Assessing Forest Fire Risk and Fire Propagation in the Area of Valia Calda, National Park of North Pindos, Greece

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Abstract. Fire hazards and risk are of great interest in terms of prevention and control. This study focuses on the construction of a GIS-based tool for fire growth patterns and fire propagation characteristics for modeling such hazards in the national park of Valia Calda in Pindus Mountain, Greece. At a first stage, data concerning previous fires in the region have been collected and analyzed for calibrating the parameters of the software package G-FMIS in an ARC-GIS platform that was used as a tool for simulating the fire behaviour and spread in the forest ecosystems of the Park area. Calibration was made through reconstruction of the propagation of the past fires based on observed isochrones and relevant fire growth data such as fire perimeter and burned area. Simulation of the past fires was performed for the real duration of the event using one-hour time intervals. The second stage following the calibration of the fire simulator focused on producing scenarios of eventual fire occurrence and relative analysis of their potential propagation pattern. Potential fire spots have been identified based on the distribution of the human activity in the Park. Meteorological data sets have been created, based on the prevailing values of the weather parameters in the area including less probable extreme meteorological scenarios. Based on the aforementioned scenarios a number of simulations have been performed and the fire propagation data have been analyzed in the context of fire prevention planning for the area.

Keywords. Natural hazards, national park, forest fires, fire propagation growth, simulation.

1. Introduction

The National Park of Valia Calda in Pindus Mountain is an ecosystem of great importance for the grater area of Epirus, Thessaly and Western Macedonia. It is located at the northern part of Pindus Mountain chain and has been characterised, one of the most critical and representative national parks of Greece. It is located between the town of Metsovo, the city of Grevena and the cluster of Eastern Zagori villages. The whole area lies at an altitude from 1000m to 2175m where the highest crown is. The forest ecosystems of the national park include large areas of sparse or dense tufts of *Fagus sylvatica, Pinus nigra* and *Pinus heldreichi sp.,* in immiscible or mixed populations. It also contains areas such as grasslands and pastures while in some cases the landscape is mainly of rock formations. The area has been under protection regime with a valid legal status since 1966 [1], while the protected region of the national park has been divided in two zones: a) the core and b) the peripheral zone. The core covers almost 33.6 km^2 and the peripheral zone 35.3 km^2.

The climate plays an important role to the preservation and modulation of the ecosystems grown in the park, while influences the climate behaviour in the grater area. In the area, rainfall and snowfall may be intense for a long period during winter, while temperatures, even in the warmest months of the year, remain at relatively low levels.

Despite the fact that few forest fires have occurred in the area there are serious ecological, social and economic reasons why one should evaluate the risk of forest fire in the area. Although the area has been characterised as National Park, several actions and activities take place in the area with the tolerance of the local authorities that in some cases may become a risk or a hazard for Valia Calda.

In order to create a tool that would hopefully operate as an integrated system of risk management, the present work focused and dealt with forest fires having as pilot area the area of Valia Calda. The main axis of preparedness for forest fires is the scientifically substantiated organisation of prevention and the development of technology of the integrated management for forest fire incidents in the area [2]. To achieve the aforementioned, this study is focused on the construction of a GIS-based tool for fire growth patterns and fire propagation characteristics for modelling such hazards in the national park of Valia Calda. The software package G-FMIS in ARC-GIS platform was used as a tool for simulating the fire behaviour and spread in the forest ecosystems of the Park area.

2. Materials and methods

The first part of the study was to provide the main digital cartographic material in addition with the basic structure of the databases that would contain the elements and attributes needed for the construction and completion of the GIS system for Forest Fire Management.

2.1. Datasets and thematic layers

The base maps created contained information and data that were recorded in several databases (feature attributes). The following data categories were introduced: a) study area, b) basic elevation network, c) basic road network d) vegetation and habitat e) basic hydrographic network f) DEM (Digital Elevation Model), g) sites of interest h) type of forest biomass. The thematic layers (shape files) created are shown in Figure 1.

The creation of Vegetation Ecosystems was carried out by Supervised Classification of a multi-spectral image from the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) sensor [3]. Reflective bands of ASTER were used, covering the spectral range from 0.52–2.43 μm [4], [5], [6], [7], [8]. Land Cover classes were chosen according to the Greek National Forest inventory [9], [10], [11]. Training areas were identified on the images while ground surveys were also made to confirm the land cover. The vegetation ecosystems were classified in 11 categories (Figure 1). The land cover classes with different forest types were is some cases difficult to discriminate giving inaccurate results. For this purpose, vegetation maps provided by the National Forest Authority were also used in order to evaluate the classification and to complete problematic areas. The database of vegetation was further developed by adding several indices that represent vegetation density, flammability, moisture content and other information that would provide data for forest fire modelling.

2.2. Meteorological data

For the construction of the scenarios of potential wildfires, the specification of the most appropriate meteorological stations that provided reliable meteorological data was necessary. For the area of Valia Calda several datasets of two meteorological stations (M.S.) were used: the M.S. of Krania and the M.S. of Metsovo. Both stations are located outside the National Park near the village of Krania in the Prefecture of Grevena and in the village of Metsovo in the Prefecture of Ioannina. These two were chosen because the datasets were of longer period of time since for such applications time series of 30 years and more are needed.

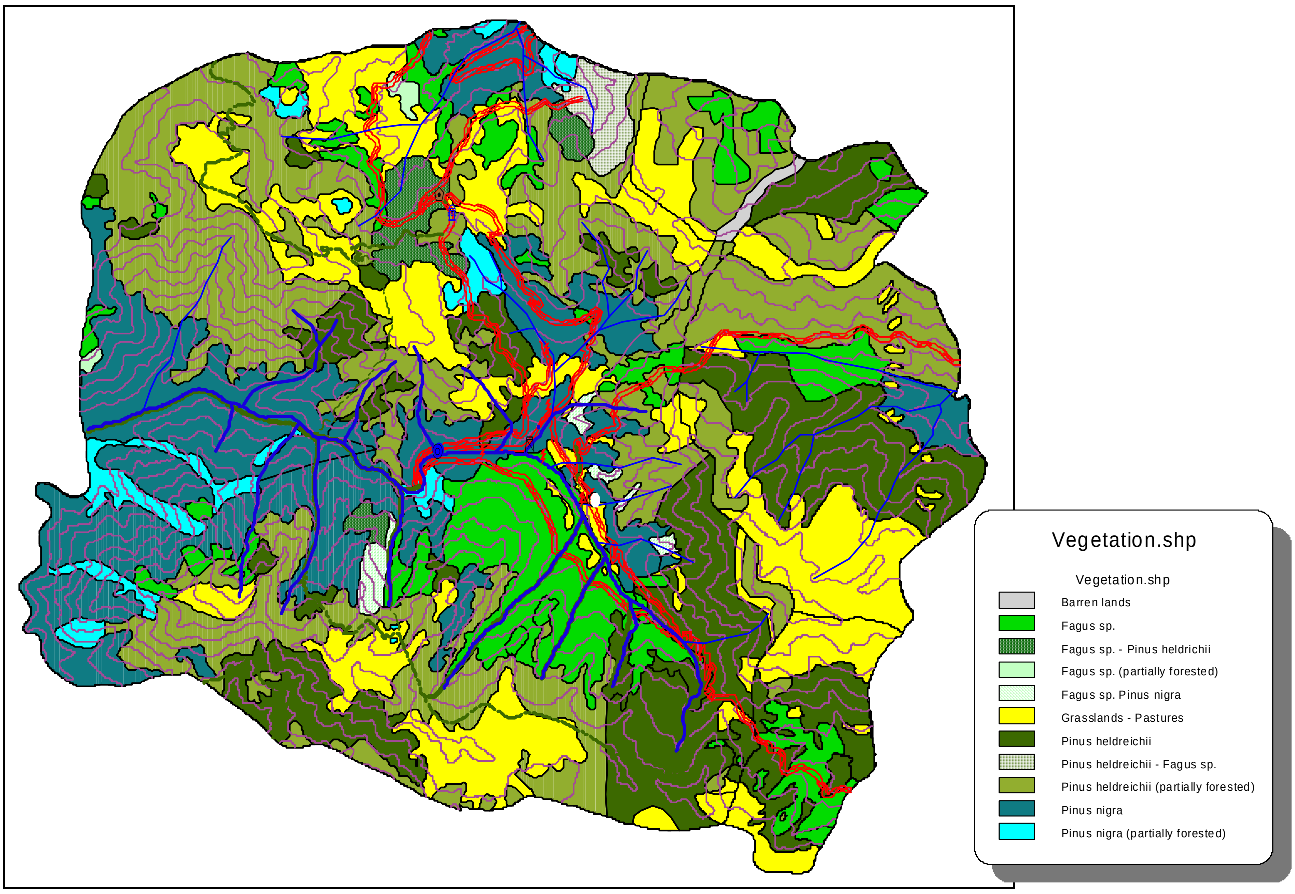


Figure 1: Thematic map with all information levels-layers.

Emphasis was given on the time periods of higher risk. High temperatures and wind speeds are the elements mostly evaluated in terms of fire risk modelling. The analysis that took place showed that in the area of Valia Calda the most commonly appearing wind speed is of 2-3 m/s while the direction is usually South-East or East. The data used consisted of numerical and descriptive values for: air temperature, wind speed, wind direction, precipitation, and humidity are given. These data were processed before the input in the model of fire propagation.

2.3. The G-FMIS simulator

The FMIS simulator (Fire Management Information System) is a tool that contributes to the implementation of a fire propagation evaluation system (BEHAVE) which uses a two-dimension heat transfer model. For the application of the results in three dimensional space, a modified least route algorithm is used combined by a cellular automated propagation algorithm [12], [13], [14], [15], [16], [17]. The simulator used for Valia Calda is the G-FMIS (Fire Growth Simulator) under ARC-GIS environment, giving the abilities of combining multiple results of simulation by geospatial analyses of fire parameters in the area of interest. The analysis and the simulation of forest fire propagation for the area of Valia Calda were realised through GIS techniques and by the use of forest-fire simulator G-FMIS. The FMIS simulator was developed by the "ALGOSYSTEMS" company, in several versions during the last decade.

The work was organised in two further stages. At the first stage, data concerning two previous fires (1988 and 1993) in the region have been collected and analysed for calibrating the parameters of the G-FMIS, according to the fuel types and the meteorological values of the region. Calibration made through reconstruction of the propagation of the past fires based on observed isochrones and relevant fire growth data such as fire perimeter and burned area. Particular analysis of the wind field pattern was performed using the NuAtmos model [18]. Simulation of the past fires was performed for the real duration of the event using one-hour time intervals.

The second stage following the calibration of the fire simulator focused on producing scenarios of eventual fire occurrence and relative analysis of their potential propagation pattern. Potential fire spots have been identified based on the distribution of the human activity in the Park. Meteorological datasets have been created, based on the prevailing values of the weather parameters in the area including less probable extreme meteorological scenarios. Based on the aforementioned scenarios, a number of simulations have been performed and the fire propagation data have been analysed in the context of fire prevention planning for the area.

For the evaluation of the simulation model and procedure, data of two registered major forest fires in the area of Valia Calda were analysed. These fires developed in years 1988 (Figure 2) and 1993 (Figure 3) and burned 5 and 620 ha respectively. The data of these forest fires were examined and evaluated in order to be put into the simulation model.

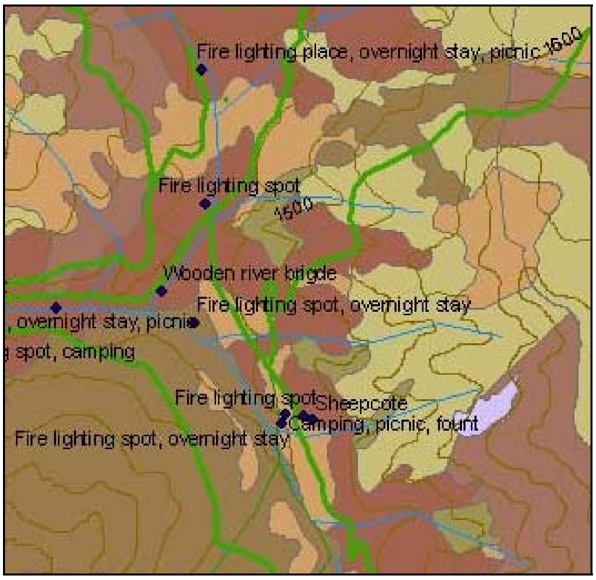


Figure 2: Burnt area by forest fire in 1988.

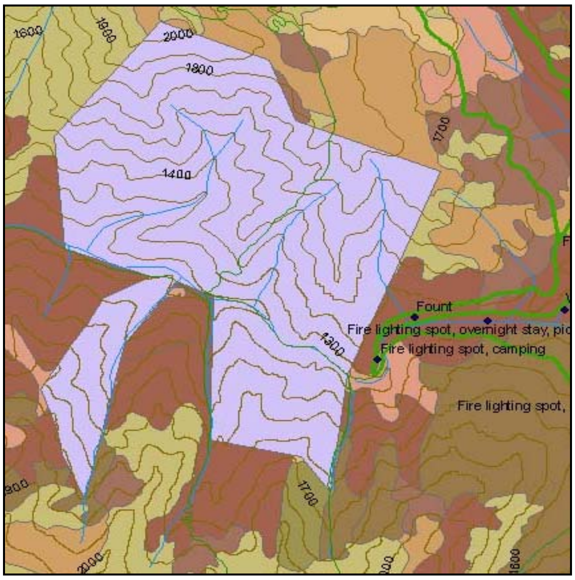


Figure 3: Burnt area by forest fire in 1993.

The method used, needed the division of the procedure in three main parts: 1) the creation of the geographic database, 2) the adjustment of functional parameters of the simulator based on the behaviour of past forest fires and 3) the simulation, based on probable scenarios according to possible ignition spots.

3. Calibration of propagation models

In order to provide a reliable simulation the thematic map of forest ecosystems was transformed in typical forest fuels according to the Prometheous project [19] and based on bibliographical references. The parameters used are shown in Table 1.

Table 1. Fuel parameters of the Valia Calda's Park forest vegetation.

Fuel	P.heldreichi partial	P.heldreichi	P.nigra partial	P.nigra	Fagus sp. partial
Fuel load 1h (kg /m2)	0.2132	0.2359	0.1804	0.2132	0.4578
Fuel load 10h (kg /m2)	0.1	0.1525	0.0517	0.0611	0.0651
Fuel load 1000h (kg /m2)	0.25	0.4025	0.0264	0.0312	0.0238
Live woody (kg /m2)	0.15	0.35	0.56	0.88	0.1
S/V dead (m2/m3)	66	66	66	66	82
S/V average (m2/m3)	66	66	66	66	82
Fuel depth (cm)	6	6	7	8	6
Compactness	0.02	0.003673	0.014	0.0264	0.0045
Optumum compactness	3.69	3.3	3.5	2.5	3.87
Heat content (J/gr)	19000	19000	16500	16500	15000
Mois. of extinction (%)	30	30	30	30	25

Fuel	Fagus sp.	Grass-land	P.held Fagus sp.	Fagus sp.-P.heldr	Fagus sp.- P. nigra	Barren Land
Fuel load 1h (kg /m2)	0.654	0.45	0.262	0.3354	0.19	0.2
Fuel load 10h (kg /m2)	0.093	0.05	0.09	0.09	0.065	0.03
Fuel load 1000h (kg /m2)	0.034		0.153	0.085	0.024	
Live woody (kg /m2)	0.2		0.19	0.15	0.15	
S/V dead (m2/m3)	82	115	75	75	66	115
S/V average (m2/m3)	82	115	75	75	66	115
Fuel depth (cm)	4	25	7	7	6	12
Compactness	0.0896	0.0010	0.015	0.015	0.011	0.0011
Optumum compactness	4.55	0.25	3.9	4.15	3.95	0.25
Heat content (J/gr)	15000	16500	18000	18000	16500	12000
Mois. of extinction (%)	25	15	30	30	30	10

This type of correspondence and standardisation of forest fuels was also imported to the G-FMIS simulator for the simulator of the two past forest fires of 1988 and 1993 (Figure 4). By taking into account the ignition spots of those fires, the isochronals of perimeter propagation and the meteorological data of each time, several runs were carried out in order to optimize the shape-area and the evaluation of speed propagation. The procedure described above gave the opportunity to modify some of the model parameters so as to provide a more reliable and “true” propagation model. This procedure may be described as calibration of the propagation model.

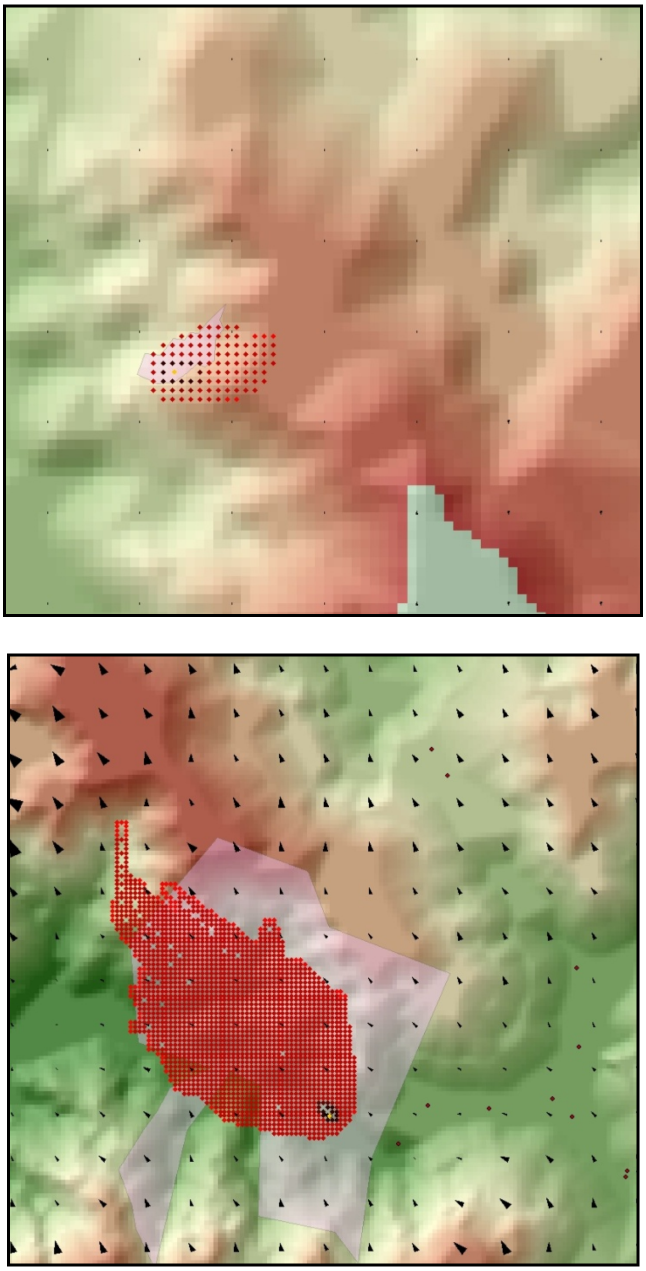


Figure 4: Calibration of the G-FMIS for the fire of 1988 (top) and 1993 (bottom).

4. Construction of forest fire scenarios

Forest fire scenarios need the assignment of spots of high risk in terms of ignition and the evaluation of meteorological conditions. For the first one land use was determined with respect to sites of human activity in the whole area. Five spots were determined to be the ones of higher risk for fire ignition. These spots have characteristics such animal sheltering, recreation areas and past ignition spots. Figure 6 presents a diagram of all the input data that have been used in order to develop the fire risk scenarios.

Figure 5: Input data used for the fire risk scenarios in Valia-Calda.

The meteorological data concerned mainly the time period of July-August. For this time of the year the wind speed and direction parameters were evaluated as they were the ones of higher risk. The analysis showed that in the study area the most probable wing direction is South-East or East while the wind speed fluctuates from 2 to 3 m/s. According to the available data 5 sets of different wind speed and direction were used. Each set includes parameters from both meteorological stations and a combination of the data took place.

As already mentioned, the wind speed is unlikely to show values greater than 4 m/s. Despite this, the scenarios chosen included much higher values up to 8m/s of wind speed on order to cover every possible course and to study the performance of each fire in extreme conditions. The G-FMIS simulator used grid values of these parameters produced by interpolation of the meteorological data available from the two stations (Figure 6). Five (5) possible ignition spots and five (5) meteorological datasets were produced as scenarios. Each simulation had a time step of one hour while the total duration was 12 hours for each scenario. Figures 7-11 present five of the fire propagation scenarios that resulted from these simulations, as the most representative ones, given the input meteorological conditions and the spread of the fire in the final area. These scenarios had the following input parameters:

a) *Scenario 1: wind speed: 6m/s, wind direction: 140^o.*
b) *Scenario 2: wind speed: 5m/s, wind direction: 100^o.*
c) *Scenario 3: wind speed: 5m/s, wind direction: 150^o.*

d) *Scenario 4: wind speed: 8m/s, wind direction: 150°.*
e) *Scenario 5: wind speed: 3m/s, wind direction: 150°.*

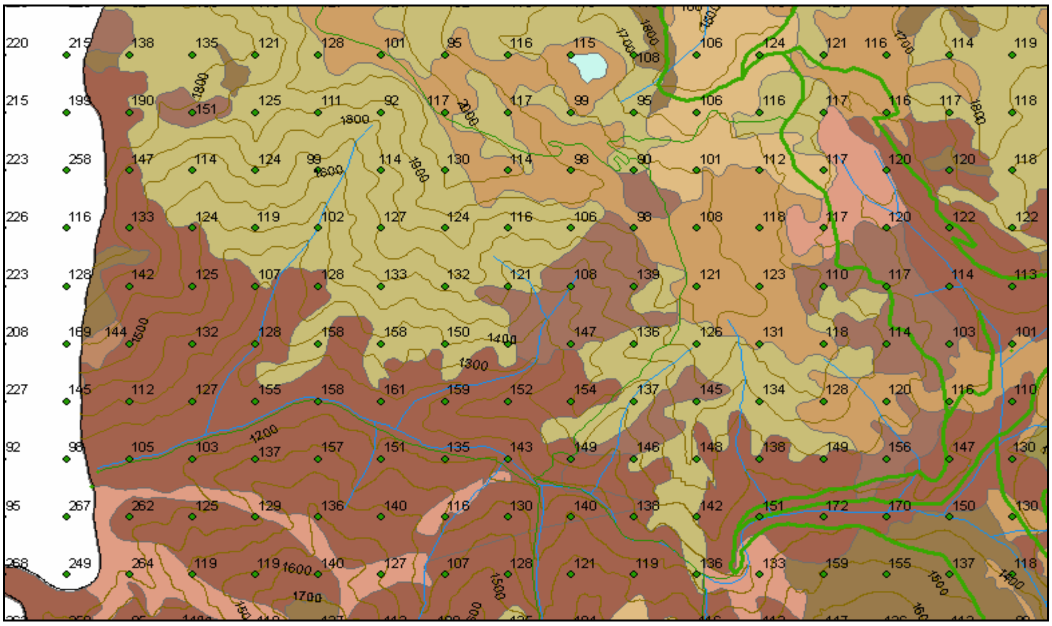


Figure 6: Grid values of wind direction produced by interpolation of meteorological data from Metsovo and Krania.

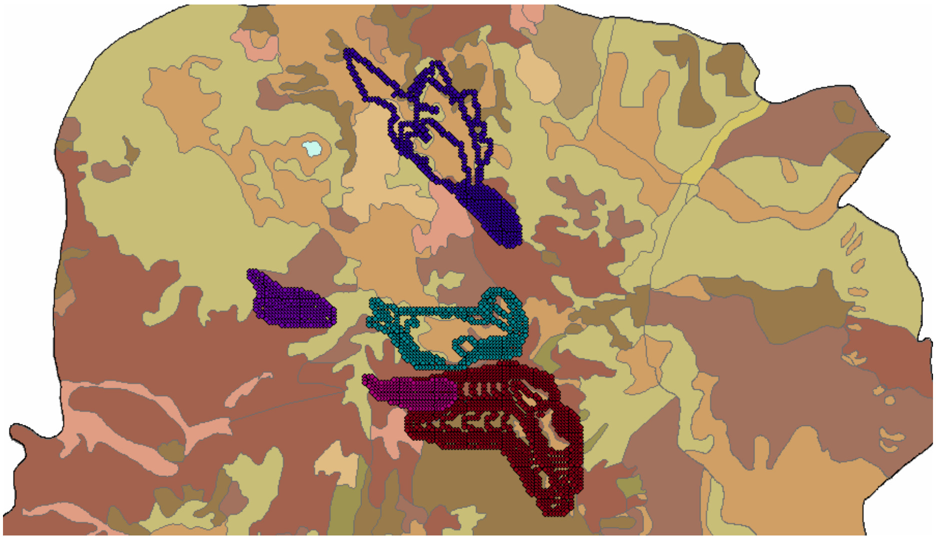


Figure 7: Fire propagation in Valia-Calda based on the input parameters of Scenario 1.

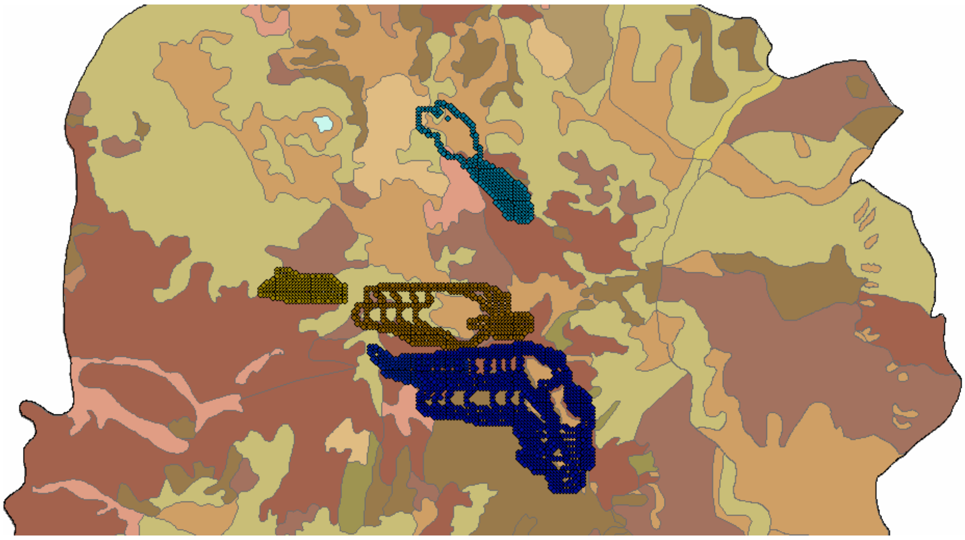


Figure 8: Fire propagation in Valia-Calda based on the input parameters of Scenario 2.

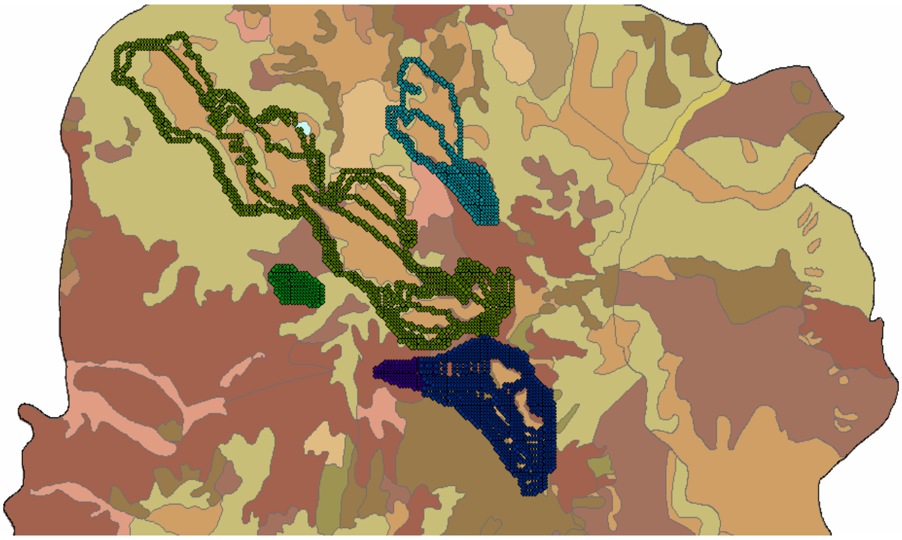


Figure 9: Fire propagation in Valia-Calda based on the input parameters of Scenario 3.

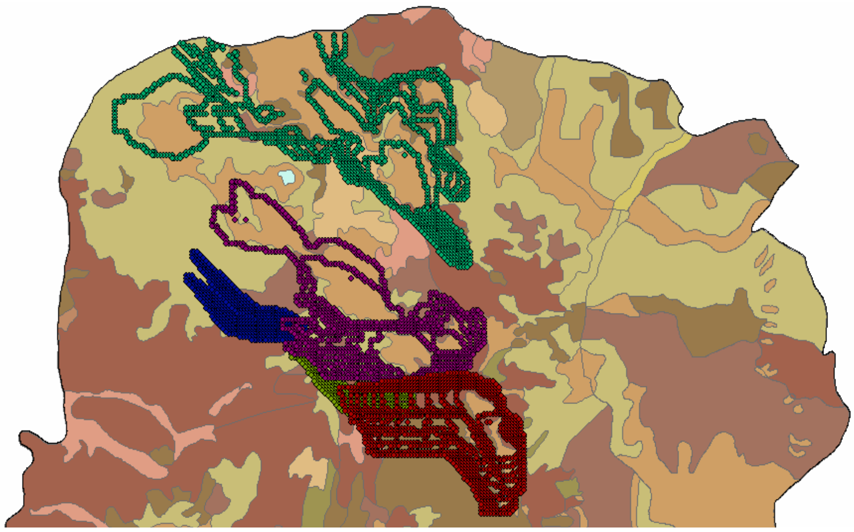


Figure 10: Fire propagation in Valia-Calda based on the input parameters of Scenario 4.

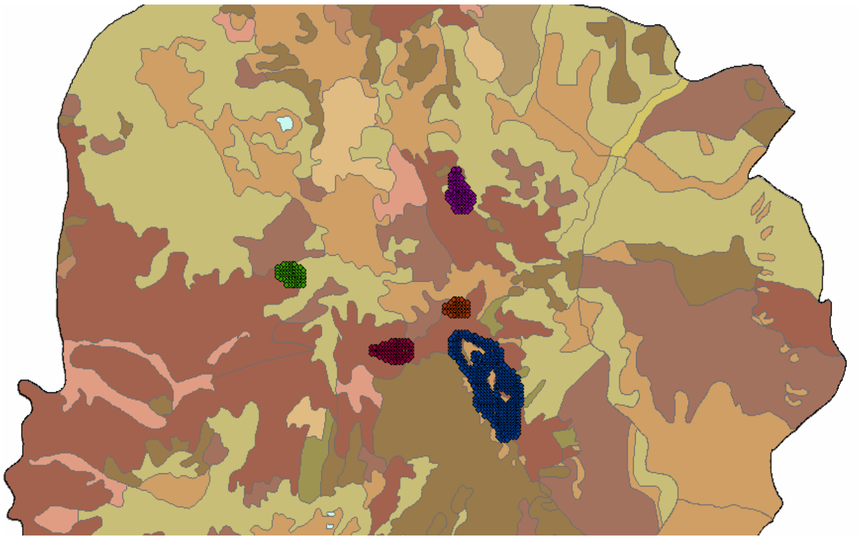


Figure 11: Fire propagation in Valia-Calda based on the input parameters of Scenario 5.

5. Results of forest fire propagation scenarios

The types of forest ecosystems of Valia Calda and the meteorological conditions in the area do not favour fire ignition and propagation in general (absence of understory, existence of open stands). Due to the formation of the forest, there is no development of a continuous fuel bed that would lead to the rapid fire propagation. The use of G-FMIS simulator of the evaluation of substitutional scenarios of fire growth in the area of National Park of Valia Calda gave the ability to determine tree distinctive groups of fire behaviour, based on burnt area and perimeter, as derived by the simulation procedure. The first group includes forest fire with high propagation speed that is mainly caused and maintained in areas of underbrush vegetation. Simulation scenarios for such areas showed maximum propagation speed for a long period of time (Figure 12).

Forest fires that are to be expanded without being controlled in areas with more flammable vegetation types are most likely to expand in large areas and to create several fire sheets [20]. These forest fires need to be spotted and controlled immediately before they gain access to areas of high slope of flammable vegetation. In case of extreme weather conditions those fires will become incontrollable in 2 to 3 hours.

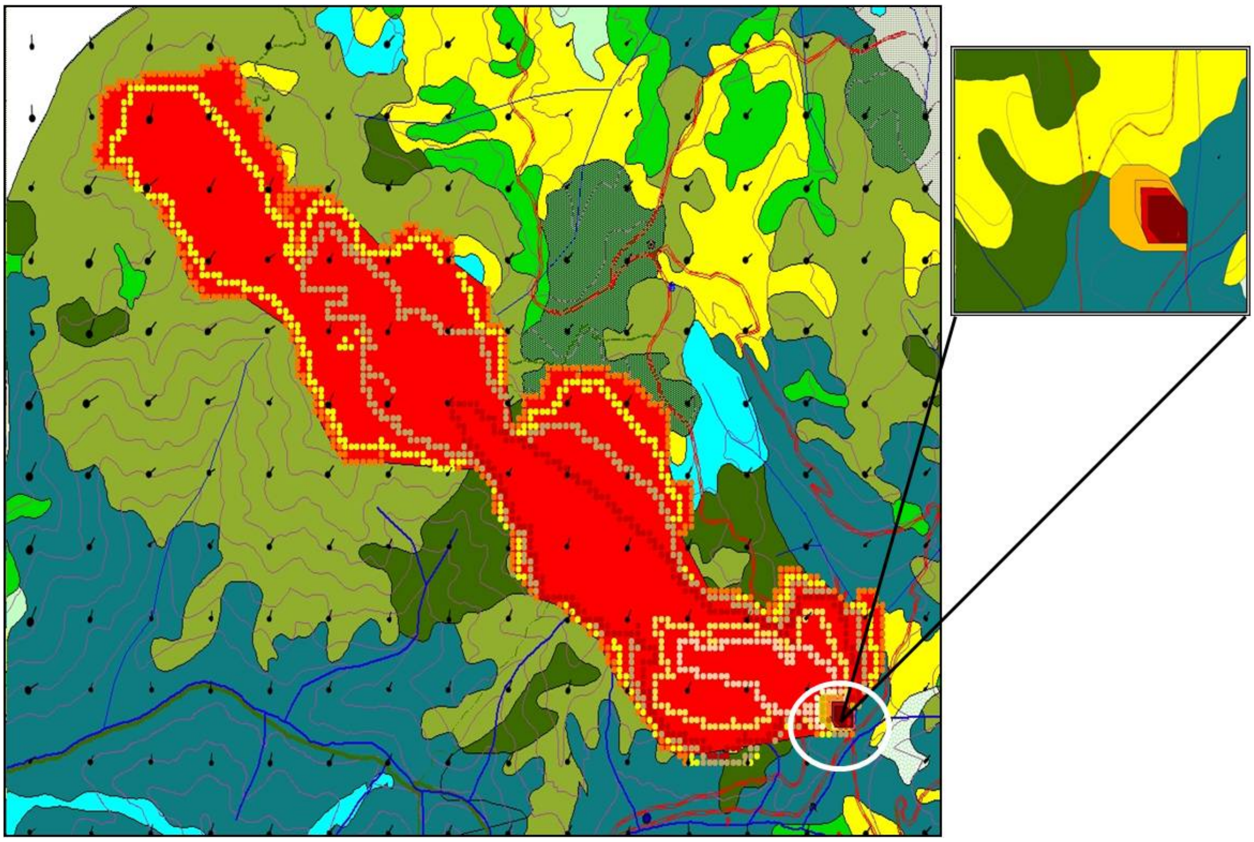
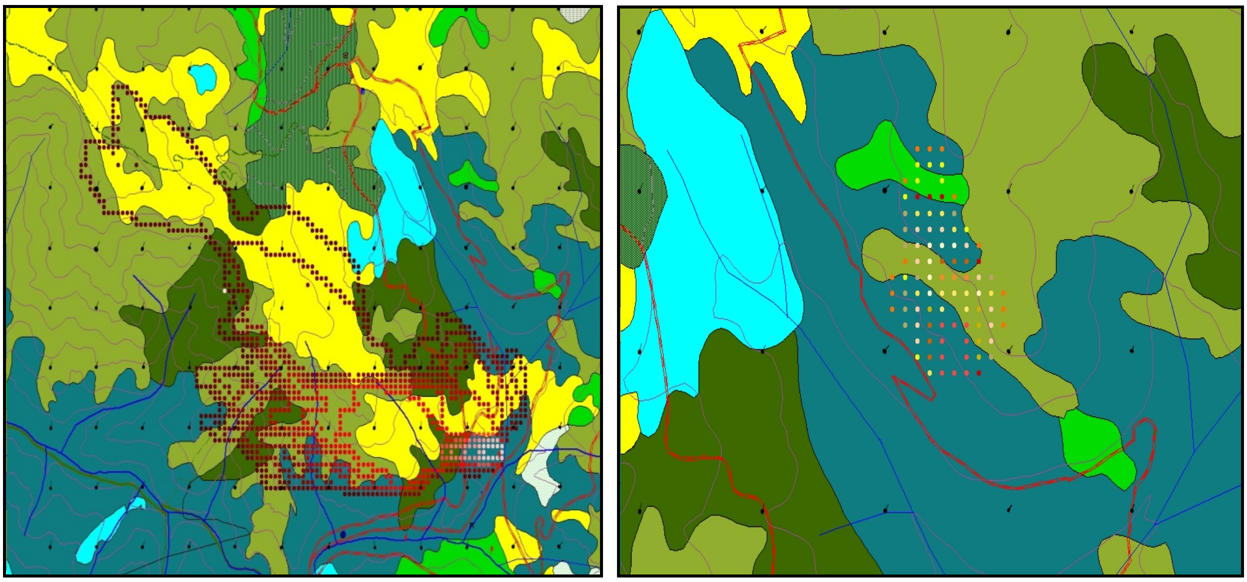


Figure 12: Simulation of the propagation of potential fire with contours of 1, 2, 3 and 6 hours in the small image and 12 hours in the big one. The fire will propagate rapidly after the 6th hour due to change of the fuel bed composition.

The second group refers to forest fires that show fluctuations in the type of growth. These fires mostly present a medium propagation speed. Their growth is affected by the topography and relief of the area as well as by the fuel density (Figure 13a). The third group includes forest fires that grow with low speed (mild meteorological conditions). These are the easiest to control due to the lack of accelerative parameters (Figure 13b).



(a) (b)

Figure 13: Influence of topography and wind to the fire growth pattern (a) and fire with limited growth due to weak wind (b).

It would be very useful, though, to manage and control larger forest fires under the umbrella of a national program in order to preserve natural ecosystems. This could be accomplished by implementing the methodology described in this paper in more areas of interest or in greater areas in Pindus Mountain. Since this is a pilot application, feedback and experience gained by the use of this program would result to the improvement of the application so as to expand it in the future.

6. Conclusions

According to the evaluation of the meteorological data in the event of fire in the area of Valia Calda during the months of high risk, July and August, it is more likely that the fire follows a patters of the second or third group mentioned above. Nevertheless, it is necessary to take into account the worst case meteorological scenario in order to implement a strategic prevention plan.

From the five spots examined and evaluated the ones of higher risk are those were human activity might develop (camping places), followed by spots of animal sheltering. The G-FMIS simulator does not provide the ability of simulating local phenomena. It is important thought to examine the behaviour of a fire in gorges, culches and water currents where due to the high slopes and the dense vegetation fire might prove unpredictable and dangerous. The wind conditions created by a fire itself, may differentiate the predicted growth pattern and change its direction.

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