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Application note

SYPYDA: A software tool for fire management in Mediterranean pine forests of Greece

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ABSTRACT

The main objective of this study is the design and the development of a fire management software tool for Mediterranean pine forests of Greece. The system operates as a standalone application and allows the end users to apply various fire environment (meteorology, topography, fuel) scenarios in order to estimate the characteristics of fuel complexes in Mediterranean pine stands, to predict the expected fire behavior, as well as to implement and evaluate fuel treatments for reducing the intensity and severity of fires in such ecosystems. The system simulates fire behavior (probability of crown fire initiation, type of fire, rate of spread and fireline intensity) in different types of understory vegetation and stand overstory structure under different weather conditions using current well-tested fire behavior prediction models. All user interaction with the software is done via a friendly and modern Graphical User Interface (GUI), designed in Windows Presentation Foundation/eXtensible Application Markup Language (WPF/XAML), a framework with User Interface (UI) elements coded in C# .NET. The proposed system is expected to assist forest researchers, forest service officials and land managers to evaluate fuel hazard and assess the potential for initiation and spread of wildfires in Aleppo and Calabrian pine forests in Greece.

1. Introduction

Wildland fires are the most destructive type of forest disturbance in Greece. Aleppo pine (*Pinus halepensis* Mill.) and Calabrian pine (*Pinus brutia* Ten) occupy approximately 560,730 ha as dominant species which is equivalent to approximately 18.7% of the total forest land in the country. These pine forests of Greece grow under more arid conditions than those of the west Mediterranean, thus resulting in increased fire frequency and intensity (Barbero et al., 1998). During a 26 year period (1984–2009), 4725 fires (14.6% of total fires in Greece) occurred in Aleppo and Calabrian pine forests, burning 296,517 ha (approximately 27.7% of the total burned area). On the average, 2.85% of the total Aleppo pine and 1.48% of the total Calabrian pine forested area are burnt in Greece every year (Mitsopoulos, 2009). Both species are characterized by the dense broadleaved-evergreen shrub understory (known as "maquis") below the live crown fuel layer which creates ladder fuels that facilitate fire transition from the understory fuel layer to the canopy fuel layer (Quezel, 2000). This situation, together with low moisture content and strong winds during summer periods, leads to extreme fire behavior associated with crowning, increased rate of spread, fireline intensity, flame length and spotting (Werth et al., 2011).

Fires in pine forests, in terms of fire behavior modeling, are complex phenomena since both fuel strata layers (canopy and surface) are involved during the fire initiation and propagation phases (Scott and Reinhardt, 2001). Therefore, accurate description of canopy and surface fuels characteristics is a basic requirement for use in fire management decision support systems which embed semi-empirical and empirical fire behavior models, such as FARSITE (Finney, 1998), BehavePlus (Andrews, 2009), NEXUS (Scott and Reinhardt, 2001), CFIS (Alexander et al., 2006). All the above mentioned systems and software programs are the primary planning tools used by forest managers to compare the anticipated effects of fuels treatments alternatives (Affleck et al., 2012) and to modify fire behavior (Stephens, 1998).

Measurements of canopy fuel characteristics, such as canopy fuel load (CFL), canopy bulk density (CBD) and canopy base height (CBH) are a prerequisite for reliable crown fire behavior prediction (Cruz and Alexander, 2010), while shrub fuel height (SFH) and shrub fuel load (SHL) are clearly involved in the initiation of crown fires by increasing fire intensity and serving as the ladder that establishes continuity between the canopy and shrub fuel layers (Castedo-Dorado et al., 2012).

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Canopy and shrub fuel characteristics in Aleppo and Calabrian pine are relatively unknown by forest managers in Greece. Moreover, there are no tools available to estimate these characteristics in the region, while measuring both canopy and shrub fuel in the field is a very difficult, time-consuming and costly task (Reinhardt et al., 2006; Cruz et al., 2003). Therefore, forest managers cannot use fire behavior simulation systems correctly in order to select the most appropriate fuel treatments in Mediterranean pine of the country.

The main objective of this study is to present a software tool for fire management in Aleppo and Calabrian pine in Greece by providing an overview of the components comprising the system.

2. Material and methods

2.1. System components

The SYPYDA is comprised of three different components. These involve: (1) regression models for predicting fuel complex characteristics based on stand basal area, dominant height and elevation (2) predicting the potential fire behavior (type of fire, the fire rate of spread and the fireline intensity) and (3) implementing and evaluating fuel treatments effects on fire behavior potential in Aleppo and Calabrian pine forests.

2.1.1. Regression models for predicting fuel complex characteristics

Fifty six (56) sample plots were selected in two different Aleppo pine and two different Calabrian pine representative sites (four in total) which cover a wide range of geographical conditions in Greece. In each plot fuel complex characteristics were measured according to Mitsopoulos and Dimitrakopoulos (2007) and Xanthopoulos and Manasi (2002) methodologies. In every plot, stand overstory parameters (stand density, basal area, canopy closure, quadratic mean diameter) and topography factors (elevation, slope, aspect) were measured. More details on the four study areas and the fuel sampling campaign can be found in Mitsopoulos and Xanthopoulos (2015) study. Stepwise linear regression was used in order to derive models for predicting fuel complex characteristics of the studied species. Regression analysis considered all of the independent variables as potential regressors. The significance level for entering variables in the models and retain them in the resulted equations was set at 0.01. The criteria used to evaluate the adequacy of the linear models were the adjusted coefficient of determination (R_{adj}) and the root mean square error (RMSE).

2.1.2. Predicting the potential fire behavior

For predicting fire behavior the following models were used:

(1) Crown fire initiation model Cruz et al. (2004):

$$\ln\left(\frac{P_x}{1-P_x}\right) = 3.397 + 0.370U - 0.664FSG - 4.354S_{x1} - 1.787S_{x2} - 0.286m_e$$

where

P_x = crown fire initiation probability.
U = wind speed (km h^{-1}).
FSG = fuel strata gap (m).
S = surface fuel load (kg m^{-2}).
m_e = dead fine fuel moisture content (%).

In case of predicted crowning then the Cruz et al. (2005) crown fire rate of spread is used:

$$R_{ca} = 11.76U^{0.86}\rho_c^{0.18}\exp(-0.17m_e)$$

where

R_{ca} = crown fire rate of spread (m min^{-1}).
U = wind speed (km h^{-1}).
ρ_c = canopy bulk density (kg m^{-3}).
m_e = dead fine fuel moisture content (%).

If the fire remains in the shrub fuel layer the Anderson et al. (2015) shrub fire rate of spread is used:

$$R_{shrub} = 3.61U^{0.91}h^{0.18}\exp(-0.076m_e)$$

where

R_{shrub} = shrub fire rate of spread (m min^{-1}).
U = wind speed (km h^{-1}).
h = shrub fuel height (m).
m_e = dead fine fuel moisture content (%).

The fireline intensity in both cases is calculated by the Byram (1959) equation:

$$I_B = Rw_aH$$

where

I_B = fireline intensity (kW m^{-1}).
R = crown or shrub fire rate of spread (m s^{-1}).
w_a = fuel load (kg m^{-2}).
H = heat content (kj kg^{-1}).

2.1.3. Evaluating fuel treatments effects

Four different fuel treatments (thinning, pruning, shrub removal and controlled grazing) were selected to be included in the system. In each of the treatments, fuel complex characteristics values were adjusted accordingly based on the user inputs. Thinning and pruning affect canopy fuel characteristics (canopy bulk density and fuel strata gap), while shrub removal and controlled grazing the understory shrub layer (shrub fuel load and height).

2.2. Object-oriented programming

All parts of the application were developed using the Microsoft Visual Studio 2013 Professional on Microsoft Windows 8.1, with the .NET Framework 4.5.

The graphical user interface was implemented with the WPF framework, which integrates multimedia, graphics, animations and interactivity into a single runtime environment. The various graphical elements and controls were designed with XAML. XAML is a declarative markup language based on XML and is used for the creation of UI elements, increasing the flexibility of the graphical user interface development. Telerik UI for WPF also helped in the design and creation of most of the graphical controls.

The rest of the application is mostly written in C#, due to its object-oriented features. The object-oriented application design facilitates a code base that is transparent, reusable and extendible. The two following software libraries were also used: (a) AutoMapper for automatic matching and data transfer between objects and (b) PostSharp tool for checking and correcting the source code.

3. Results and discussion

Fig. 1 shows the information flow of the SYPYDA software tool. During the first component the user enters the basal area, the dominant height and the elevation of the selected forest stand and SYPYDA calculates the fuel complex characteristics. The above mentioned variables are available data found in all forest invento-