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Development of an optimal methodology for forecasting forest fire behaviour in Greece

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Dissertation Abstract

The objective of this dissertation was to improve wildfire behaviour prediction in Greece for supporting fire management (prevention and suppression) and for improving fire fighter safety.

A database of one hundred and ninety six fire behaviour data records was developed from field observations and measurements made during the evolution of a large number of wildfires in Greece, in eight fire seasons (2007-2014). The results of the dissertation, were incorporated into a spreadsheet which can be used as a Decision Support System (DSS).

Subsets of the database were used to test the agreement of predictions of the BehavePlus surface fire behavior prediction system and the CFIS (Crown Fire Initiation and Spread) with field observations. Furthermore, predictions of three spatial wildfire spread simulation systems, namely FARSITE, G-FMIS and FLogA, were compared to fire spread regarding the head Rate of Spread (ROS) and the burned area of a part of a large carefully documented fire that took place in North East Attica in August 2009.

The empirical capacity of firefighters, Forest Service employees and volunteers, with varying firefighting involvement and experience, to assess expected fire behaviour for a set of conditions was examined through a specially designed questionnaire. The questionnaire consisted of illustrations, through photos and descriptions, of 15 wildfire situations. The respondents were asked to choose through multiple choice questions of fire behaviour.

Furthermore, empirical equations were developed for the prediction of surface and active crown wildfire ROS and for the estimation of the minimum surface ROS value for active crowning. Plume dominated fire behaviour was analysed and compared with wind driven active crown fire behavior. Presence or lack of spotting were also examined for 106 fire cases, categorizing them in four empirical spotting classes (absence of the phenomenon, rare, limited and massive spotting) and correlating these classes with air Relative humidity (RH%) values. The results of all these efforts were as follows.

It was found that for the Greek fuel models "Evergreen-schlerophyllous shrublands (1.5 - 3 m), "Evergreen schlerophyllous shrublands (up to 1.5 m)", "Phrygana II

(Sarcopoterium spinosum)" and "Mediterranean grasslands", BehavePlus can be a useful tool for predictions of surface wildfire ROS in tall maquis, short maquis, phryganic areas where the dominant species is Sarcopoterium spinosum and grass, respectively. Four statistically significant linear regression equations describing mathematically the relation of the predicted to the observed ROS were developed. They can be used for adjusting BehavePlus predictions to match "real world" fire behaviour and can also be incorporated in fire spread simulation systems used in Greece. The analysis of the flame length (FL) for the same fuel types which were described by the same fuel models, showed that BehavePlus predictions are not reliable. The finding that FL is seriously under-predicted when using BehavePlus with the Phrygana II fuel model to predict fire behaviour in Sarcopoterium spinosum dominated phrygana fields is an important result that can be very useful for the safety of firefighters. It should be seriously taken into consideration in operational firefighting in the country as the underestimation takes place in a narrow band of FL values that includes the FL threshold value of 1.2 m which is considered as the limit for direct attack on the flames with hand tools.

CFIS failed to predict the crown fire type and the active crown fire ROS in Aleppo pine forests with tall maquis understory. As a result, it is deemed as inappropriate for operational use in Greece before further testing, but it may be useful as a training tool for the estimation of crown initiation. The necessary input data can be estimated using the DSS, which includes three different ways of Canopy Bulk Density (CBD) estimation for *Pinus halepensis* forests.

FARSITE failed to produce reasonable fire behaviour simulations despite the use of both the appropriate four custom Greek fuel models and realistic wind field data. G-FMIS and FLogA produced better results and their performance improved further when the Wind Adjustment Factor (WAF) was applied.

Surface headfire ROS in short maquis was modeled as a power function of midflame wind velocity ($Wind_{midflame}$, km/h). The empirical equation had an exponent equal to 1.036. The equation is valid for fine dead fuel moisture content (FDFMC) values from 4% up to 8% and $Wind_{midflame}$ values up to 16.5 km/h. Surface headfire ROS in grasslands was also modeled successfully as a power function of $Wind_{midflame}$ with an exponent equal to 1.199. The equation is valid for FDFMC values from 4% up to 9% and $Wind_{midflame}$ values up to 25 km/h. The values of the exponents of both these empirical equations are in the 1 to 2 range, which is in agreement with the results of other similar published modeling efforts.

The analysis of the subsets of passive crown and active crown fires led to the generation of a ROS criterion for active crowning in Aleppo pine forests with tall maquis understory. The equation that was developed calculates, for any specified value of CBD, the critical surface ROS value (threshold) above which active crowning can be sustained.

A preliminary result about active crown ROS in Aleppo pine forests is that it is 2.06 times greater than surface ROS in tall maquis understory. It was also found, using t-test analysis, that the behaviour of the powerful, plume dominated fires of the database was affected by the conditions that the plume generates rather than by the characteristics of the fuels that the fire spreads in.

Analysis of the observations and measurements of spotting on maquis, small xeric shrubs (phrygana) and grass, led to some preliminary conclusions. No spotting was observed at air relative humidity (RH) values higher than 40.3%. Massive spotting that triggered extreme fire behavior was documented for RH values lower than 17%.

In regard to the questionnaire, analysis of the empirical fire behaviour estimation by firefighters and individuals with varying firefighting experience showed that fire behaviour in fine fuels was seriously underestimated, a case of eruptive fire behaviour associated with a box canyon was not recognized and there were weaknesses on telling the difference between the behaviour of a heading and a flanking fire. The results support the conclusion that fire behaviour training is needed for filling the knowledge gaps which were revealed.

Based on the findings of the study, a table was assembled suggesting the wildfire behavior prediction method of choice for each fuel and fire type. A second table was also developed identifying the most appropriate prediction method for use by the authorities for fire prevention, suppression and training purposes. Limitations, weaknesses and strengths are also reported, and cases for which there is no available wildfire behavior prediction method are identified.

Key Words: Wildfire, forest fire, fire behaviour prediction, fire behaviour modelling, surface fire, crown fire, evergreen schlerophyllous shrublands, maquis, phrygana, grassland, fuel models, Aleppo pine, *Pinus halepensis*, Canopy Bulk Density (CBD), spotting, Decision Support System, Greece