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# FIRE BEHAVIOR IN BLACK PINE (*PINUS NIGRA* ARN.) PLANTATIONS IN SOUTHERN BULGARIA: A SIMULATION STUDY

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## Abstract

Surface and canopy fuel characteristics that influence the initiation and spread of wildland fires were measured in representative Black pine (*Pinus nigra*) plantations in Southern Bulgaria. Potential fire behavior (type of fire, probability of crown fire initiation, crown fire type, rate of spread, fire line intensity and flame length) in Black pine plantations was simulated with the most updated fire behavior models. The probability of crown fire initiation was high even under moderate burning conditions, mainly due to the low canopy base height and the heavy surface fuel load. Assessment of surface and canopy fuel characteristics and potential fire behavior can be useful in fuel management and fire suppression planning.

**Key words:** surface and canopy fuels, fire behavior, rate of spread, fire line intensity, flame length.

## Introduction

Wildland fires are the most destructive disturbance of the natural lands. Natural landscapes have always been subjected to fire in southern Europe and thus, burning became part of their dynamic natural equilibrium (Moreno and Oechel 1994). Recent changes in land-use patterns have caused the reduction or abandonment of traditional activities, such as extensive grazing or wood harvesting. This resulted in increase of the amount of fuel available for burning (Perez et al. 2003).

Fire behavior models implemented in fire management decision support systems require accurate descriptions of fuel complex characteristics. Until recently, fuel complex characterization has been limited to surface fuel beds (Anderson 1982, Dimitrakopoulos 2002), due to the restricted applicability of fire behavior simulation models only to surface fuels (Andrews 1986). The development of fire behavior models and systems designed to predict fire behavior (Van Wagner 1977, 1989; Scott and Reinhardt 2001; Cruz et al. 2004, 2005) made necessary the measurement of surface and canopy fuel data.

Crown fire modelling depends on two basic procedures: the analysis of surface to crown fire transition and the study of crown fire rate of spread. An extensive review of the existing crown fire models can be found in Pastor et al. (2003).

The objective of this study was to assess the potential fire behavior in Black pine plantations in Southern Bulgaria by using simulations with the most recent fire behavior models.

## Material and Methods

### Study area

The study area was located in the eastern part of Ivaylovgrad region (26°06′N, 41°31′W) and Harmanli region (25°97′N, 41°55′W) in Southern Bulgaria. The altitude ranged from 50 m to 840 m a.s.l. and the climate is of sub-mediterranean type, with cold winters and dry hot summers. The mean annual rainfall is 775 mm and the mean annual air temperature is 13°C. In the past, numerous fires have burned different parts of the forest. The forest comprises of even-aged stands, often with a sparse understorey of herbaceous vegetation and a substantial layer of pine needles litter. The forest site was characterized by a mean tree height of 18 m and a mean stem density of 750 stem $ha^{-1}$. Slopes ranged from 20 to 50%.

### Modelling fuel and fire behavior

In one representative sample plot (25 m x 20 m), surface and crown fuel parameters were measured according to Koukoulomatis and Mitsopoulos (2007) study. Surface fuel parameters were measured in ten 1 $m^2$ sampling plots. The clip and weight method was used for the determination of all fuel loads by size category (Brown et al. 1982). Crown fuel biomass was estimated by using site-specific crown fuel allometric equations (Koukoulomatis and Mitsopoulos 2007), while canopy fuel vertical profiles were developed using Scott and Reinhardt (2001) method.

Potential crown fire behavior was simulated using Cruz et al. (2004, 2005) crown fire initiation and spread models, with input data the canopy and surface fuel load values of the sample plot. These models have been tested and evaluated in high intensity experimental crown fires in pine plantations with satisfactory results, while other crown fire models (Rothermel's surface and crown rate of fire spread models with Van Wagner's crown fire transition) have shown to have significant underprediction bias when used in assessing potential crown fire behavior in conifer forests and plantations (Stocks et al. 2004, Cruz and Alexander 2010). The type of fire (active crown fire or passive crown fire) was assessed by Van Wagner's (1977) criterion for active crown fire spread. Available surface fuel loads are required to run the crown fire initiation model (Cruz et al. 2004). For this, the surface fuel model, typical of the understory vegetation of Black pine forest was used as surface fuelbed during the fire simulation (Koukoulomatis and Mitsopoulos 2007). Low burning conditions were set to fine fuel moisture of 14% and 10 $km.h^{-1}$ windspeed, moderate burning conditions to fine fuel moisture of 10% and 20 $km.h^{-1}$ windspeed, while extreme burning conditions were set to fine fuel moisture of 6% and 30 $km.h^{-1}$ windspeed. All the wind values refer to 10 m open windspeeds. Fireline intensity was estimated by Byram's (1959) equation. Crown fire intensity was calculated by adding the available canopy fuel load to the available surface fuel load. The litter, the live foliage and the live and dead branches with diameter less than 2.5 cm were considered as available surface fuel load. Surface fuel consumption by the fire was adjusted to 90%, 60% and 30% of the total load, representing extreme, moderate and low burning conditions, respectively. Heat content values for all simulations were obtained from Dimitrakopoulos and Panov (2001). Crown fire flame length was estimated according to Thomas' (1963) flame length equation. Surface fire behavior was modeled using Rothermel's rate of spread model (Rothermel 1972). All crown fire behavior predictions refer to level terrain and are valid only for active crown fires.

## Results and Discussion

Table 1 presents surface and canopy fuel characteristics that were measured at the sample plot. Table 2 presents surface and active crown fire behavior potential that should be expected in the plot according to the fire behavior models simulation. Crown fireline intensity and flame length reached up to 91 500 kW.m$^{-1}$ and 53 m, respectively. Simulations with wind speeds greater than 20 km.h$^{-1}$ always lead to crown fire initiation regardless of the canopy and surface fuel characteristics. All simulations under extreme burning conditions resulted in crown fire initiation, as it is often reported in field observations (Alexander 1998). Under moderate burning conditions both crown and surface fires were observed, depending mainly on the fuel characteristics (CBH, surface fuel bed height, CBD)

**Table 1. Surface and canopy fuel characteristics at the sampled plot.**

| Fuel model | Surface fuel load, t.ha$^{-1}$ | Litter depth, cm | Litter weight, t.ha$^{-1}$ | Canopy fuel load, kg.m$^{-2}$ | Canopy bulk density, kg.m$^{-3}$ | Canopy base height, m |
|---|---|---|---|---|---|---|
| Litter layer of Black pine forest | 3.1 | 0.8 | 6.2 | 1.2 | 0.13 | 3.8 |

**Table 2. Potential fire behavior of Black pine plantations.**

| | Rate of spread, m.min$^{-1}$ | | | Fireline intensity, kW.m$^{-1}$ | | | Flame length, m | | |
|---|---|---|---|---|---|---|---|---|---|
| | Burning conditions | | | | | | | | |
| | Low | Moderate | Extreme | Low | Moderate | Extreme | Low | Moderate | Extreme |
| Black pine plantation fuel complex | 6.3[a] | 22.8[b] | 61.5[b] | 3,123[a] | 24,771[b] | 91,459[b] | 1.9[a] | 22[b] | 53[b] |

[a] Surface fire resulted
[b] Crown fire resulted

of the stand. Under low burning conditions, in all cases fire spread was limited to surface fuels. Active crown fire rate of spread in Black pine plantations ranged from 22.8 to 61.5 $m.min^{-1}$. In most cases, crown fire behavior simulations indicated that crown fire transition and spread is a common feature in Black pine plantations. The low fuel strata gap, the heavy available surface fuel load and the substantial height of the surface fuel bed that characterize Black pine fuel complexes increase dramatically the likelihood of crown fire initiation. Active crown fire rate of spread, fireline intensity and flame length in Black pine stands were found similar to values reported in typical active crown fires in the International Crown Fire Modelling Experiment, where the rate of crown fire spread ranged from 15.8 to 69.8 $m.min^{-1}$, the fire intensity from 20,000 to 100,000 $kW.m^{-1}$ and the flame front was 2–3 times the mean stand height (Stocks et al. 2004). Under extreme burning conditions, active crown fire rate of spread was even observed in Black pine plantations with CBD lower than Agee's (1996) threshold value (0.10 $kg.m^{-3}$), as the simulation results indicated.

Surface fire predictions, crown fire initiation and rate of spread models used in this simulation are empirical. Nevertheless, they have been tested in high intensity experimental wildland fires with satisfactory results (Stocks et al. 2004). Furthermore, the variability in fuel complex characteristics used during model conception and the physical fuel (CBD, fuel strata gap, surface fuel consumption) and weather (wind speed, fine fuel moisture content) parameters, should make them applicable to other conifer fuel complexes as well. Additionally, wind speed is the variable that has the most influence in crown fire behavior. Wind speed is the dominant factor that affects fire behavior in wildland forests (Dimitrakopoulos and Dritsa 2003). Passive crown fire characteristics were not simulated due to the lack of a validated model that predicts passive crown fire behavior.

## Conclusion

This study simulated the initiation and spread of wildland fire in representative Black pine (*Pinus nigra*) plantations in Southern Bulgaria. Potential fire behavior (type of fire, probability of crown fire initiation, crown fire type, rate of spread, fireline intensity and flame length) in Black pine plantations assessed with the most updated fire behavior models.

Fire behavior prediction in Black pine plantations can be useful in fire management, fire prevention planning or in decision making during actual fire suppression. The current fire behavior simulations are just a supplement to the efforts for fire prevention and active suppression tactics and their accuracy must be validated with real observations from wildfires burning in the field.

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