Forest Fire Studies on Fire Behaviour: Key Topics and Their Importance

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Abstract— Every year thousands of hectares of forest fires occur in Mediterranean countries and there are major damages. The effects of forest fires are quite extensive when considered from the organism to landscape level in the short term and long term. Forest fires show different behaviours depending on where they come from and the factors that affect it with the flammable materials. Forest fire triangles provide important framework to study the forest fires. Flammable materials can be changed and controlled by time and space. Therefore, they are separated from meteorological and topographic factors that cannot be controlled. The main types of forest fire are ground, surface and crown fire. These types of fire reveal differences in terms of the danger and its fighting. In this study, the main topics of forest fire behaviour and fuel model researches and their importance will be present. The research of forest fire requires the need to study in very different areas. The studies required for the development of fire propagation and fuel models in fire management systems is gradually increasing. Estimations of typical forest fire features such as fire propagation ratio, fuel consumption, fire intensity, and flame size utilize fuel loading values, as well as spatial heterogeneity, which affects these factors. A significant feature of forest fire risk analyses is the fact that cause-based ignition, fire behaviour, and fire management have multivariate uncertainty factors. All of these research needs are basic components of the fire decision support system, which is a essential prerequisite of an effective fire management system.

***Keywords*— forest fire research, fire behaviour, fuel models**

I. INTRODUCTION

A forest fire is a fire that tends to spread freely due to its openness and burning flammable materials in the forest such as grass, shrub, thin and thick dry plant branches, foliars, logs, According to this definition, forest fires are characterized by their openness and spread ability. Every year thousands of hectares of forest fires occur in Mediterranean countries and there are major damages. The effects of forest fires are quite extensive when considered from the organism to landscape level in the short term and long term. The main ones are listed as stimulating soil microbial processes, soil heating, tree mortality, fuel consumption, smoke production, and damage to air quality and atmospheric chemistry as a result of smoke dispersion, erosion, and vegetation succession [1][2]. In order for an effective fire management, it is necessary to accurately estimate the fire behaviour which occurred in the past or will be possibly in the future. It is important that the level of effectiveness of fighting with forest fires is continually improved depending on tactics and strategies so that the damage caused by forest fires is minimized. Therefore, accurate prediction of fire behaviour and pre-determination of the effects of fire are very important [3]. Forest fires show different behaviours depending on where they come from and the factors that affect it with the fuel materials. Forest fire triangles provide important framework to study the forest fire behaviour (Fig. 1).

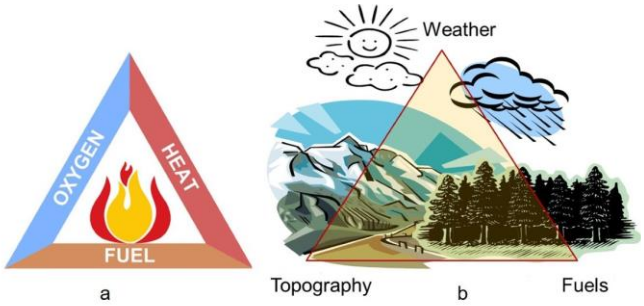

Fig. 1 The fire triangle (a), forest fire triangle (b)

Turkey's Marmara, Aegean and Mediterranean regions are covered with 1st degree fire sensitive forest areas (Fig. 2). In these regions, especially forests covered tourism, settlement and agricultural areas are at risk of forest fire.

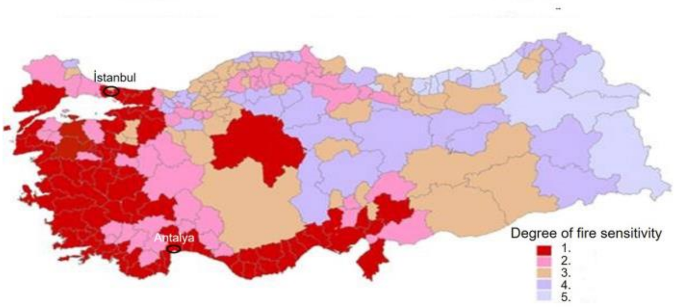

Fig. 2 Sensitive areas of the forest fires in Turkey (www.ogm.gov.tr)

II. FIRE BEHAVIOUR

The definition of fire behaviour is: The manner in which fuel ignites, flame develops, and fire spreads and exhibits other related phenomena as determined by the interaction of fuels, weather, and topography [4]. The forest fires, the place where it takes place and the flammable substance they show different behaviours depending on the influencing factors. Knowing these differences in fire behaviour is important to determine the tactics and strategies in respect to suppression of forest fires. The ability to successfully and effectively overcome with forest fires depends on reliable estimation of the fire hazard and fire behaviour. First of all, it is necessary to know the properties of fuel together with the meteorological and topographic factors controlling and determining the fire behaviour [3].

The fire behaviour parameters (Fig. 3) which are measured during fires (controlled or in the field), the forward and lateral rates of spread, flame length, height and form, fire intensity, head fire width, spotting distance, fuel consumption, and fuel layers [5] [6].

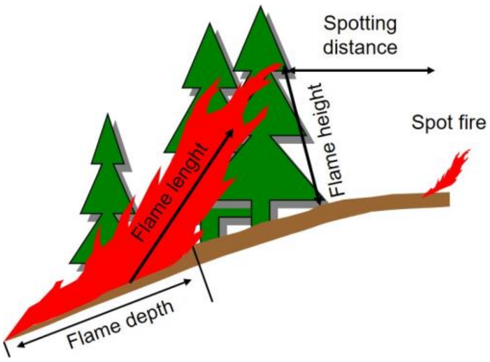

Fig. 3 Flame characteristics to predict fire behaviour

Forest fire growth modelling can help to develop the optimal plan for suppression of forest fire according to fire management. Therefore, fire-growth models have begun to evolve into the centre of forest fire behaviour research. The fire propagation models can be classified as statistical and empirical, semi empirical and physical models [5]. The reporting temporal and spatial measurements of past fires in detail provides significant convenience in fire-growth models (Fig. 4).

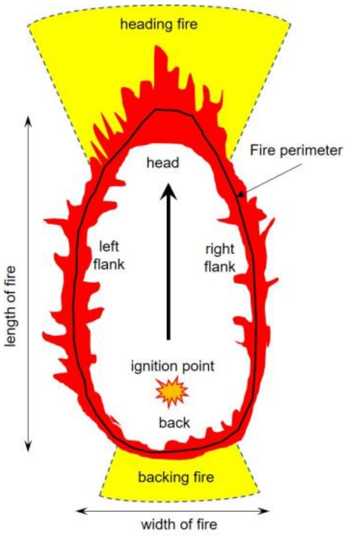

Fig. 4 Spatial measurement of forest fire

Temporal and spatial variations of forest fire spread and behaviour can be predicted using fire simulator software which are based the semi-physical or empirical fire propagation models [7] [8]. The spatial growth of fire is usually simulated as elliptical wave propagation by applying the Huygens' principle. The fire simulators require specific input layers (elevation, slope, aspect, fuels, percent canopy cover, etc.) consisting of georeferenced digital map data to support fire growth modelling capabilities [8] (Fig. 5).

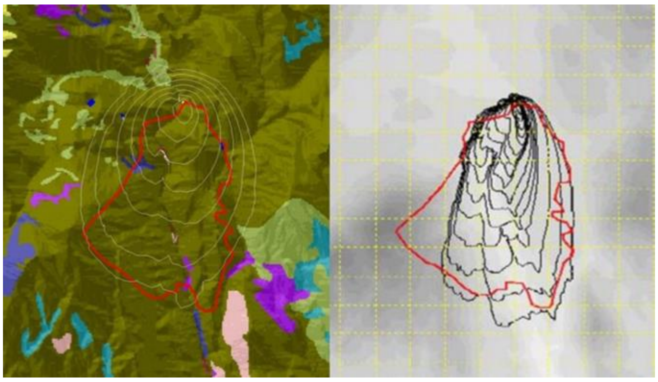

Fig. 5 Examples of fire growth simulation model output from different simulators compared to observed fire perimeter (red line) [9]

There are complexities surrounding a complete quantitative description of fire propagation [10]. Numerous experiments are needed to estimate the fire behaviour variables in laboratory environments at high levels. Large fires occur in environmental conditions that are located in different spatial variability. Therefore, the fire does not develop in uniform (Fig. 6). But, the fires that are controlled in laboratory or prescribed in the forest are spatially uniform. However, fire growth simulations can generate detailed maps for fire behaviour by accommodating many types of spatial and temporal heterogeneous scales [11].

Fig. 6 Spatially not uniform burning in large fires

The fire characteristics chart (Fig. 7) allows firefighters to relate fire behaviour predictions and observations to the difficulty of suppressing fires. For example, Fires A and B (Fig. 2) have the same flame length and fireline intensity, but dramatically different spread rates and heat per unit area [12].

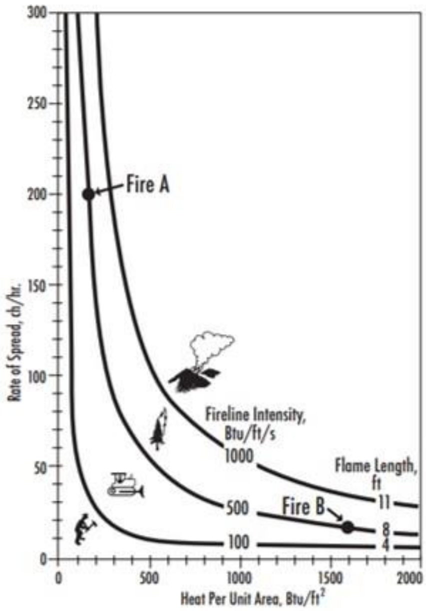

Fig. 7 The fire characteristics chart to predict fire behaviour [13]

The comprehensive study of extreme fire behaviour is more complex and needed more research. Particularly, crown fires and spot fires indicate erratic or severe burning conditions that dramatically change the face and effects of a fire but can also create spectacular threats to firefighters [12]. It is almost impossible to recognize extreme fires in the laboratory or prescribed fire environment (Fig. 8 and 9).

Fig. 8 Experimenting the fire spread rate in laboratory environment with inclined fuelbed

Fig. 9 Prescribed fire to estimate fire behaviour parameters

III. FUEL MODELLING

Fuels of forest fire are live and dead organic matter called forest biomass. The forest fuelbed is vertically stratified into three fuel layers—ground, surface, and canopy fuels (Fig. 10). Surface fuels are all biomass within 2 m above the ground surface. Ground fuels are all organic matter below the litter and above the mineral soil, which is called duff in most upland forests. Canopy fuels are the biomass above the surface fuel layer. Fuelbed layers are composed of finer-scale elements called fuel components, which are fuel types that are defined for specific purposes, mostly for fire behaviour and effects prediction [14].

An important prerequisite for successful fire management is the accurate estimation of the fuel load [15]. Equations for estimating fuel load are an important basis for determining fire behaviour, fire hazard risks, fire management plans, and decision-supporting system for fire management [16]. Predicting tree biomass based on fuel inventories provide an important modeling data for fire managers and researchers to determine aboveground primary production and so to estimate the fuel load characteristics [15].

Flammable fuel materials in the forest can change over time and be controllable [3][14]. The prediction of a reliable fire behaviour depends largely on the properties of the flammable fuel material [3][8]. Therefore, it is very important to get a good estimate of fuel quantity, structure, composition, continuity, height and moisture in order to fire management treatments. For this reason, fuel models have been established by intensive researches on identification of fuel types and integration into fire behaviour models [3]. The actual physical characteristics of fuel (fuel load, fuel moisture, moisture of extinction, heat content, etc.) are used as set of standard fuel models or specific customized fuel models in estimating fire behaviour [8].

The changing fuel mosaic should be use in fire and fuel management to develop management plans that effectively integrate wildfires, controlled wildfires, prescribed fires, and fuel treatments to minimize firefighting costs [14].

The fuels that provide the energy flux that enables a fire to spread have generally been assumed to be those that are consumed in the continuous flaming zone of a fire front [6].

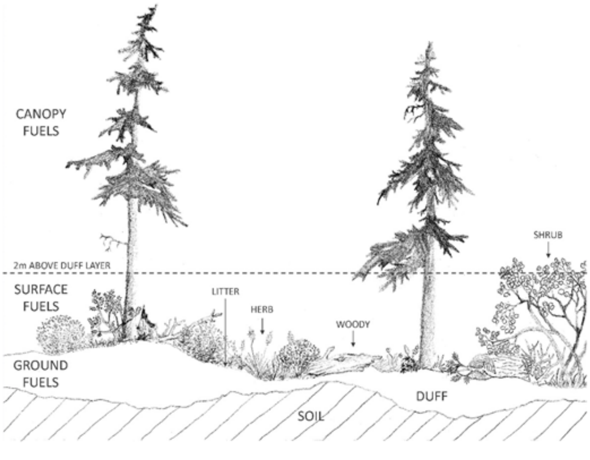

Fig. 10 Illustration of a wildland forest fuelbed showing the three major strata: ground, surface, and canopy fuel [17].

III. DISCUSSION AND CONCLUSIONS

The development of fire management policies in the forestry are required in order to reduce the fire risk by applying methods and models for planning the operational phases of fire management. The use of a simulator as component of a decision-support system for planning the fire management practices involves the assessment of the simulation accuracy under different environmental and vegetational conditions [8]. In order to strengthen this, the reporting of historical fires is important for the updating of fire behavior predicting modelling. These fires are also important in terms of observing mistakes or invalid applications made during firefighting in fire management.

Although fuel characterization and classification are a mathematical modelling [16], the differences in these models is generally due to the distinguishing features of individuals in nature, and the complex compositions that stem from structural and spatial distributions [18] [19]. For this reason, there is a need to constantly renew and develop fuel classification approaches. Especially in large administrative areas, fuel loads will not be unique due to the reasons mentioned above, and there is consequently a need for different fuel load standards rather than a single fuel load standard [16] [20].

REFERENCES

[1] L. J. DeBell, R. W. Talbot and J. E. Dibb, “A major regional air pollution event in the northeastern United States caused by extensive forest fires in Quebec, Canada”. *Journal of Geophysıcal Research*, 109, D19204, 2006.

[2] L B. Lentile, Z.A. Holden, A.M.S. Smith, Remote sensing techniques to assess active fire characteristics and post-fire effects. *International Journal of Wildland Fire* vol 15(3), pp. 319–45, 2006.

[3] E. Bilgili, B. Sağlam, Ö. Küçük, Yangın Davranışının Tahmini Ve Yangınlarla Mücadeledeki Önemi. *Gazi Üniv. Orman Fakültesi Dergisi*, vol 2 (2),pp.124-134, 2001.

[4] (2003) CIFFC. Canadian Interagency Forest Fire Centre website (online). Glossary of Forest Fire Management Terms. Available: http://www.salmonarmmuseum.org/docs/2003_fire_glossary.pdf

[5] J. M. C. Mendes-Lopes, J. M. P. Ventura, J. M. P. Amaral, Flame characteristics, temperature-time curves, and rate of spread in fires propagating in a bed of Pinus pinaster needles. *International Journal of Wildland Fire*, 12, (1), pp 67-84, 2003.

[6] J. Myers, J. Gould, M. Cruz, M. Henderson, Fuel Dynamics and Fire Behaviour in Australian Mallee and Heath Vegetation. *USDA Forest Service Proceedings RMRS-P-46CDM*, p. 221-227, 2007.

[7] P.L. Andrews, L.P. Queen, Fire modeling and information system technology. *International Journal of Wildland Fire* 10, pp. 343-352, 2001.

[8] B. Arca, P. Duce, G. Pellizzaro, V. Bacciu, M. Salis, D. Spano, Evaluation of Farsite simulator in a Mediterranean area. The 4th International Wildland Fire Conference, 13-17.May.2007, Seville Spain, 2007

[9] H. G. Pearce, Review of Fire Growth Simulation Models for Application in New Zealand. Client Report No. 16246. Foundation for Research, Science and Technology, 2009.

[10] H. E. Anderson, Flame shape and fire spread. Fire Technology, (February), 51-58, 1968

[11] M. A. Finney, Calculation of fire spread rates across random landscapes. *International Journal of Wildland Fire*, 12, 167-174. 2003.

[12] P. N. Omi, Forest fires : a reference handbook. ABC-CLIO Press. Santa Barbara, California, 347 pp. 2005.

[13] P. L. Andrews, “BEHAVE: Fire Behavior Prediction and Fuel Modeling System—BURN Subsystem, Part 1.” USDA Forest Service General Technical Report INT-194, 130 pp. 1986.

[14] R. E. Keane, Spatiotemporal Variability of Wildland Fuels in US Northern Rocky Mountain Forests. *Forests*, vol. 7, 129, 1-16. 2016.

[15] B. Bond-Lamberty, C. Wang and S. Gower, 2002. Aboveground and belowground biomass and sapwood area allometric equations for six boreal tree species of northern Manitoba. *Canadian Journal of Forest Research* 32, 1441-1450, 2002.

[16] M. Alexander, Simple question; difficult answer: how much fuel is acceptable? *Fire Management Today* 67, 6–11. 2007.

[17] R.E. Keane, Wildland Fuel Fundamentals and Applications; Springer: New York, NY, USA, 2015.

[18] D.L.R. Affleck, C.R. Keyes, J.M..Goodburn, Conifer crown fuel modeling: current limits and potential for improvement. *Western Journal of Applied Forestry* 27, 165-169, 2012.

[19] P.M. Fernandes, Combining forest structure data and fuel modelling to classify fire hazard in Portugal. *Annals of Forest Science* 66, 415 p9, 2009.

[20] D.V. Sandberg, R.D. Ottmar, G.H. Cushon, Characterizing fuels in the 21st century. International Journal of Wildland Fire 10, 381-387, 2001.