI			
Cistus monspeliensis	**	***	**	*
Rosmarinus officinalis	*	**	n.s	n.s
Phillyrea angustifolia	n.s.	n.s	n.s	n.s
Pistacia lentiscus	n.s.	n.s	n.s	n.s

*p ≤0.05; **p ≤0.01; ***p ≤0.001

Table 3. Significance of correlation coefficient between the LFMC and soil moisture content or mean value of daily maximum air temperature calculated over 10 days before sampling.

species	soil moisture.	T max
Cistus monspeliensis	*	***
Rosmarinus officinalis	**	**
Phillyrea angustifolia	n.s	n.s
Pistacia lentiscus	n.s	n.s

*p ≤0.05; **p ≤0.01; ***p ≤0.001

For example, the species more sensitive to seasonal variability (*Cistus* and *Rosmarinus*) are shallow rooted shrubs and consequently particularly affected by variations in moisture availability of the soil surface layers. These species avoid water stress either by adjustment of the growing period or limiting water loss reducing their transpiring surface (Correia et al., 1992; Harley et al., 1987; Gratani and Varone, 2004; Munné-Bosch et al., 1999). *Cistus* and *Rosmarinus* show a real increase of fire risk, in term of ignitability, during the drought season. They reached time to ignition smaller than 17 s, in summer when LFMC values ranged between 70-90 %. In winter and spring, when LFMC values are equal or higher than 200 %, the fire risk, in term of ignitability, became low. So that, for this group of species, it could be useful modelling variations of live fine fuel moisture as function of meteorological variables, in order to predict a component of seasonal fire risk.

On the other hand, *Pistacia lentiscus* and *Phillyrea angustifolia* are evergreen sclerophillous species, tolerant to water stress and affected by drought conditions only when they are particularly severe. Several authors found that these species, probably because of their deep roots, rely preferably on deep water sources (Kummerow, 1981; Correia et al., 1992; Alessio et al., 2004; Manes et al., 2002). They are less sensitive to changes in moisture content of the soil surface layers, and leaves moisture content primarily depends on the moisture status of the deeper soil layers which is less dependent on seasonality. For this group of species predictive models based only on meteorological parameter can not be adequate to describe seasonal variations of fuel moisture content as reported by other authors for some species of Pinus (Viegas et al., 2001; Dimitrakopoulos and Bemmerzouk, 2003). Nevertheless, *Pistacia lentiscus* and *Phillyrea angustifolia* showed low LFMC an ID time values during the whole year. Therefore, for these species the risk related to fuel status is high and constant over all year.

4. CONCLUSIONS

In this work the important role of moisture content and of its variation on live fine fuel ignitability in Mediterranean vegetation were confirmed. Strong relationships between live fine fuel moisture content and time to ignition were observed for all species. Moreover, two groups of species were been identified as function of seasonal variability of LFMC and time to ignition: species characterized by almost constant values of LFMC and high ignitability risk all over the year, species with wide seasonal variability of LFMC and ignitability risk (low in winter, high in summer). For the second group of species, meteorological models to forecast live fine fuel moisture variation can be particularly useful in order to predict a component of seasonal fire risk.

5. REFERENCES

Alessio G.A., de Lillis, M., Brugnoli, E., lauteri M., 2004: Water source and water use efficiency in Mediterranean coastal dune vegetation. *Plant Biology* **6** (3), 350-357.

Baldocchi D., 1997: Measuring and modelling carbon dioxide and water vapour exchange over a temperate broadleaved forest during summer drought. *Plant Cell. Environ.* **20**, 295 - 312.

Bunting S.C., Wright H.A., Wallace W.H., 1983: Seasonal Variation in the Ignition Time of redberry Juniper in west Texas. *Journal of range management* **36** (2), 169-171.

Carlson J.D., Burgan R.E., 2003: Review of users' needs in operational fire danger estimation: The Oklahoma example. *International Journal of Remote Sensing*, **24** (8), 1601-1620.

Castro, F.X., Tudela, A., Sebastià, M.T., 2003: Modeling moisture content in shrubs to predict fire risk in Catalonia (Spain). *Agric. For. Meteorol.*, **116**, 49-59.

Chandler P., Cheney P., Thomas L., Trabaud L., Williams D., 1983. *Fire in Forestry vol. 1*, New York Jhon Wiley & Sons.

Correia O.A., Martins A.C., Catarino F.M., 1992: Comparative phenology and seasonal foliar nitrogen variation in mediterranean species of Portugal. *Ecologia Mediterranea*, **XVIII**:7-18.

Dennison P.E., Roberts D.A., Thorgusen S.R., Regebrugge J.C., Weise D., Lee C., 2003. Modeling seasonal change in live fuel moisture and equivalent water thickness using a cumulative water balance index. *Remote sensing of Environment* **88**, 442-452.

Dimitrakopoulos A.P., Bemmerzouk A.M. 2003: Predicting live herbaceous moisture content from a seasonal drought index. *Int. J. of Biometeorol*, **47**, 73-79.

Dimitrakopoulos A.P., Papaioannou K.K., 2001: Flammability Assessment of Mediterranean Forest Fuels. *Fire Technology*, **37**, 143-152.

Fernandes, P.M., 2001: Fire spring prediction in shrubs fuels in Portugal. *For. Ecol. Manag.*, **144**, 67-74.

Gratani L., Varone L., 2004: Leaf key traits of *Erica arborea* L., *Erica multiflora* L. and *Rosmarinus officinalis* L. co-occurring in the Mediterranean maquis. *Flora,* **199**, 58-69.

Harley P.C., Tenhunen J.D., Beyschleg W., Lang O.L., 1987: Seasonal changes in net photosynthesis rates and photosynthetic capacity leaves of *Cistus salvifolius*, a european Mediterranean semidecidous shrub. *Oecologia,* **74**: 380-388.

Hernando Lara C.,Moro C., Valette J.C., 1994: Flammability parameters and calorific values of *Erica arborea* and *Arbutus unedo*. *Proc 2nd Int. Conf. Forest Fire Research* vol. II pp 481-489. Coimbra Nov. 1994.

Kummerow J., 1981:Structure of roots and root systems. In *Ecosystems of the world 11, Mediterranean –type shrublands*. Di Castri F., Goodal D.W., and Specht R.L. (Eds). Elsevier Amsterdam 269-288.

Manes F., Capogna F., Puppi G., Vitale M. 2002: Ecophysiological characterization of *Phillyrea angustifolia* L. and response of resprouts to different fire disturbance intensities. In *Fire and Biological processes,* pp 115-130- edited by Trabaud L and Prodon R. Backhuys Publishers

Munné-Bosch S., Nogués S., Alegre L. 1999: Diurnal variations of photosynthesis and dew absorption by leaves in two evergreen shrubs growing in Mediterranean field conditions. *New Phytol*., **144**, 1069-119.

Pellizzaro G., Cesaraccio C., Asunis C., Caria C., 2003: Analysis of fuel type and vegetation structure for fire risk index development. In *Proceedings of the 2nd International wildland fire ecology and fire management Congress*. Coronado Springs resort, Orlando, Florida 16-20 November 2003.

Piñol J., Filella I., Ogaya R., Peñuelas J., 1998: Ground-based spectroradiometric estimation of live fine fuel moisture of Mediterranean plants. *Agricultural and Forest Meteorology*, **90**:173-186.

Pyne S.J., Andrews P.L., Laven R.D., 1996: Introduction to Wildland Fire. John Wiley & Sons, inc. 2nd edition

Ralph M. Nelson Jr., 2001: Water relations of forest fuels. In: *Forest Fires – behavior and ecological effects*. Johnson E.A. and Miyanishi K. Editors. Academic Press pp79-149.

Trabaud L., 1976: Inflammabilité et combustibilité des principales espèces des garrigues de la région méditerranéennes. *Oecologia Plantarum*, **11** (2). 117-136

Valette J.C., 1990: Inflammabilités des espèces forestières Méditerranéennes – Consequences sur la combustibilité des formations forestières. *Revue forestiére francaise*, **42**:76-92.

Van Wagner C.E., 1977: Conditions for the start and Spread of Crown Fires. *Canadian Journal of Forest Research*, **7**, 23-34.

Viegas .X., Piñol J., Viegas M.T., Ogaya R.,2001: Estimating live fine fuels moisture content using meteorologicaly-based indeces. *Int. J. Wildland Fire,* **10**, 223-240.