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Fuel types identification for forest fire risk assessment in Bulgaria

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Abstract
Knowledge of the spatial distribution of fuel types is essential for implementation of the fire models predicting fire behaviour, severity and spread. In the present study, the most commonly used fuel classifications systems currently employed worldwide and the associated methods for generating a fuel type classification has been examined and compared. Based on a critical analysis of the state-of-the-art and on the main advances achieved in different classification systems, a simple quantitative methodology for development of a fuel type model has been developed. The results obtained showed that Austrian stands are characterized by a higher fuel load concerning both – live and dead biomass. The load of the dead material ranged from 13.3 t/ha to 47.0 t/ha and the load of the live fuel material was within the range 1.60 kg/m2 - 2.08 kg/m2. The density of the crown was also higher and equal to 0.354 kg/m2. The moisture content of the live leaves branches and dead material for Austrian pine and beech stands was relatively low in comparison with those for the other tree species.

***Keywords**: forest fuels, fuel type, fire behaviour prediction*

1. Introduction

Numerous forest fire studies report relationships between fire behaviour, fire suppression and their dependence on the forest fuels (Burgan and Rothermel, 1984; Fryer and Johnson, 1988; Burgan *et al.*, 1998; Chuvieco *et al.*, 1999; Arroyo *et al.*, 2006). The rationale for using vegetation characteristics to classify fuels is that fuels are ultimately derived from vegetation. The increase in density and surface and canopy fuels has enhanced the risk of high-severity fires (Miller *et al.*, 2009, 2012; Taylor *et al.*, 2014). The fuel type classifications are usually based on the vegetative characteristics of a particular site or location. Fire behaviour fuel models are used as input to the Rothermel´s (Rothermel, 1972) fire spread model, which is used in a variety of fire behaviour modelling systems. Different kinds of fuel models are used in fire science (Rothermel, 1972; Albini, 1976; Anderson 1982). The variation in predicted spread rate among models is attributed to fuel load by size class (0 to 0.64 cm, 0.64 to 2.54 cm, and 2.54 cm to 7.62 cm diameter), fuel-bed depth, and fuel particle size, surface-area-to-volume (SAV) ratio by component. Later, the fuel particle heat content was included as a fuel model parameter for the BEHAVE fire behaviour prediction (Andrews, 1986; Burgan and Rothermel, 1984), FARSITE (Finney, 1998) and BehavePlus (Andrews *et al.*, 2003) models. It should be mentioned that Albini's fuel models specified an extinction moisture content value for each fuel model, whereas this parameter was held constant for Rothermel's fuel models. The fuel moisture was considered for distinguishing the two major groups of fuel models: live and dead. The 1-, 10-, 100-, and 1000-h time-lag classes represent the dead fuels (Cohen and Deeming, 1982). The live fuels are further classified into herbaceous and woody shrub.
FARSITE (Fire Area Simulator) model developed by Finney (1998), includes both type of models - for crown fire behaviour as well as surface fuel models and therefore require information of crown fuel

parameters such as percentage canopy cover, canopy height, crown base height and crown bulk density. The next fuel models in the USA paid attention on the fuel beds and their classification according to the capacity to support fire and consume fuels (Sandberg *et al*., 2001; Ottmar *et al*., 2007). The fuel classification system called Prometheus has been adapted for Mediterranean conditions (Arroyo *et al*., 2006). The main criterion of classification in this system is the type and height of the propagation element divided into three major groups: grass, shrubs or ground litter and trees. The main approach of the BEHAVE system was applied for developing the other systems, such as the CARDIN system in Spain (Caballero *et al*., 1994) and for development of general fuel models for some regions in Greece (Dimitrakopoulos *et al*., 1999, Dimitrakopoulos *et al*., 2001) and photo keys (ICONA 1990) for different environments. Knowledge of the spatial distribution of fuel types is also essential for implementation of the fire models predicting fire behaviour, severity and spread.

In this paper, we examine the most commonly used fuel classifications systems currently employed worldwide and the associated methods for generating a fuel type classification. Based on the analysis of state-of-the-art and on the main advances achieved in different classification systems, a simple quantitative methodology for development of a fuel type model is presented.

2. **Methods**

Six sampling sites (SS) have been established in the western region of Bulgaria (Government Forestry Enterprises “Nevestino”), which is one of the most frequently affected by forest fires (Figure 1). The main tree species are *Fagus sylvatica L., Pinus sylvestris L., Pinus nigra Arn., Quercus cerris L., Quercus frainetto Ten*.. The main characteristics of the location and the stand’s surface biomass parameters have been collected. At field conditions, the following parameters of the stands were measured: the crown cover, crown height, diameter at breast height (D.B.H.), height difference between surface and first tree branches. Information on the distribution of live and dead fuels in the pre-specified four size classes was obtained by separating all live and dead fuels in 1 m^2 plots and weighing them. The fine live biomass - leaves, twigs and branches less than 0.64 cm in diameter and thicker and live shrub biomass (if present at sampling sites) have been also collected. The dead woody fuel loading was measured collecting the material from 50 cm x 50 cm square plots in three replications at each sampling site. The material was divided into classes characterizing the drying rates of the various fuel particles, so called 1-, 10-, 100- and 1000 h time lag fuels. The fuel load values for collected size classes for live biomass and dead material were determined.

The moisture content of the various elements of the fuel complexes (live needles and leaves, woody shrub stems, ground litter, duff, etc.) was also determined by collecting samples from the sampling sites, weighing them, oven-drying them for 48 hours at 1050C, and weighing them again. This information was used to adjust all measured weights in the sample plots to oven-dry fuel loadings.

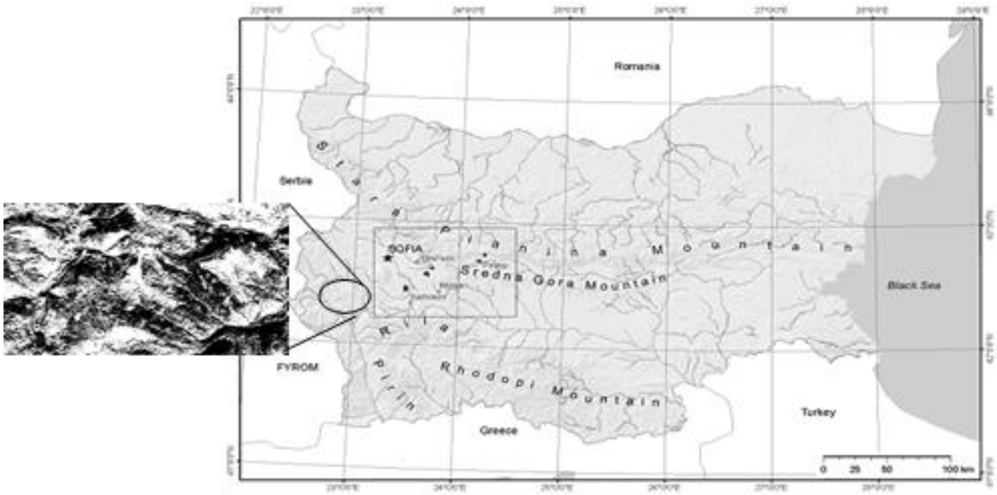

Figure 1. Legend of figure 1

3. Results

For the current investigation, the live fuel load (LFL) in the tree crown was determined as the weight of the lives/needles for the unit horizontal area (in kg/m2). The calculation was performed using equations 1, 2 and 3. The diameter at breast height (D.B.H.) of all trees from the sampling plot was used.

For Austrian pine: $CrFL = 1.324 - 0.13dbh + 0.025dbh^2$ (1)

for Scots pine: $CrFL = 0.023dbh^{1.802}$ (2)

where *CrFL* [kg] is the weight of crown fuel material of a tree with diameter at breast height (dbh).

$$CFL = \frac{\sum_{i=1}^{n} CrFL}{PP}\left[kg/m^2\right] \quad (3),$$

where *CFL* is the quantity of the fuel material of the continuous canopy (in kg/m^2), represented as the sum of the quantities for all separated trees on the territory of the studied sampling site, divided by its area *PP* (m^2).

The fuel load for live biomass of the deciduous forest was not determined, as its role in crown forest fires is negligible. The quantity of the fuel load of the dead material is important in case of surface fires in coniferous and deciduous forests. The highest fuel load of live biomass was found for Austrian pine stands – from 1.60 kg/m^2 to 2.08 kg/m^2 (Table 1).

Besides the fuel load, the moisture content of the various fuel materials was determined (Figures 2, 3).

Table 1. Crown fuel characteristics

SS	Main tree species	Crown fuel (leaves and twigs) (kg/m^2)	Height of crown (m)	Crown fuel density (kg/m^2)
SS1	Beech			
SS2	Scots pine	1.04	10.54	0.188
SS3	Austrian pine	2.08	12.50	0.354
SS4	Oak			
SS5	Austrian pine	1.17	11.96	0.147
SS6	Austrian pine	1.60	8.02	0.294

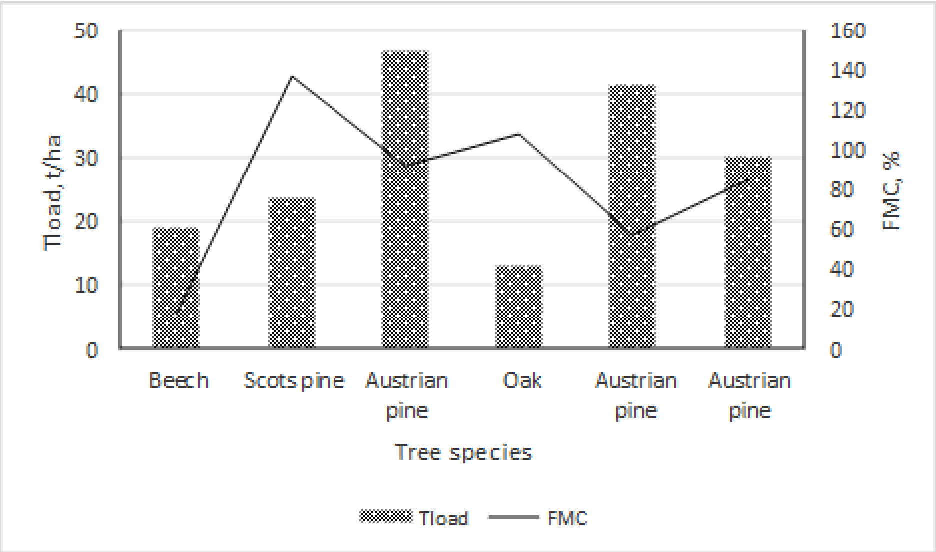

Figure 2. Fuel characteristics of sampling sites (Tload – total load; FMC – Fuel moisture content, %).

The most important variable of interest for the analysis is the total fuel loading (TLOAD), for each location. For our purpose, TLOAD represents the sum of litter load (LL), 1-hr dead woody fuel, 10-hr dead woody fuel, 100-hr dead woody fuel, cones, and bark. Similar to the load of the live biomass, the highest TLOAD was found for Austrian pine stands – from 30.0 t/ha to 47.0 t/ha (Figure 2).

Fuel moisture affects ignition by absorbing energy when being vaporized, and by diluting flammable volatiles, which increases the ignition delay time. Moist fuels reduce to less intense fires in contrast to the dry fuels that burn more fiercely (Van Wagner, 1967; Catchpole and Catchpole, 1991).

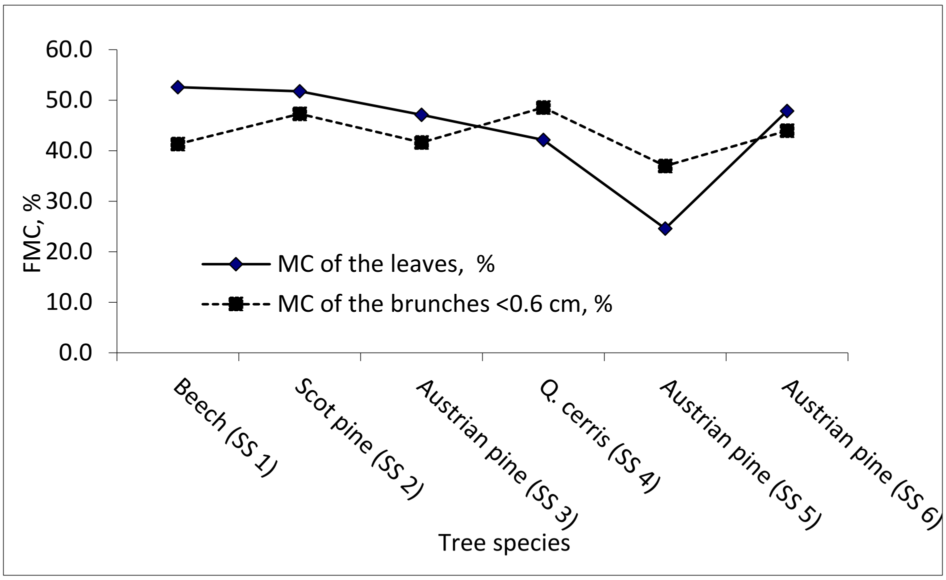

Figure 3. Moisture content (MC) of the live fuel load.

The experimental results show that the FMC of the live leaves/needles and brunches varies from 24. 6% to 52,6 %. Based on the definition of the moisture of extinction (ME) (32% of plant fresh weight), in could be noted that very flammable is the plantation of the Austrian pine from SS 5, as its moisture content was less than 25% (Figure 3). The MC of the brunches changes within narrower limits.

4. Conclusions

The results obtained clearly show that Black Pine stands are characterised by a higher fuel load concerning both – live and dead biomass. The load of the dead material ranged from 13.3 t/ha to 47.0 t/ha and the load of the live fuel material was in the range 1.60 kg/m2 - 2.08 kg/m2. The density of the crown was also higher and equal to 0.354 kg/m2. The moisture content of the live leaves branches and dead material for Black pine and beech stands was relatively low in comparison with those for the other tree species.

5. Acknowledgements

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