



**Fire Management concerning major Natural and Cultural Heritage Sites of the
EUR-OPA countries**

Work Package 2:
Pilot project in Greece

Deliverable title:

***Landscape level fire risk assessment methodology demonstrated in Mt. Athos
cultural heritage site***

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The Global Fire Monitoring Center (GFMC)

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SUMMARY

The primary fire management goal of the present deliverable is the demonstration of a landscape fire risk study and to assess exposure of the historic scene and the associated cultural resources of the Mt. Athos cultural site to fire. The study is organized to combine the latest scientific knowledge of fire risk studies and integration of Very High Resolution (VHR) imagery and geospatial data in fire management issues. The Minimum Travel Time (MTT) fire simulation algorithm using the FlamMap software was performed to characterize the potential response of wildfire risk components to typical weather and fuel moisture summer conditions. Furthermore, wildfire risk exposure and Expected Net Value Change (ENVC) were estimated using the ArcFuels software. Site-specific (local) fuel models of the study area were created by measuring fuel parameters in the field in representative natural fuel complexes, while the spatial extent of the different fuel types and High Value Recourses (HVR) (e.g., Monasteries) were determined using Very High Resolution (VHR) imagery. The overall methodology is presented in the following chart:

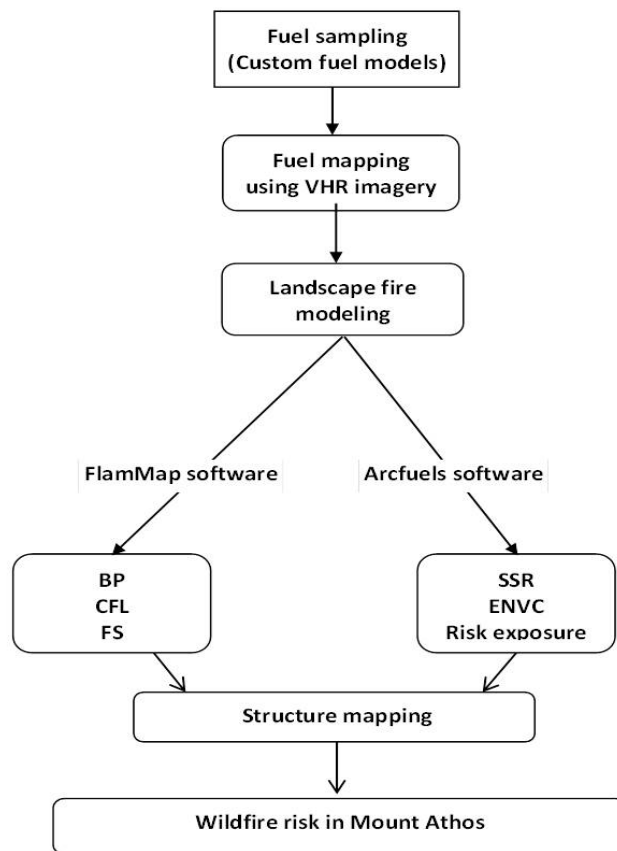


Figure 1. Methodological approach used

1 INTRODUCTION

1.1 Wildfire risk in cultural monuments

The majority of cultural heritage and archaeological sites, especially in the Mediterranean region, are covered with vegetation or situated close to forest regions. Therefore they are exposed to increased risk of forest fire. Such fires may break out from within the site and spread towards nearby forests and other wooded land, or conversely start in nearby forests and spread to archaeological sites.

Forest fires are a growing problem in the Mediterranean area, and cause substantial losses to vegetation, housing, infrastructures, and human lives. Wildfire spread and behaviour are affected by many factors including weather, fuels, topography, and ignition patterns. The role of humans in Mediterranean forest fires is an important factor, since more than 90% of fire ignitions are caused by anthropogenic factors (arson, negligence, power lines, etc.). Socio-economic changes have led to an increase of the anthropic pressure in urban and coastal areas and to a progressive abandonment of farming and agro-forestry activities. This has favoured substantial increases in fuel loading and continuity, especially where agricultural areas and pastures have converted to shrublands and woodlands. In addition, a number of studies have suggested that in the last decades climate change was responsible for the rise in potential fire risk, due to the increase of temperature, heat waves frequency and duration, and to the reduction of rainfall.

Fire risk is a combination of likelihood, intensity and effects. Advances in fire risk assessment systems have resulted largely from improvements in software, systems integration, data availability, GIS and simulation techniques. Computer models can replicate spatially explicit fire growth through heterogeneous fuels, and map fire behavior characteristics across large landscapes. Geospatial data on important social and ecological values that are potentially affected by fire are now widely available for many regions of the world. Online weather, fuel and burn severity datasets have helped feed and validate large scale modeling efforts. All of these technological advances have facilitated the quantification of likelihood, intensity and effects at a range of spatiotemporal scales.

The estimation of risk is based on the expected value of the conditional probability of an event occurring times the consequence of the event given that it has occurred. With these definitions, risk is the expectation of loss, and includes some assessment of three risk components: (1) likelihood of the event; (2) expected intensity and (3) one or more effects related to the expected intensity. Therefore, fire risk is the expectation of loss or benefit, and the loss or benefit may occur to any number of social and ecological values affected by fire.

1.2 Fuel maps

Efficient forest fire management requires an accurate knowledge of fuels at many spatial and temporal scales. Fuels are defined as the physical characteristics, such as loading, size, and bulk density, of the live and dead biomass that contribute to the spread, intensity, and severity of wildland fire. Based on knowledge of the spatial extent of the fuels, national authorities and fire managers can design fire prevention, detection, suppression and fire effects assessment strategies, such as the use and distribution of available fire-fighting resources, fuel treatment practices, fire towers and water tanks construction, trace gas emissions, and monitoring of vegetation recovery after fire. In addition, accurate knowledge of forest fuel extent can be an effective component for mitigating the impacts of future wildfire on ecosystem services and restoring desirable structural attributes to fire suppressed forests as well as to infer ecosystem impacts of historically natural wildfires. Remote sensing and Geographic Information Systems (GIS) technology is capable of produce spatial estimations of fuel types and fuel loads, based on satellite systems of different spatial, temporal and spectral characteristics.

2 MT. ATHOS SETTING

The Athos Peninsula or Holy Mountain is the Easternmost of Halkidiki's three peninsulas and Mount Athos encompasses an area of 33042 ha (Figure 2). Over its thousand-year history, the area has acquired various names that convey both its cultural and natural / environmental importance: the Holy Mountain (or simply 'the Mountain'), because of its dominating position; the Community of the Holy Mountain; the Ark of Orthodoxy; and, the Garden of the Virgin. In 1988, the Holy Mountain was designated a mixed World Heritage site, following significant efforts made and actions taken related to the protection of both its cultural and natural heritage. The entire area of the Holy Mountain has also been included in the Natura2000 network.

The area presents a variform terrain. There is a mildly wavy row of hills in the central part of the peninsula with a gradually increasing altitude that varies between 450 and 990 m before climbing to an altitude of 2,033 m (the summit of Mount Athos) to the Southeast. The relief consists of deep, steep traverse gullies alternating with steeper folds. The intense relief of the Athos Peninsula is the result of the great difference in altitude between areas and by the steep slopes that rise up almost from sea level. The wide variety of habitats in the area has managed to sustain itself thanks to the diverse and distinct geographical, geological and climatic characteristics found on Mount Athos. It is these unique features, coupled with the almost complete absence of adverse effects on the environment (e.g. there has been no grazing for centuries) that help explain the rich and extremely interesting vegetation, flora and fauna to be found on the peninsula. The special characteristics of the surroundings, the monasteries and their architecture, the relatively limited human activity and the singular and isolated location of the peninsula have combined to make Mount Athos one of the most unique and important coastal landscapes in Greece and the Mediterranean area as a whole.

The flora found on the Holy Mountain is another feature of its singularity. It is one of the richest areas in Greece in this respect, according to the bibliography detailing the wealth of plant life and the various endemic, rare and endangered species to be found there. The flora of the Holy Mountain includes 1453 plant species. The area is dominated by forest habitats and all the natural processes that ensure their ecological and environmental maintenance and survival. Forests cover most of the peninsula, with chestnuts (*Castanea sativa*) dominating its central and southern parts. The North of the peninsula is home to sclerophyllous evergreen (mostly *Quercus ilex*) vegetation in tree form, mixed oak forests (*Quercus frainetto*) and chestnut and pine forests (*Pinus halepensis*). The Southern section also contains some patches of primitive forms of vegetation, with forests of beech, fir and black pine.

The area has experienced two severe fire events during the last years occurred particularly in those areas where flammable forest species, such as pine and evergreen hardwood shrubs, grow in close proximity. A large fire broke out on the Holy Mountain in 1990 which burnt 2200 ha of forest and threatening the monasteries and sketes with complete destruction. In 2012, a large fire burnt 5000 ha of forests and wildlands in the area and flames have reached a lot of monasteries and other structures.

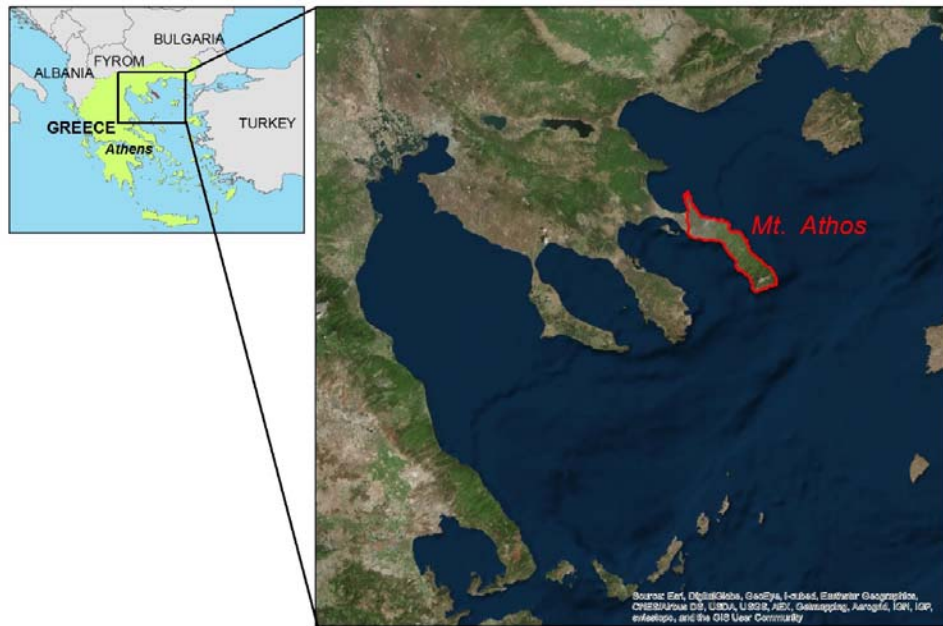


Figure 2. Study Area

3 OBJECTIVES OF THE PROPOSED PLAN/STUDY

The objectives of the current fire study are:

- 1) To estimate current fire risk components in Mt. Athos cultural heritage site.
- 2) To assess exposure of Mt. Athos cultural monuments to fire.

4 CURRENT FIRE RISK

4.1 Fuel sampling

A field campaign was conducted in summer 2013. The sampling method used a total of 49 rectangular plots. In each plot, surface and canopy fuels were measured using standard fuel inventory methods (Figure 3). The data were analysed statistically to define distinct fuel types (models). Six different fuel types has been resulted (Figure 4).



Figure 3. Fuel sampling in the field

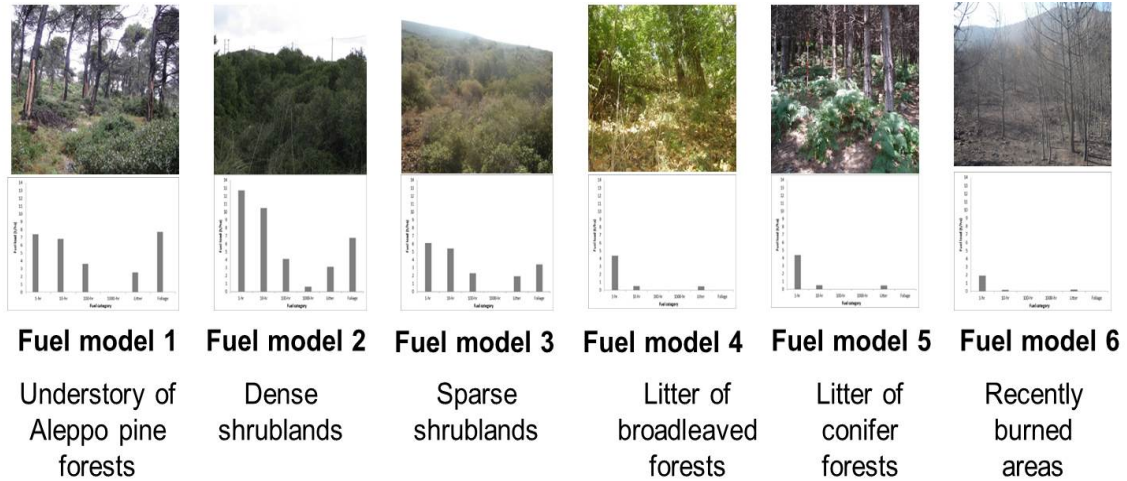


Figure 4. Fuel models of Mt Athos

4.2 Datasets used in the study

The Digital Elevation Model (DEM) of the area were generated from digitized contour lines on a 1:50000 topographical maps. Topographic maps, scale 1: 50000, provided by the Army Map Service of Greece and were used for the DEM production. These maps were compiled by means of vertical aerial stereopairs of 1945, scale 1:42000, and were photogrammetrically updated in 1972. The DEM was constructed by digitizing the 20 m contour lines of these maps. The projection of the DEM is the Greek National Geodetic System (EGSA 1987). Slope and aspect images were generated from the DEM, using the corresponding algorithms within GIS environment.

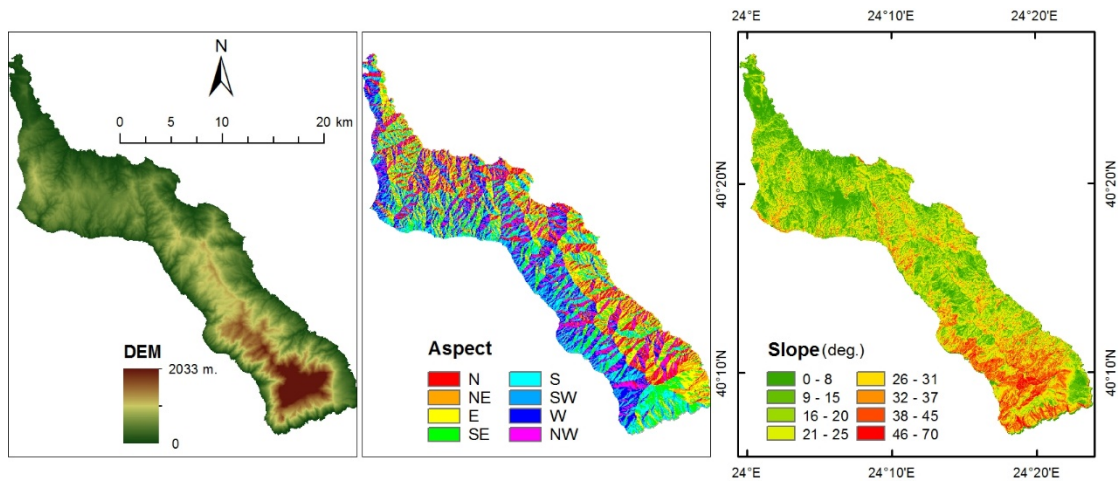


Figure 5. DEM, aspect and slope of Mt. Athos

4.3 Fuel mapping

For fuel type mapping over Mt. Athos, a RapidEye image was acquired. RapidEye is a commercial optical Earth observation mission. The *Nearest Neighbor* resampling method was applied for projecting the image to the Greek National Geodetic System (EGSA 1987). The image processing included the correction of the effects caused by the solar zenith angle, solar radiance and atmospheric scattering.

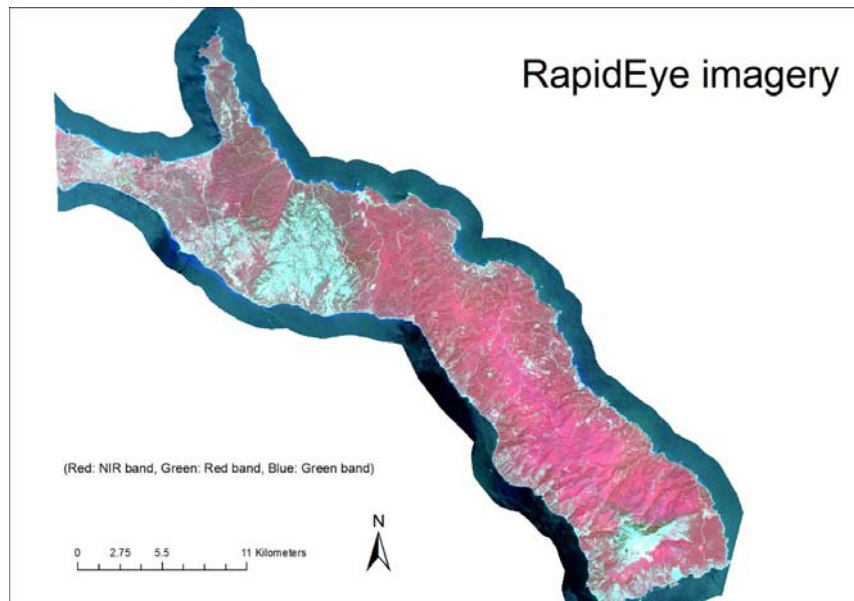


Figure 5. RapidEye imagery acquired over Mt.Athos

The classification of the image and fuel type delineation was carried out following an object based image analysis approach consisting from segmentation and classification procedures. To delineate individual meaningful objects, a multi-resolution segmentation algorithm was applied using the Trimble eCognition v8.7 software, while the classification of the segments produced has been achieved by performing Classification and Regression Tree analysis (CART).

The majority of the area is occupied from broadleaved forests (36%) and sparse shrublands (18%) and recently burned areas-grasslands (16%). Dense shrublands also occupy a significant part of the study area (16%) as well as Aleppo pine forests (10%).

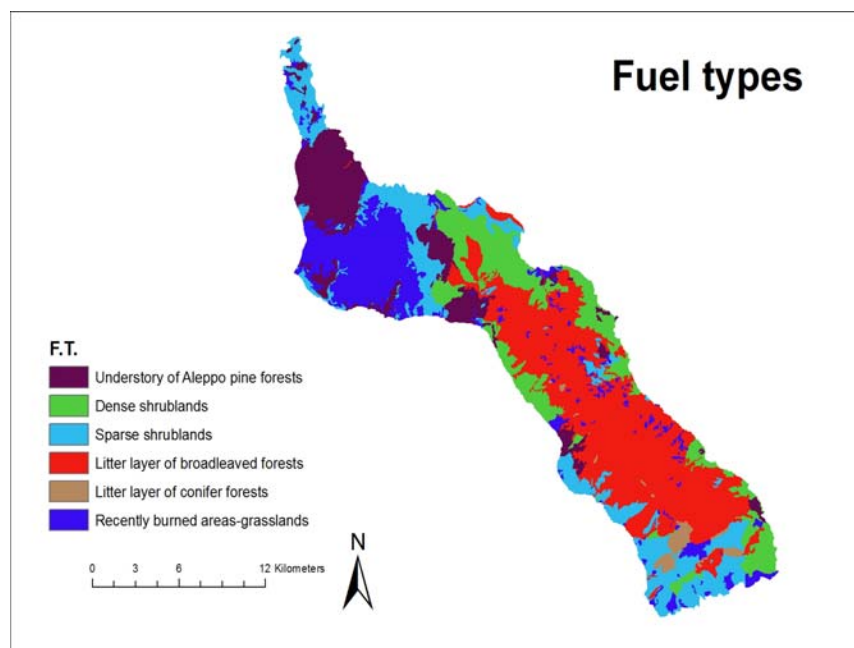


Figure 6. Spatial extent of the different fuel types over the study area

4.4 Structures mapping

Mt. Athos includes 20 monasteries, sketes, cells, arsanas, hermitages and small chapels and churches. To identify them spatially, large scale orthophotographs were used and their location was extracted through photo interpretation and available analogue maps (Figure 7). There are 20 monasteries located on the Mt. Athos. In addition, cell is a house with a small church, where 1–3 monks live under the spiritual and administrative supervision of a monastery. Sketes represent small communities of neighboring cells. Finally arsanas represent assigned landing areas of the monasteries or sketes.

The majority of the structures mapped is located in the center-north part of the peninsula, nearby Moni Koutloumousiou and Karyes. Karyes is a settlement in Mount Athos, where is the seat of the clerical and secular administration of the Athonite monastic state. Apart this area, a lot of monasteries are located along the coast of the peninsula, as well as sketes and cells. It was also noted that, the Monasteries or other large complexes are usually found being surround by small agricultural parcels or very low vegetation areas due to the activities of the monks. On the other hand, cells or small churches are well distributed within the dense vegetation of the inner peninsula.

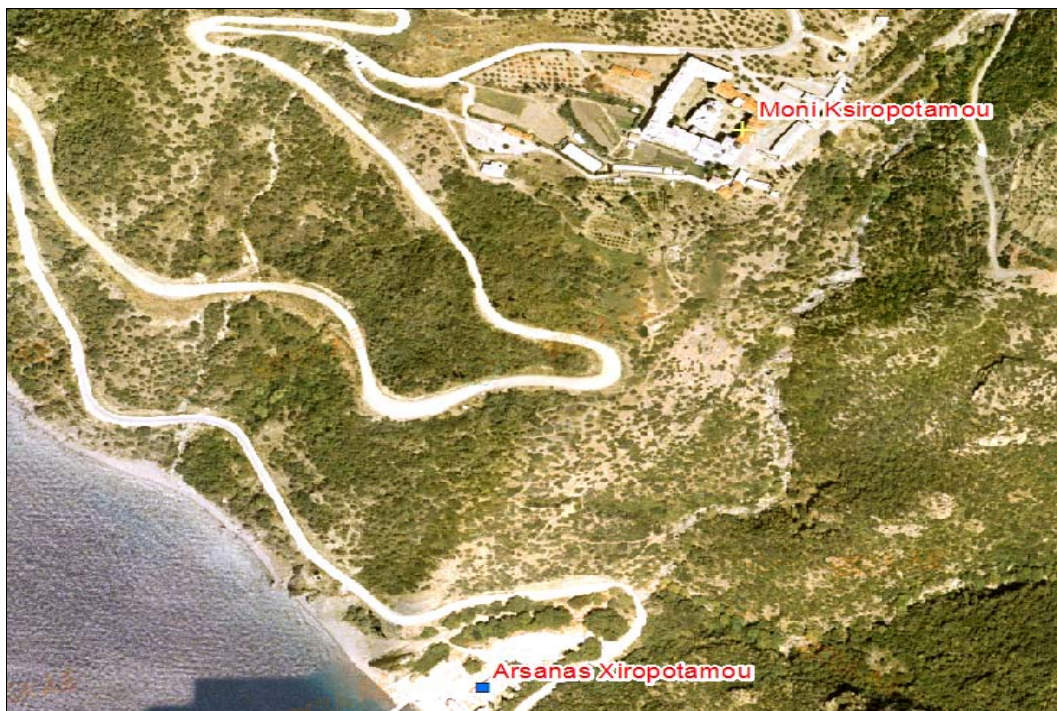


Figure 7. Large scale structure mapping

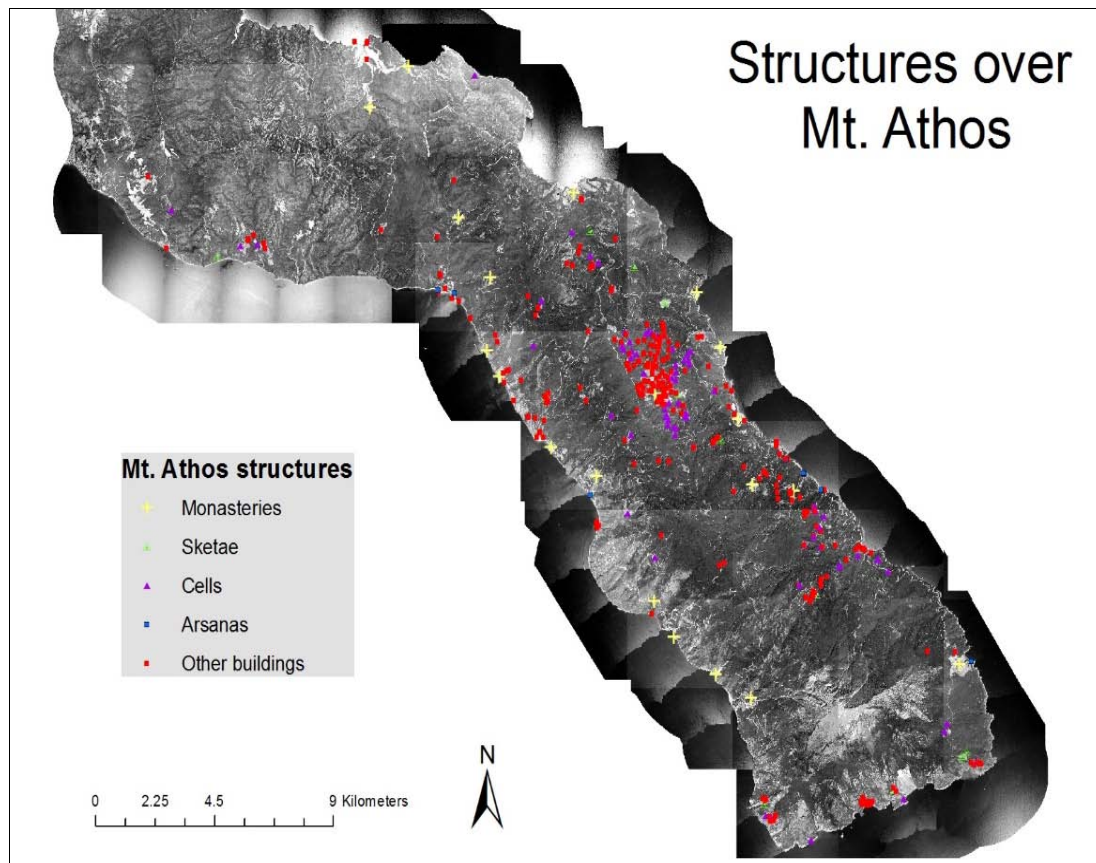


Figure 8. Overall structures mapping over Mt. Athos

4.5 Current fire risk

In order to assess fire risk, we used a landscape fire behavior modeling approach. Simulated wildfire spread and behavior was performed with the Minimum Travel Time (MTT) algorithm, as implemented in FlamMap software. The MTT algorithm replicates fire growth by Huygens' principle where the growth and behavior of the fire edge is a vector or wave front. MTT simulations were conducted by using as input data the DTM of the area, the spatial extent of the fuel models and the fuel parameters values of each model in the study area were and used to build 10 m x 10 m raster input files for fire simulations. Canopy cover information of the forest area was extracted from the satellite imagery and field measurements. We used MTT to simulate fire behavior following 30000 random ignitions across the study area. The duration of all fires was set to 480 minutes (6 hours). Simulated fire behavior was performed by using the dominant weather and fuel moisture conditions obtained by the Greek Meteorological Service (1-hr fuel moisture 6%, wind speed 30 Km/h and wind direction NE).

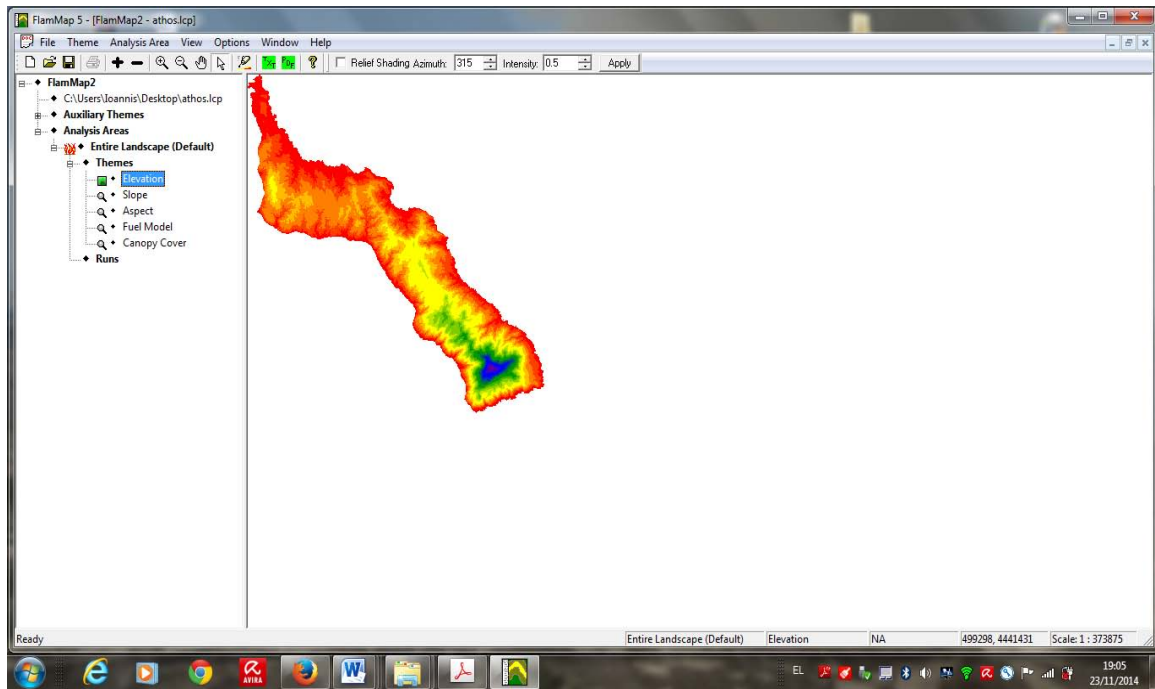


Figure 9. FlamMap user interface

The outputs obtained for every simulation were Burn Probability (BP), Conditional Flame Length (CFL) Fire Size (FS) and Source–Sink Ratio (SSR). The conditional burn probability (BP) output defines the probability each pixel burns for twenty 0.5 m intervals of flame length (from 0 to 10 m). So, BP is the chance that a pixel will burn at a given flame length interval considering one ignition in the whole study area under the assumed fuel moisture and weather conditions. Moreover, conditional flame length (CFL) is a weighted probability of flame length given a fire occurrence. Conditional flame length is the average flame length given among the simulated fires that burned a given pixel and is a measure of wildfire hazard. FlamMap also generates text files containing the fire size (FS, ha) and ignition x–y coordinates for each simulated fire. These outputs were used to analyze spatial variation in fire size. Fire size (FS) refers to the average fire size (ha) for all fires that originated from a given pixel. The SSR ratio measures a pixel's wildfire contribution to the surrounding landscape (FS) relative to the frequency with which it is burned by fires that originated elsewhere (BP) or were ignited on the pixel.

The maps of the four fire risk components are shown below:

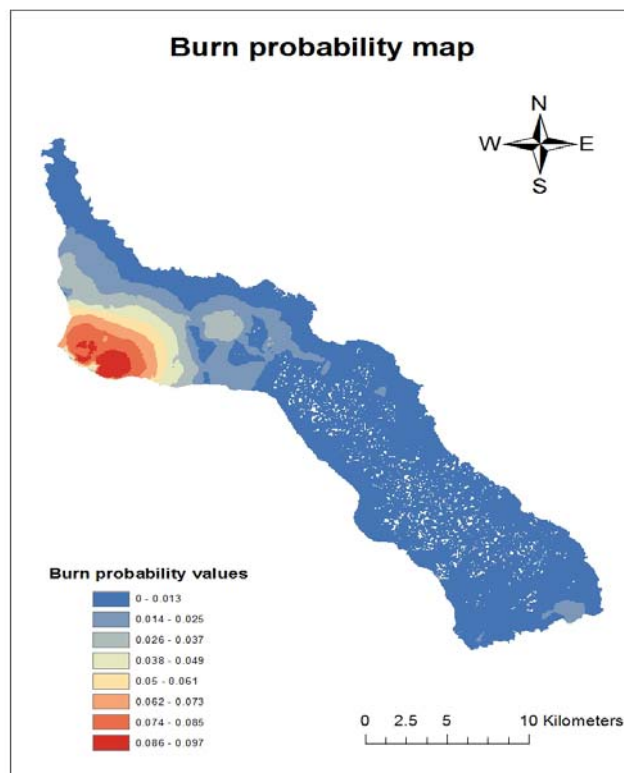


Figure 10. Burn Probability map

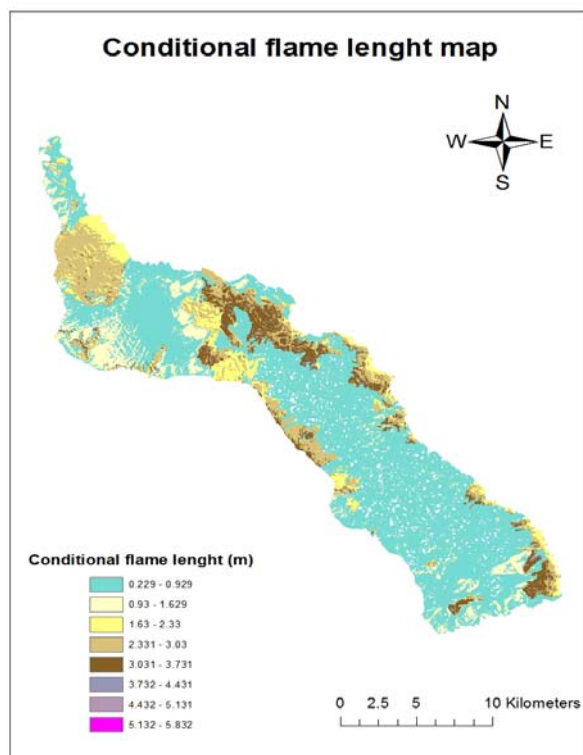


Figure 11. Conditional flame length map

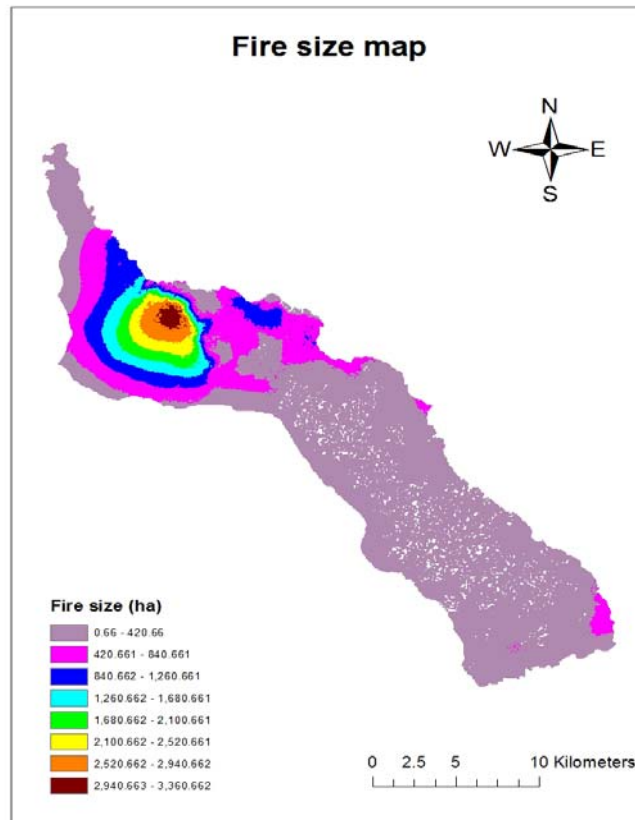


Figure 12. Fire size map

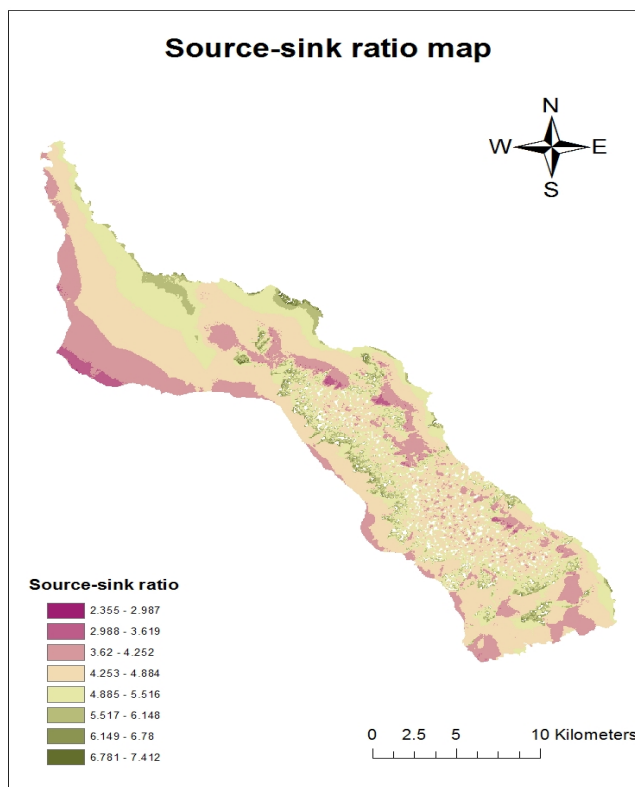


Figure 13. Source-sink ratio map

4.6 Mt. Athos High Value Resources Assets (HVRA) exposure to fire

Wildfire exposure analysis, which assesses relative risk in terms of likelihood (burn probability), potential intensity (mean conditional flame length), and expected fire size for the individual structures of Mt Athos is shown in Figures 14 and 15. Each point in the scatter plots represents a structure location point. The scatter plots were divided into four equal quadrants. The bottom-right quadrant shows areas with high burn probabilities and low potential intensity and/or fire size, while the upper-right quadrant presents areas with high burn probabilities and high potential intensity and/or fire size. The bottom-left quadrant depicts locations with low burn probabilities and low potential intensity and/or fire size, while the upper-left quadrant features locations with low burn probabilities and high potential intensity and/or fire size. According to the simulation run, most of the structures are allocated in the lower-left quadrant, thus revealing that they are not posing strong loss potential from wildfires. However, a few structures appear in the other quadrants without following a particular pattern.

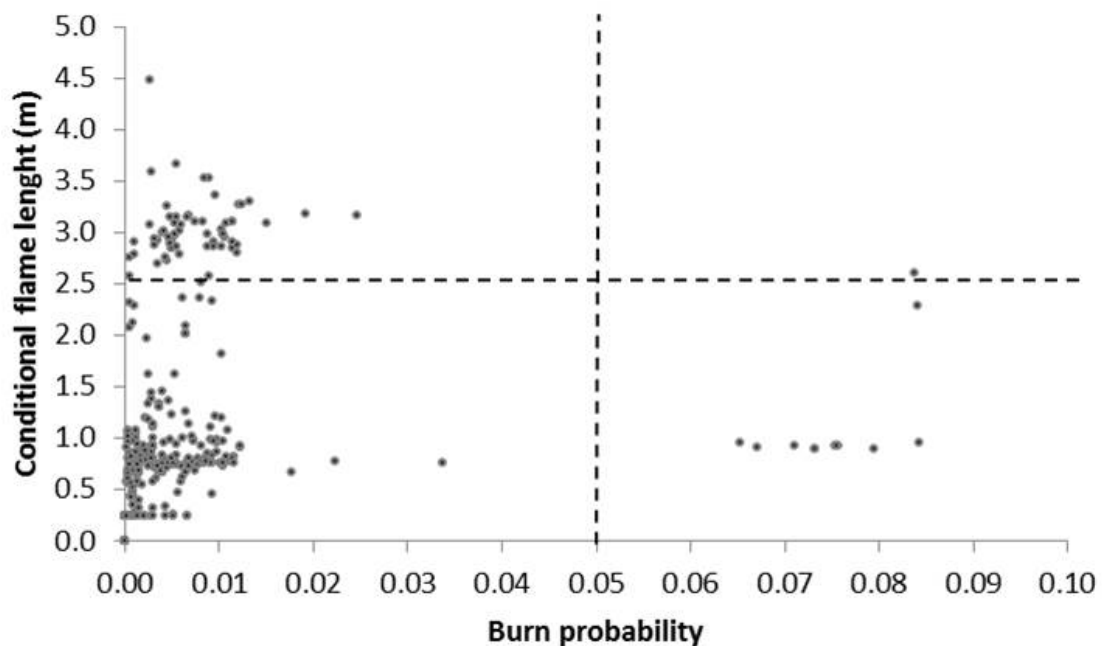


Figure 14. Scatter plots showing burn probability versus conditional flame length for the structures in Mt Athos

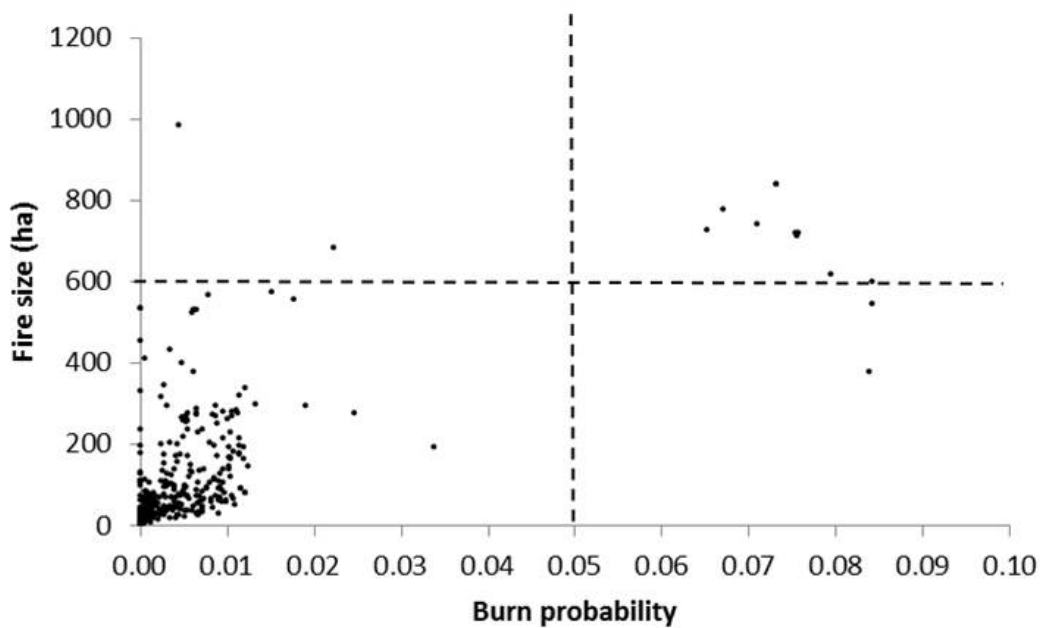


Figure 15. Scatter plots showing burn probability versus fire size for the structures in Mt Athos

Table 1 presents the 20 UNESCO monasteries fire risk exposure and assessment in Mt. Athos classified in different fire risk categories. Overall, all UNESCO monasteries are located in areas with low burn probability potential. However, some of them (8 of the 20), if an ignition will occur, high intense and severe fires are expected.

Table 1. Fire risk and exposure of the UNESCO monasteries in Mt Athos

UNESCO monastery	Exposure to wildfire
Moni Esfigmenou	Low burn probability and high potential intensity
Moni Zografou	Low burn probability and high potential intensity
Moni Pantokratoros	Low burn probability and high potential intensity
Moni Stavronikita	Low burn probability and high potential intensity
Moni Dochiariou	Low burn probability and high potential intensity
Moni Ksenofontos	Low burn probability and high potential intensity
Moni Iviron	Low burn probability and high potential intensity
Moni Agiou Panteleimonos	Low burn probability and high potential intensity
Moni Batopediou	Low burn probability and low potential intensity
Moni Konstamonitou	Low burn probability and low potential intensity
Moni Koutloumousiou	Low burn probability and low potential intensity
Moni Ksiropotamou	Low burn probability and low potential intensity
Moni Filotheou	Low burn probability and low potential intensity
Moni Karakallou	Low burn probability and low potential intensity
Moni Simonos Petras	Low burn probability and low potential intensity
Moni Osiou Grigoriou	Low burn probability and low potential intensity
Moni Megistis Lavras	Low burn probability and low potential intensity
Moni Agiou Dionysiou	Low burn probability and low potential intensity
Moni Agiou Pavlou	Low burn probability and low potential intensity

5 CONCLUSIONS

This study assessed four important wildfire risk component (BP, CFL, FS, and SSR) values and investigated the potential effect for the UNESCO protected area in Greece. Localized fuel models have been developed based on extensive fieldwork and have been mapped by using Very High Resolution imagery. Site-specific fuel models should be adopted to provide more reliable spatial fire risk predictions, especially in the case of the fragmented and heterogeneous Mediterranean landscape. FlamMap simulations resulted in high fire risk in the shrublands and Aleppo pine fuel types under typical summer conditions in the area. Furthermore, wildfire exposure of the structures in the area has been determined, thus providing an overall fire risk assessment to cultural values in the area.

The proposed methodology presents an integration of fuel sampling, fuel mapping, and landscape fire behavior simulation for fire management planning across the landscape. The final fire risk maps are the end product, and they can be fully exploited operationally by local fire management authorities without further processing. Outputs created from this study can be used as valuable components of judicial short and long-term wildland fire prevention and management in Greece and elsewhere in the world. Further studies of fire risk methods in the field are necessary in order to validate and calibrate the outcomes of the FlamMap fire simulators, especially in Mediterranean vegetation conditions. Additionally, the potential future change of fuel spatial extent and fuel load values could be further examined to allow researchers and land managers to address potential future changes to fire severity and regimes, shifts in fire risk distributions, potential carbon emission released from wildfires, post-fire soil erosion, and the ecological restoration of degraded ecosystems/landscapes after wildfires.

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