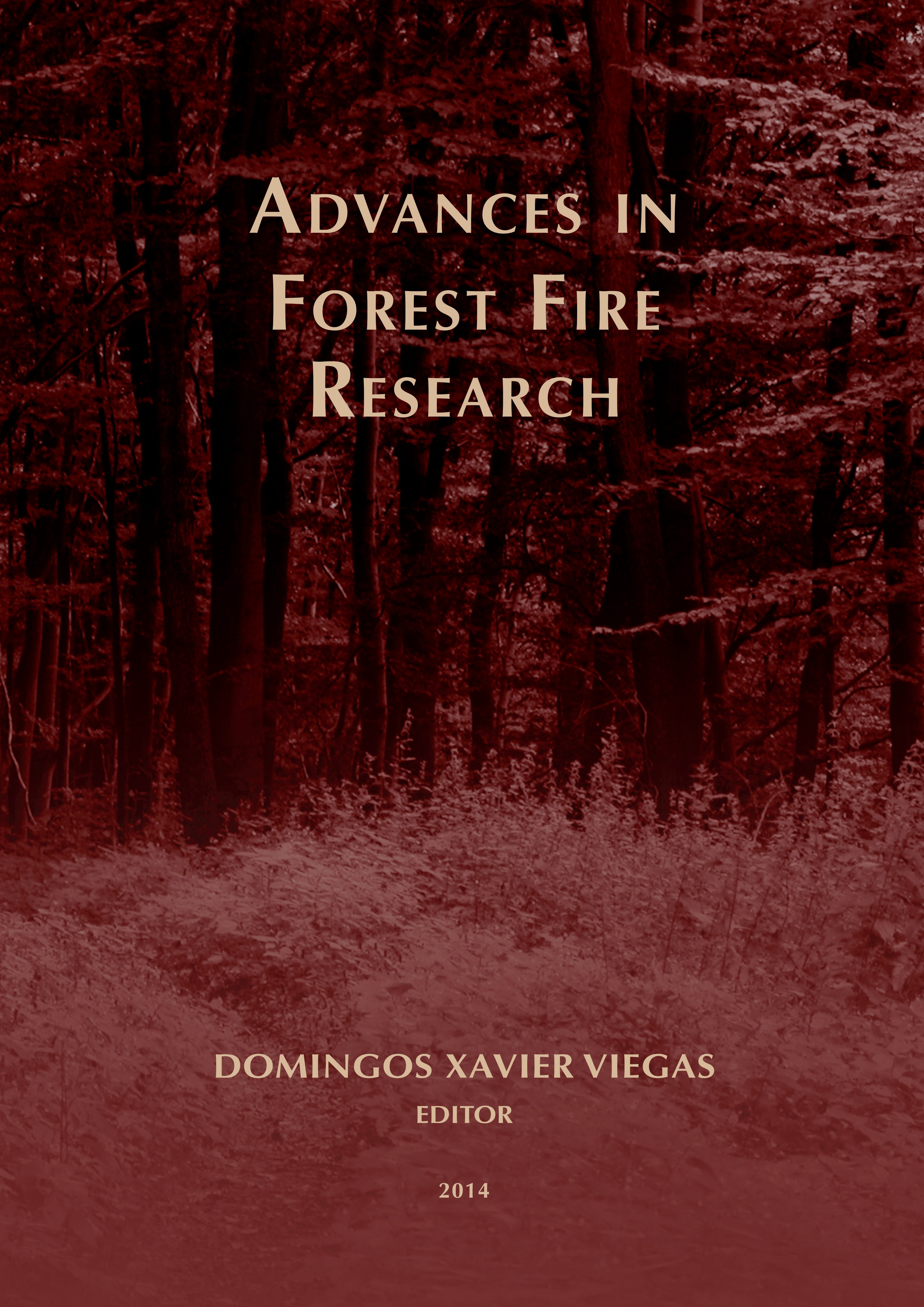

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Data preparation for fire behaviour fuel modelling in the test case of Zlatograd forestry department

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Abstract

Since the year 2000 Bulgaria is facing progressive increase of wildland fire occurrence. That is caused mainly because of human mistakes in having fire camps or agricultural land processing after crop harvesting. At the moment Bulgaria has no working mechanism to spot such fires before they become a threat, however the team from Bulgarian Academy of Sciences is working on fire behaviour modelling issues since 2007 and in this work will be presented the first attempts for Bulgarian forestry data classification according to the existing 53 FBFMs, and estimations where custom fuels has to be prepared for better representation of the potential fire spread. Calibrations with FARSITE runs have been performed for the area of Zlatograd Forestry Department (Bulgaria) data set (Dobrinkova et. all 2014). The results are compared with Harmanli (Bulgaria) WRF-Fire/S-Fire simulations (Jordanov et. all 2012) in order to see how the different fire behaviour fuel models estimations reflect in the final simulated burned area. Conclusions for fire behaviour fuel modelling based on both simulation approaches in Zlatograd and Harmanli areas gives future application of the presented work for Bulgarian test cases.

Keywords*: Bulgaria, Forestry data, fire behaviour fuel model data preparation, fuel modelling*

1. Introduction

FARSITE runs with the standard or custom Fire Behaviour Fuel Models in Bulgaria has never been done until our first attempts for this on the test cases selected randomly for the period 2011-2012 on the territory of Zlatograd Forestry Department. In the previous works on Bulgarian test case nearby the area of Harmanli town has been used CORINE categories (Jordanov et. all 2012; Dobrinkova et. All 2011). The approach in Harmanli test case gives CORINE species division adapted only to the thirteen classes of Anderson (Anderson 1982). However this approach has some weaknesses, because fuel load parameters description with satellite images only is hard to be provided.
The current work present chronologically how the available forestry data from the Zlatograd Forestry department is prepared for the FARSITE runs from turning the list of biological species into FBFMs according to the FARSITE input instructions. Most of the collected data has been provided as paper maps which processing into digital GIS (Geographic Information System's) layers had to meet the requirements of FARSITE. The standard FBFMs (Anderson 1982) and (Scott and Burgan 2005) has been taken into consideration with their parameters for fuel load (1-hr, 10-hr, 100-hr, live herbaceous and live woody), compared to the test cases according to the best collected data.
This work is giving both Harmanli and Zlatograd FBFMs methodologies and how they have been implemented in the WRF-Fire/S-Fire and FARSITE runs. The conclusions give comparison on the achieved results with some plans for future refinements.

2. Harmanli test case data preparation and FBFMs summary

In the Harmanli test case has been used WRF-Fire/S-Fire computer based tool, which is a combination between the mesoscale atmospheric code WRF-ARW (Skamarock 2008) with a fire spread module, based on the Rothermel model (Rothermel 1972) implemented by the level set method. A simulation with WRF-Fire/S-Fire requires input data from a variety of sources from meteorological initial and boundary conditions to static surface properties.

For the meteorological inputs the U.S. National Center for Environmental Protection (NCEP) gives a 1 degree resolution grid covering the entire globe with 6 hour reanalysis cycle. The data is freely available and can be downloaded automatically over HTTP by using a simple script. Creating simulation also requires a number of static data fields describing the surface properties of the area. All such data is available as part of a standard global dataset for WRF. The fields in this dataset are available at various resolutions ranging from about 1 km to 10 km, which is sufficient for most mesoscale weather modeling purposes. Each field is stored in a unique format consisting of a series of simple binary files described by a text file. A geogrid utility in the WRF preprocessor (WPS) interpolates the data in these files onto the model grid and produces an intermediate NetCDF file used in further preprocessing steps. While the standard geogrid dataset is sufficient for most weather forecasting applications, it lacks two high resolutions fields. These fields are surface topography and fuel information. Both are essential for modeling fire behavior because they directly affect the rate of spread of the fire front inside the model.

Topography at a resolution of about 90 m for the area of Harmanli is used from the Shuttle Radar Topography Mission (SRTM) at http://eros.usgs.gov. The data received from the server is a GIS raster format (DTED), which is processed and converted to geogrid binary data format.

The final piece of surface data needed for input into geogrid is a categorical field describing the properties of the fuels. In the U.S., this data is readily available from the USGS, however, no such data exists for the Harmanli or any other Bulgarian region region. Instead for this field is used data from the Corine Landcover Project (financed by the European Environment Agency and the member states) see Table 1. This project provides landcover data for Bulgaria with 100 m resolution with a 25 ha minimum mapping unit http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster.

Table 1. Fuel categories from satellite imagery and CORINE code (in parentheses)

Category	Description
1	Artificial, non-agricultural vegetated areas (141,142)
2	Sport Complex,Irrigated Cropland and Pasture,Bare Ground Tundra, Arable land (211,212,213), Open spaces with little or no vegetation (331,332,333,334,335)
3	Cemeteries, Dryland Cropland and Pasture, Grassland, Permanent crops(221,222,223), Pastures (231), Heterogeneous agricultural areas(241,242,243,244), Scrub and/or herbaceous vegetation associations (321,322,323,324)
4	Herbaceous Tundra, Parks
5	Wooded Wetland
6	Wooded Tundra, Orchard
7	Mixed Forest
8	Deciduous Needleleaf Forest, Forests (311,312,313)
9-13	N/A
14	Urban fabric (111,112), Industrial, commercial, and transport units (121,122,123,124), Mine, dump and construction sites (131,132,133), Wetlands(411,412,421,422,423), Water bodies (511,512,521,522,523)

The downloaded satellite data along with orthophoto data from the geoportal of the Ministry of Regional Development (MRD) of Bulgaria can be used to estimate the fuel types of the domain like conifer or deciduous woods. All rivers, lakes, villages and forest areas can be vectorized using the orthophoto images combined with CORINE2006 into a GIS vector shape file. The vectorized file provides very high accuracy of representation for non burning areas like rivers and lakes. For the areas

with woods is used Table1, where a description of the fuel categories for the Harmanli simulation corresponds to the Anderson thirteen classes with additional one class for the non burning areas. This fuel level data combined with the vectorized landcover areas gives us a final shape file with attributes for each polygon fuel level. The resulting input files contain all the standard WRF fields along with several additional variables generated from the high resolution topography and fuel categories.
However no fuel load description about 1-hr, 10-hr, 100-hr, live herbaceous and live woody parameters can be estimated with such approach. The problem here is that the satellite images from CORINE project can not provide high resolution with all species information on the land cover. The ortophotoes can provide the canopy cover, but not the fuel load description and in these cases the best solution is to find forestry department plan for any wild land area in Bulgaria. The Bulgarian Forestry department plans contain information which can be used for the fuel load estimations and refinements in the Table 1 categories. Such approach is described in the Zlatograd test case area.

2.1. Harmanli test case analysis

The Harmanli test case simulation result is presented on the Figure 1B. The simulated area has significant similarity in the fire spread shape, but it does not fully comply with the real burnt area Figure 1A. The total simulated burnt area also does not correspond with the real one.

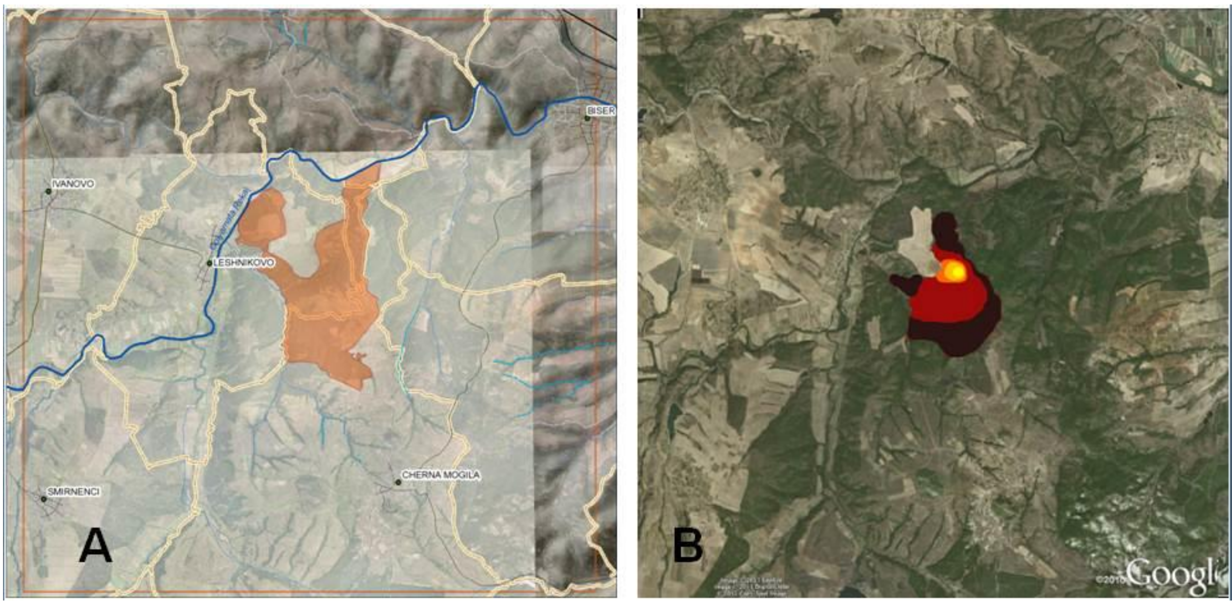

Figure 1. A. Real burned areaof the fire Harmanli(Bulgaria) test case, B. Simulated burned area on the Harmanli(Bulgaria) test case

The difference can be caused mainly from two components the fuel type definitions and weather inputs in the fire zone described in the simulation methodology of Harmanli fire simulation. Further analysis need to be performed and more information on the real fire spread has to be collected in order to be finally defined which components has to be additionally refined. The result however is important, because with this simulation is given the opportunity to operational teams of the responsible authorities in Bulgaria to achieve results on fire spread even with weather inputs and estimations on fuels and topography.

3. Zlatograd test case data preparation and FBFMs summary

The forestry department of Zlatograd area covers 33,532 ha, of which 31,856 ha are state owned forests. It consist of the municipalities Zlatograd, Madan and Nedelino. In the period 2011-2012 fifteen different size and location wildland fires had occurred in Zlatograd forestsry department (Table 2). These wildfires burned in a variety of vegetation types and were more than likely started by humans to clear agricultural debris or prepare fields, based on the villages nearby. Paper maps from the forestry department identified the ignition location and final fire shape; this data was digitized in a GIS, which allowed each ignition point to be viewed with background orthophotos and the spatial Zlatograd vegetation classification showing pre-fire vegetation (Figure 2).

Table 2. Fire information provided by the Zlatograd Forestry. Department for the period 2011-2012

Fire No.	Vegetation type	Burned area in decares	Date of occurrence	Hour of start	Hour of end
1	Durmast	3.0	25 March 2012	1330	1530
2	Beechwood	5.0	29 March 2012	1400	1800
3	Scotch pine	1.0	16 June 2012	1500	1700
4	Scotch pine	7.0	6Aug. 2012	1640	1950
5	Scotch pine	5.0	6 Aug. 2012	1710	2130
6	European black pine	4.0	27Aug. 2012	1200	1600
7	Scotch pine	3.0	5 Sept. 2012	1400	2030
8	Scotch pine	6.0	6 Sept. 2012	1400	1930
9	Scotch pine	2.0	6 Oct. 2012	1600	2320
10	Scotch pine	1.0	16 March 2011	1310	1400
11	Scotch pine	1.0	5 April 2011	1715	1900
12	Scotch pine	1.0	10 April 2011	1130	1530
13	Grassland	3.0	30 Aug. 2011	1400	1800
14	Scotch pine	4.0	12 Sept. 2011	1230	1900
15	Scotch pine	1.0	15 Sept. 2011	1600	1830

Figure 2a: Digitalized shapes from paper map

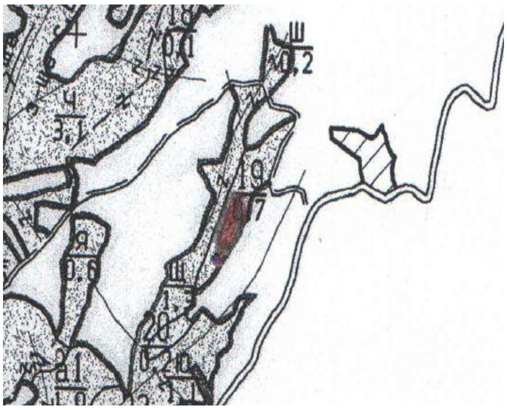

Figure 2b: Paper map sample

3.1. Zlatograd test case data preparation and analysis

The first step in preparing data to run spatial fire behaviour analyses was to determine suitable fuel models for fire locations in the Zlatograd test area. This was done by using BehavePlus (Andrews 2007). BehavePlus is a point fire behaviour prediction system that can be used to analyze fire growth and behaviour for homogeneous vegetation with static weather data. Using a number of standard fuel models developed for the United States (Anderson 1982; Scott and Burgan 2005), was evaluated which fuel models were best able to produce estimates of fire behaviour and growth in BehavePlus similar to those observed on each of the fifteen fires.

In addition to fuel model, BehavePlus requires inputs for weather, fuel moisture, slope, and duration of the burning period. Weather data was obtained for each fire from TV Met, a private company in Bulgaria, which provided calculated fine dead fuel moisture values (Rothermel 1983). The weather stations in the area of interest are quite sparse and that let to estimations for some of the zones of fires. Estimations on live herbaceous and live woody fuel moisture values were based on the expected phenological stage for the time of year that the fire occurred. To estimate slope, was used 30 m resolution digital elevation model (DEM) from the National Institute of Geophysics, Geodesy, and Geography in Bulgaria, then subsequently calculated the average slope for each fire using standard geospatial processing in ArcGIS (ESRI 2010). Burn period length for each fire was obtained from the Zlatograd forestry department data (Table 2).

Based on initial BehavePlus results using standard fuel models, custom fuel models were developed for some vegetation types not well represented by the US fuel models. Custom fuel models were developed for native durmast oak and grass as well as one of the Scotch pine sites by modifying fuel loading parameters to better match local vegetation and reflect the lack of woody debris in the understory, as it is collected as firewood by the local population. The custom fuel model developed for grass has a much lower rate of spread and flame length than any of the standard grass fuel models.

Following evaluation of fuel models with BehavePlus, were then performed analyses in FARSITE, a spatial fire growth system that integrates fire spread models with a suite of spatial data and tabular weather, wind and fuel moisture data to project fire growth and behavior across a landscape. It was defined test landscapes using a 500 m buffer zone around each of the fifteen Zlatograd fires (Figure 3); this footprint comprised the extent of the spatial analysis for each individual wildfire.

Input for FARSITE consists of spatial topographic, vegetation, and fuels parameters compiled into a multi-layered “landscape file” format. Topographic data required to run FARSITE include elevation, slope, and aspect. Using the aforementioned 30 m DEM, was calculated an aspect layer, and then clipped elevation, aspect, and slope rasters to the extent of the fifteen test landscapes. Required vegetation data include fuel model and canopy cover. Fuel models within the 500 m buffered analysis area for each individual fire were assigned based on the BehavePlus analyses; fuel model assignments were tied to the dominant vegetation for each polygon based on the Zlatograd forestry department’s vegetation data. Canopy cover values were visually estimated from orthophoto images and verified with stand data from the Zlatograd forestry department. Additional canopy variables (canopy base height, canopy bulk density, and canopy height) that may be included in the landscape file were omitted, as these variables are most important for calculating crown fire spread or the potential for a surface fire to transition to a crown fire. None of the fifteen fires analyzed experienced crown fire.

Tabular weather and wind files for FARSITE were compiled using the weather and wind data from TV Met, Bulgarian meteorological company that included hourly records. Tabular fuel moisture files were created using the fine dead fuel moisture values calculated for the BehavePlus analyses for 1-hr timelag fuels. The 10-hr fuel moisture value was estimated by adding 1% to the 1-hr fuel moisture and the 100-hr fuel moisture was generally calculated by adding 3% to the 1-hr fuel moisture. The live fuel moisture values previously estimated for BehavePlus analyses were used to populate live herbaceous and live woody moisture values.

All simulations performed in FARSITE used metric data for inputs and outputs. An adjustment value was not used to alter rate of spread for standard fuel models, rather custom fuel models were created. Crown fire, embers from torching trees, and growth from spot fires were not enabled.

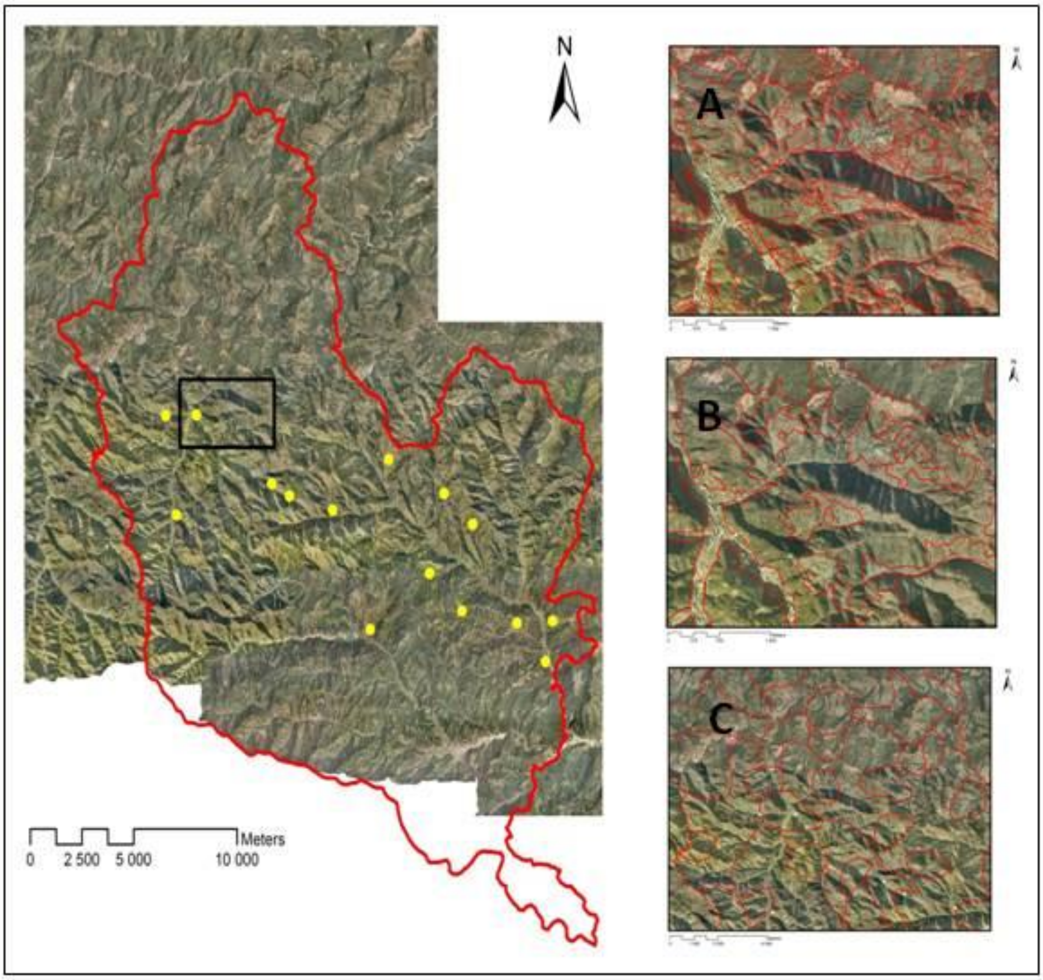

Figure 3. Location of the 15 fires (yellow dots) in the Zlatograd area that occurred in 2011-2012 that were used to develop fire behavior analysis methodology. The outline of the municipality of Zlatograd is shown in red, with the orthophoto imagery used to identify canopy cover underneath. The black box indicates the location of the three inset maps on the right. Inset maps are: A) Zlatograd forestry polygons; B) Corine land cover polygons; and C) Bondev vegetation map polygons.

From the performed analysis and achieved results with the prepared data FARSITE runs gave quite reasonable estimations of burnt areas close to the real burnt one. The results were mainly calculated with custom fuel models and standard ones based on the forty FBFMs (Scott and Burgan 2005).

4. Conclusions

Based on the work performed with Harmanli and Zlatograd forestry department's test areas summary of the most suitable approximation of classes corresponding to the vegetation types is provided in Table 3.

Table 3. Estimations from 40 standard US Fuel Models to Bulgarian Vegetation/Fuel Models

Vegetation Type	Possible Fuel Models	Logic/Assumptions
Scots pine (Pinus sylvestris)	188 (often used for ponderosa pine) 183 – modified	Ponderosa pine (*Pinus ponderosa*) may be a suitable western US proxy. Otherwise, probably a modified 183 (TL3) to increase rate of spread and flame lengths.
Black pine/Acacia (Pinus nigra/Acacia)	161 183 – probably modified	FBFM 161 works best when the understory is dominated by an herbaceous understory including forbs and grasses (it is dynamic). Creating a custom fuel model starting from FBFM 183 is another solution, to increase the rate of spread and flame lengths. Using FBFM 165 would assume ladder fuels to be present and will probably overpredict rate of spread and flame lengths.
Beechwood (Fagus sylvatica)	182/186 (dormant season fire) 161 (growing season fire)	FBFM 182 or 186 (or a custom FBFM) may be used when a fire is mostly burning through hardwood (round leaf) litter. FBFM 186 tends to have much higher rate of spread and flame lengths than 182. FBFM 161 is dynamic and may be used during the growing season when a fire would be expected to burn through the understory vegetation.
Durmast (Quercus dalechampii)	182/186 (dormant season fire) 161 (growing season fire)	FBFM 182 or 186 (or a custom FBFM) may be used when a fire is mostly burning through hardwood (round leaf) litter. FBFM 186 tends to have much higher rate of spread and flame lengths than 182. FBFM 161 is dynamic and may be used during the growing season when a fire would be expected to burn through the understory vegetation.
Grasslands	101 (may be best for grazed pasture) 102 (ungrazed pasture) Custom FBFM (lower ROS and FL than FBFM 101)	Assumes no irrigation. Rate of spread and flame length drastically change depending on chosen FBFM.

In this table are provided just first estimations on classification which for Bulgarian vegetation types can be further expand and calibrated in further test cases. The fire behaviour fuel modelling work requires future expansion and more tests with different species from all regions of Bulgaria. However the estimated first steps are good basis for development and expansion of what is achieved so far.

5. Acknowledgement

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