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Construction of empirical models for predicting *Pinus* sp. dead fine fuel moisture in NW Spain. I: Response to changes in temperature and relative humidity

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Abstract. A statistical methodology is presented for developing moisture content models from repeated measurements made on non-destructive repeated measurements. Empirical vapour exchange models for dead fine fuels generated in *Pinus radiata* and *P. pinaster* stands are developed by using the methodology proposed. Experiments were carried out with five types of fuel particles (surface and aerial fine fuels) of the two species of pine, in Lugo (Galicia, north-west Spain). The samples of each fuel type were collected and placed inside an instrument shelter so that vapour exchange with the atmosphere was the only source of moisture in the fuels. Statistical criteria obtained from the residuals indicated that the fitted models were acceptable. The cross-validation results also confirmed the validity of the fitted models. The model underlined the decisive role played by the time lag in dead fine fuel moisture content variation.

Additional keywords: fire behaviour, fire danger, vapour exchange.

Introduction

Fuel moisture content is considered as a critical factor in plant flammability-related parameters such as the probability of fire ignition (Blackmarr 1972; Wilson 1985; de Groot *et al.* 2005), ignition time (Trabaud 1976; Valette 1992; Albini and Reinhardt 1995; Dimitrakopoulos and Papaioannou 2001) and ignition potential (Chuvieco *et al.* 2004). Fuel moisture also plays a decisive role in forest fire propagation (e.g. Rothermel 1972; Albini 1985; Cheney *et al.* 1998). Consequently, dead fuel moisture assessment is required for fire danger rating, operational use of fire and fire suppression activities.

Fuel moisture content modelling has been considered one of the most difficult problems in forest fire danger rating (e.g. Chandler *et al.* 1983; Chuvieco *et al.* 2004). In fact, physical processes that determine changes in fuel moisture (latent heat effects, vapour exchange with the atmosphere and precipitation) are extremely complex (see review of concepts in Simard 1968; Hatton and Viney 1988; Viney 1991; Kunkel 2001; Nelson 2001; Matthews 2006). Dead fuels gain moisture from condensation and precipitation, and through adsorption of water vapour. Soil moisture also contributes to litter moisture (Hatton *et al.* 1988; Pook and Gill 1993). Fuels can become dry by desorption and evaporation. Adsorption and desorption are complementary processes governed by the rate of diffusion of moisture through the fuel, the relative humidity and the temperature (Nelson 2001). Wind and solar heating are other weather factors that have important effects on fuel moisture (McArthur 1967; Rothermel *et al.* 1986; Hatton *et al.* 1988; Tolhurst and Cheney 1999). Topography also affects fuel moisture because of how it interacts with weather. Finally, the characteristics of the fuel particles, the fuel location in the stand (canopy or surface) and the type of silvicultural stand management can also influence fuel moisture (Pook and Gill 1993).

Several different approaches have been used in dead fuel moisture modelling, resulting in the development of purely empirical vapor pressure model types (e.g. McArthur 1967; Pook and Gill 1993), others that also take into account the effects of precipitation and evapotranspiration (e.g. Sneeuwjagt and Peet 1998), others essentially based on the physics of the process involved (e.g. Fosberg 1971; Van Wagner 1972; Fosberg *et al.* 1981; Anderson 1990; Nelson 2000; Catchpole *et al.* 2001; Matthews 2006) and yet others based on both physical and empirical fundamentals (e.g. Van Wagner and Pickett 1985; Rothermel *et al.* 1986). Viney (1991) reviewed existing operational dead fine fuel moisture prediction models applied in extensively used fire behaviour and danger rating prediction systems in Australia, Canada and the US. Ruiz and Vega (2007) have recently updated that information.

The applicability of existing dead fuel moisture prediction models to different species, fuels and situations has been extensively addressed (see Simard and Main 1982; Simard *et al.* 1984; Rothermel *et al.* 1986; Vega and Casal 1986; Burgan 1987; Hatton *et al.* 1988; Viney and Hatton 1989, 1990; Pech 1989; Hartford and Rothermel 1991; Viegas *et al.* 1992; Pook 1993; Marsden-Smedley and Catchpole 2001; Beck and Armitage 2004; de Groot *et al.* 2005; Ruiz 2005; Wotton *et al.*

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