Mapping forest fire risk zones based on historical fire data in Mount Olympus, Greece, using Geographical Information Systems

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Abstract

Forest fires can be real ecological disasters, regardless of whether they are caused by natural forces or human activities. Forest fire risk zones are locations where a fire is likely to start, and from where it can easily spread to others areas. Anticipation of factors influencing the occurrence of fire and understanding the dynamic behavior of fire are critical aspects of fire risk management. A precise evaluation of forest fire problems and decisions on solution methods can only be satisfactorily made when fire risk zones are available. Historical fire data play a vital role in identifying forest fires and in recording the frequency of fire occurrence.

A most significant means for the materialization of the forest fire risk zone maps is the Geographical Information Systems (GIS). Olympus National Park, located in North Greece, was selected as the research area for this study because it faces a forest fire problem. The computer program PYROSTAT, specifically designed for inventory forest fire data, was used for the analysis. Topographic and vegetation information was digitized and GIS MapInfo software was used for further analysis. Five categories of forest fire risk zones ranging from very high to very low were derived automatically. A fire occurrence probability map, a fire sensitivity area map and a suppression planning difficulty map were delineated according to their sensitivity to fire occurrence during the period 1983-1999. The above maps can substantially contribute to integrated forest fire risk management.
Key words: forest fires, historical fire data, forest fire risk zones, G.I.S.

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1 Introduction

Forests are a major natural resource and they play an important role in maintaining environmental balance. The health of a forest in any given area is a true indicator of the ecological conditions prevailing in that area. Forest fires are considered to be a potential hazard with physical, biological, ecological and environmental consequences. Frequent occurrence of forest fires is one of the reasons for the degradation of forests in the Mediterranean countries. Fire is the greatest enemy of soils, standing vegetation and wildlife. Small tress and regeneration are often affected very adversely. Even big trees are not spared if the fire is severe. There are three main types of wildfires: a) Ground fires, which burn the layer between mineral soil and loose surface fuels, remove vegetation and organic matter down to bare mineral soil. b) Surface fires, which are the most common type of wildfire, burn live and dead fuels on forests floors and grass in open land. They are low intensity, rapid and reach high temperatures, no threat to tree trunks and roots and c) Crown fires, the most destructive type of wildfire, burn tree tops, the flames jump from crown to crown and the falling branches ignite spot fires (N.W.C.G. [1]).

In Greece, forest fires are the most significant abiotic factor that threats the natural ecosystems. According to a study, 47 200 fires were reported over a period of 45 years (1955-1999) affecting an area of 1 350 072 ha, which represents an average area burned per fire of 28.6 ha, the largest in Europe, thus raising questions regarding the efficiency of the fire suppression organization (Dimitrakopoulos [2]). The causes of the forest fires can be classified into three main categories: 1) natural causes, 2) intentionally/deliberately caused by man and 3) unintentionally/accidentally caused by man. Around 98% of the forest fires in Greece are anthropogenic in nature. Preparation of the forest fire risk zone maps is therefore the first step to averting disastrous and damaging incidents of forest fire.

Historical fire data play a vital role in identifying forest fires and in recording the frequency of fire occurrence (Deeming *et al.* [3], Van Wagner [4]). The European Union with Regulation No. 804/94 directed all its member countries that have a serious forest fire problem (Portugal, Spain, France, Italy, Greece) to provide annually a “minimum common core of information on forest fires” (European Union [5]). The forest fire data bank facilitates the exchange of homogenous information on forest fires, which could improve fire prevention and suppression systems (Bovio & Camia [6]). Understanding the historical occurrence of forest fires, the factors that contribute to making an environment fire prone and the factors that influence fire behavior is essential for forest fire risk zone mapping (Chuvieco & Congalton [7], Chuvieco & Sales [8]).

In the present study, an attempt was made to prepare forest fire risk zone maps by integrating historical fire records, topographic and vegetation data from a geographic information system (GIS) for the National Park at Mount Olympus, located in North Greece.

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2 Study area

The Natural Park of Olympus is located in North Greece, (22^0 44΄ longitude, 40^0 04΄ latitude), Figure 1.

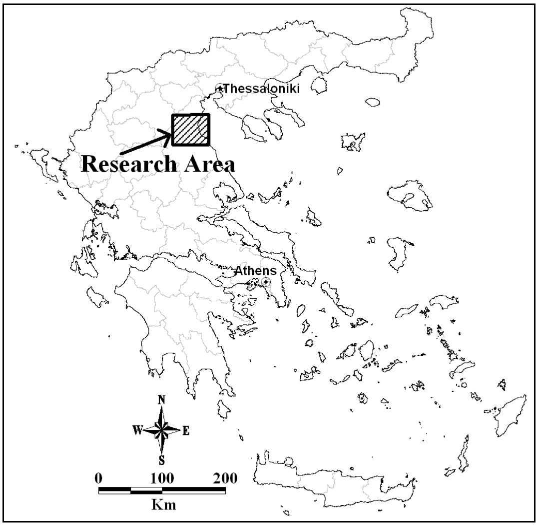

Figure 1: Location map of the research area.

Mountain Olympus is covered by rich forest vegetation of conifers and broadleaves and by unique species of herbaceous and woody plants. From geological point of view it is constituted mainly by lime stones and marbles of various dimensions. The dominance of the limestone influences the climate and the appearance of vegetation considerably. Basic characteristic of the morphology of Olympus, as in each limestone mountain, is the cutting up by deep valleys and the diversiform gradient of the slopes. The climate of Olympus is influenced by its geographic position, its volume, its rock and the display of its slopes. In mountain Olympus the Mediterranean type of climate is dominant, with its various gradations from the Eumediterranean, with soft rainy winter and dry summer, up to the Mediterranean climate of the high mountains, with heavy and prolonged winter, high precipitations but also dry summer.

3 Research method

The computer program PYROSTAT, specifically designed for inventorying forest fire data, was used for the fire data analysis. The program electronically files forest fire information and produces reports with cumulative quantitative data on forest fires (number of fires, area burned, fire causes, type of vegetation burned, fire suppression parameters, etc.), at various temporal and spatial scales.

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It also provides the user with the option to isolate, group and retrieve recorded fires that share in common a combination of factors (Dimitrakopoulos [9]).

Based on the factors that contribute to making an environment fire prone and the factors that influence fire behavior, the present study was confined to the following parameters:

i) Vegetation types,
ii) Elevation,
iii) Slope and
iv) Aspect.

3.1 Vegetation type

The following graphs (Figures 2,3,4), present the number of fires, the area burned and the average area burned per fire in each type of vegetation burned in Mount Olympus during the period 1983-1999.

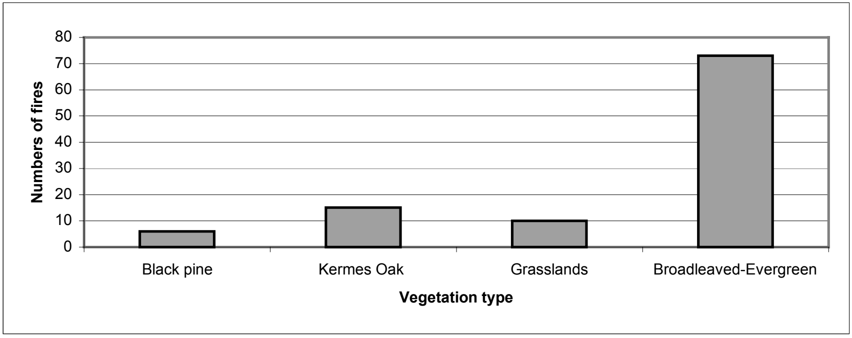

Figure 2: Number of fires in each type of vegetation burned.

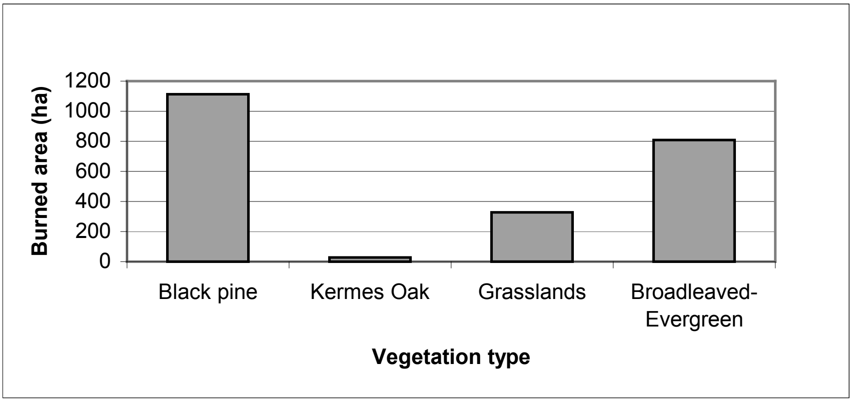

Figure 3: Burned area in each type of vegetation burned.

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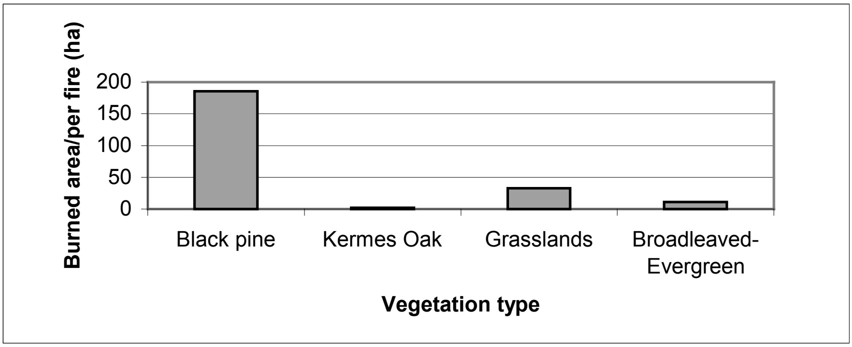

Figure 4: Burned area per fire in each type of vegetation burned.

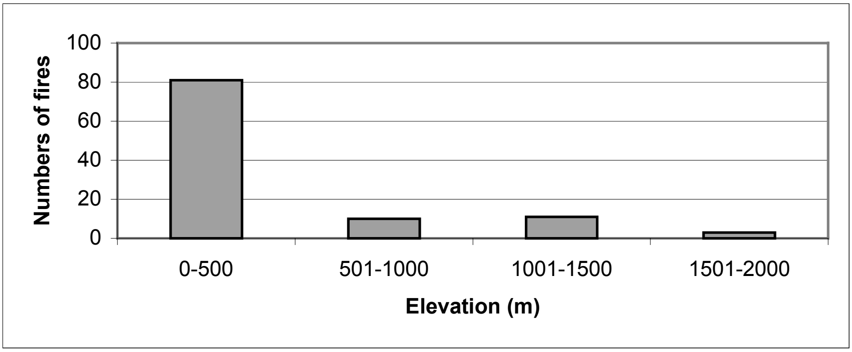

Figure 5: Number of fires in each elevation class.

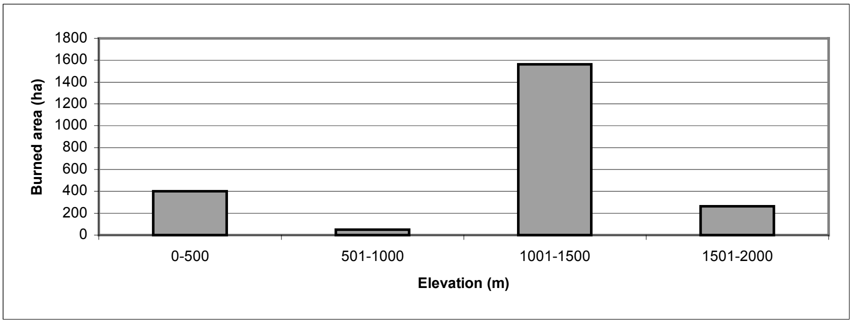

Figure 6: Burned area in each elevation class.

3.2 Elevation

The elevation above sea level influences climate and affects the general fire danger. Elevation relates to curing of fuels, precipitation, length of fire season, etc.

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The graphs (Figures 5,6,7), present the number of fires, the area burned and the average area burned per fire in elevation classes in Mount Olympus during the period 1983-1999.

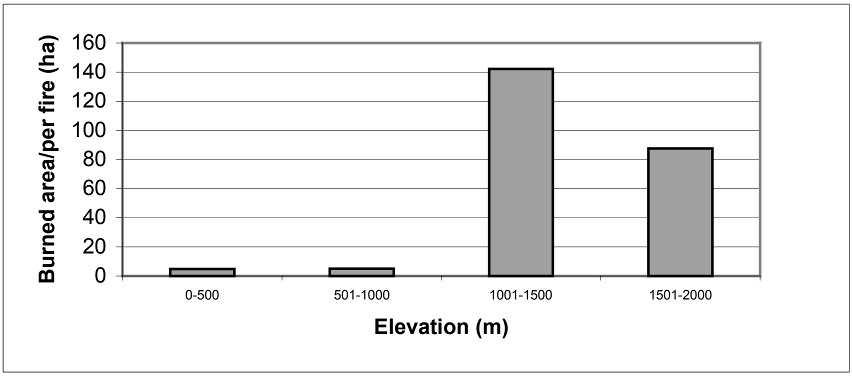

Figure 7: Burned area per fire in each elevation class.

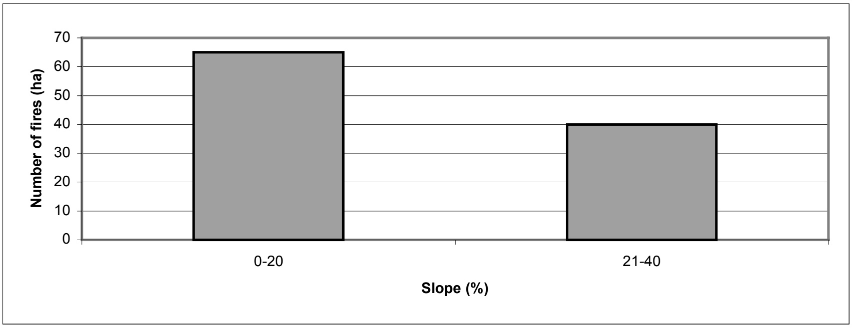

Figure 8: Number of fires in slope classes.

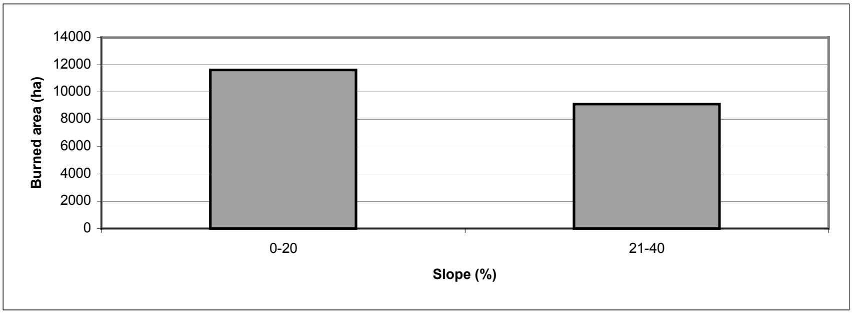

Figure 9: Burned area in slope classes.

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3.3 Slope

Slope is one of the primary factors that affect fire ignition and spread, by preheating the fuels upslope and enabling spotting to occur from rolling and aerial firebrands. The graphs (Figures 8,9,10), present the number of fires, the area burned and the average area burned per fire in every slope class, in Mount Olympus during the period 1983-1999.

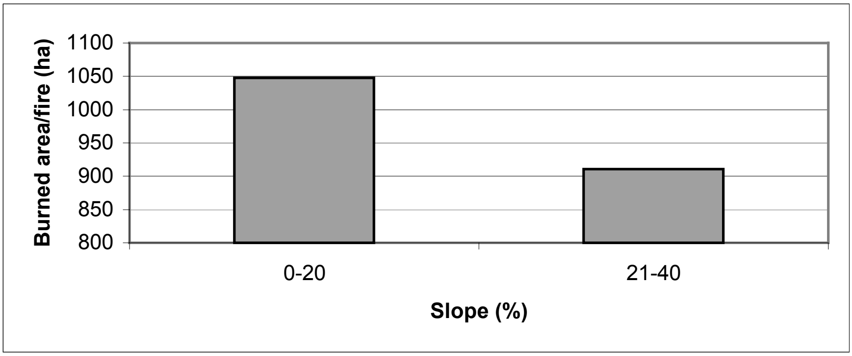

Figure 10: Burned area per fire in slope classes.

3.4 Aspect

Aspect is the direction that the slope is facing. Forest fires get larger on south aspects, because there are lower humidities, summer winds and high fuel temperatures. The following graphs (Figures 11,12,13), present the number of fires, the area burned and the average area burned per fire in every aspect type in Mount Olympus during the period 1983-1999.

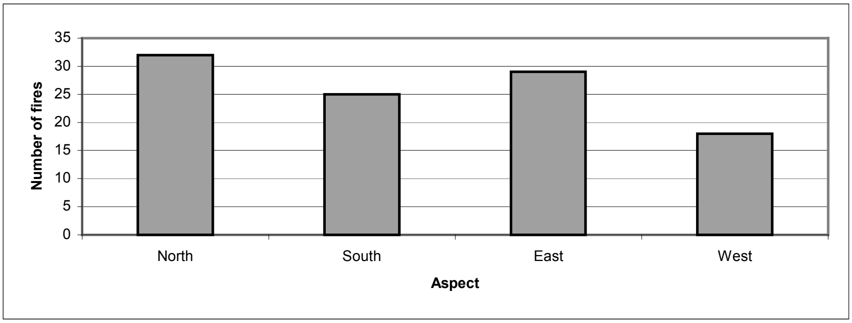

Figure 11: Number of fires in every aspect type.

For each of the above mentioned parameters was created a different raster layer in the GIS MapInfo. For the creation of these layers, selection and collection of protogenic cartographic material was performed, both in analog and digital form, which provided the background for the digitization and construction of the total geographical data base required for the forest fire zone mapping. This material consisted of topographic 1:50 000-scale maps of the Hellenic Army Geographical Service, and satellite image from LANDSAT TM-5 was used for vegetation type classification.

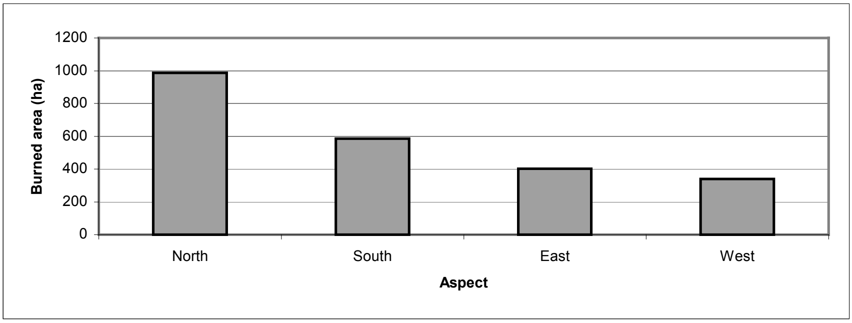

Figure 12: Burned area in every aspect type.

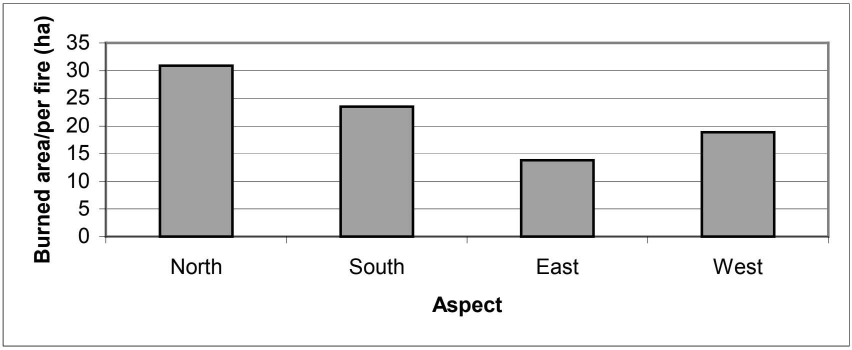

Figure 13: Burned area per fire in every aspect type.

The importing and registration of the above cartographic material was subsequently carried out using linear affine transformation (Burrough & McDonell [10], Jones [11]), which gave minor Root Mean Square errors (MapInfo Corporation [12]), as well as digitization of the geographical information.

More specifically, digitization involved peaks and contours and coastline. In particular, for the creation of the vegetation cover we used a pseudocolor satellite image from LANDSAT TM-5 of the research area where we applied a supervised classification employing Maximum Likelihood Method (Lillesand & Kiefer [13]) and ground referenced data. For the application of Maximum Likelihood Method we took into consideration the fact that the decision rule is based on the probability that a pixel belongs to a particular class. The basic equation assumes that these probabilities are equal for all classes, and that the input bands have normal distributions.

Finally, with the help of contour and peak layers we constructed the Digital Elevation Models (DEM) of the area with the application of kriging geostatistical model (Northwood Geoscience [14]; Shapiro & Westerveld [15]) and cell resolution 15m X 15m. Furthermore, slope and aspect layers were produced from DEM analysis. The above process produced approximately 10 759 476 cells, a fact that automatically reveals the difference between the traditionally applied method and its equivalent version with the use of GIS.

Table 1: Fire probability occurrence zones. (Criterion: number of fires per vegetation type and spatial data).

Fire risk zones	**Degree of fire risk**	**Description**	**Area (Km^2)**
I	Very high	Vegetation: Broadleaved-Evergreen Shrublands, Elevation: 0-500m, Slope: 0-20%, Aspect: North	49.74
II	High	Vegetation: Kermes Oak Shrublands, Elevation: 1000-1500m, Slope:21-40%, Aspect: East	13.38
III	Moderate	Vegetation: Grasslands, Elevation: 500-1000m, Slope: 0-20%, Aspect: South	27.74
IV	Low	Vegetation: Black Pine, Elevation: 1500-2000m, Slope: 21-40%, Aspect: West	8.20
V	Very low	All the other vegetation types	1 861

Table 2: Fire sensitivity areas (Criterion: burned area per vegetation type and spatial data).

Fire risk zones	**Degree of fire risk**	**Description**	**Area (Km^2)**
I	Very high	Vegetation type: Black Pine, Elevation: 1000-1500m, Slope: 21-40, Aspect: North	38.55
II	High	Vegetation type: Broadleaved-Evergreen Shrublands, Elevation: 0-500m, Slope:21-40%, Aspect: South	27.49
III	Moderate	Vegetation type : Grasslands, Elevation: 1500-2000m, Slope: 0-20%, Aspect: East	8.66
IV	Low	Vegetation type: Kermes Oak Shrublands , Elevation: 500-1000m, Slope: 0-20%, Aspect: West	57.23
V	Very low	All the others vegetation types	1 874

Table 3: Fire suppression planning difficulty areas (Criterion: average burned area per fire and spatial data.)

Fire risk zones	Degree of fire risk	Description	Area (Km^2)
I	Very high	Vegetation type: Black Pine, Elevation: 1000-1500m, Slope: 21-40, Aspect: North	38.55
II	High	Vegetation type: Grasslands, Elevation: 0-500m, Slope:0-20%, Aspect: South	39.50
III	Moderate	Vegetation type: Broadleaved-Evergreen Shrublands, Elevation: 1500-2000m, Slope:21-40%, Aspect: West	1.15
IV	Low	Vegetation type: Kermes Oak Shrublands, Elevation: 0-500m, Slope: 0-20%, Aspect: East	255.63
V	Very low	All the others vegetation types	1 626.25

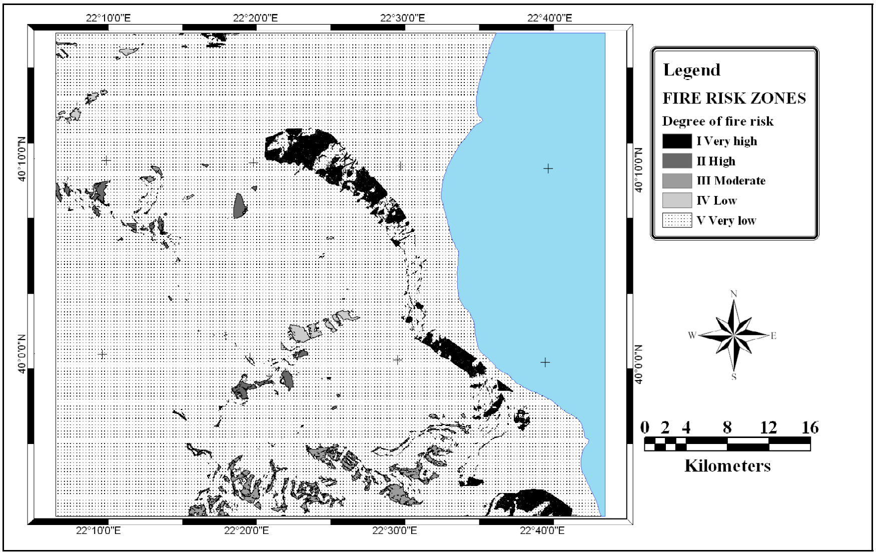

Figure 14: Fire probability occurrence map.

4 Results

After the statistical analysis with PYROSTAT five categories of forest fire risk zones ranging from very high to very low were derived automatically. Fire

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occurrence probability zones (Table 1), fire sensitivity areas (Table 2) and suppression planning difficulty areas (Table 3) were delineated according to their sensitivity to fire occurrence during the period 1983-1999.

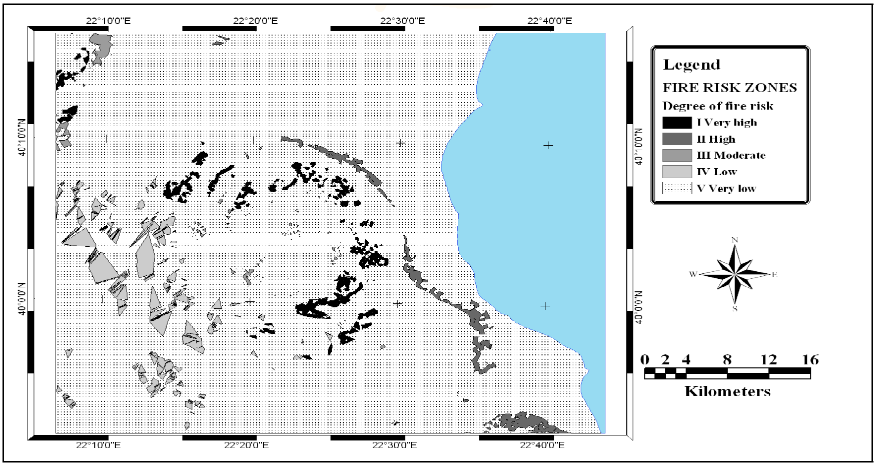

Figure 15: Fire sensitivity area map.

Using the above criterions from PYROSTAT analysis and performing the appropriate SQL queries in the Geographical data base, fire occurrence probability map, fire sensitivity area map and a suppression planning difficulty map were delineated according to their sensitivity to fire occurrence during the period 1983-1999 (Figures 14,15,16).

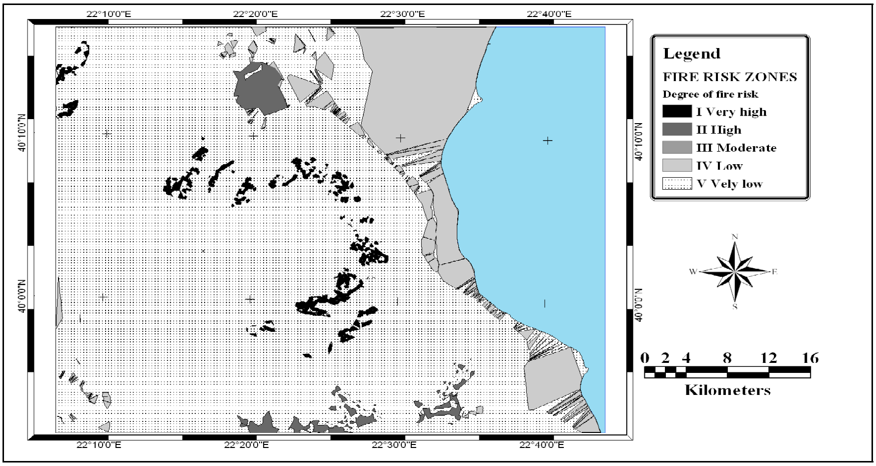

Figure 16: Fire suppression planning difficulty map.

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5 Conclusions

From the created maps and from the elaboration of the fire data arise useful conclusion about the better prevention and suppression planning of forest fires in the Olympus National Park. It has become possible the spatial distribution of forest fire risk. Then have been located the zones with increased fire probability occurrence. Yet, based on the total burned area, were demonstrated the fire sensitivity areas, where the probability of huge ecological disaster is big when a forest fire occurs. Finally, were located the areas in which the firefighting forces are not sufficient for the forest fire control. The latter is based on the average burned area per fire, which is considered, as an assessment index of forest fire suppression planning efficiency and reflects the sufficiency of firefighting forces. Such maps will help forest and firefighter department officials prevent or minimize fire risk activities within the forests and take proper suppression action when fire breaks out and would enable to set up an appropriate fire-fighting infrastructure for the areas more prone to fire damage.

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