Study on Wildfire Protection Plan

Theological School of Halki

Prepared by

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SUMMARY

The primary fire management goal of the present study is the maintenance of the historic scene and the associated cultural resources of the Theological School of Halki, the protection of the surrounding forest area and to provide specific fire prevention (fire risk assessment, fuel treatments and fire detection) activities for protecting this valuable resource asset from unwanted wildland fire. This fire management plan contains the following program direction:

- To guide the decision-making process where safety and resource values are evaluated in terms of fire risk and appropriate fire management response strategies are identified for wildland fires.
- To provide a framework for fuels management strategies through the use of specific fuel and silvicultural treatments.
- To propose an automatic detection and monitoring system for fire protection
- To provide a platform to cooperate more fully in planning and implementing a wildland fire program across the natural and cultural monuments

The proposed measures included in the plan are preparedness, prevention, and fuels management. Applicable resource goals and objectives should be approved from local forest agencies and general fire management plans. The plan is organized to combine the latest scientific knowledge of fire risk studies and integration of geospatial and sensor technology in fire management issues.

A major review of this plan should occur after ten years of implementation, or earlier if required.

1 INTRODUCTION

1.1 Wildfires affecting 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.

For example, in 2007, Ancient Olympia, which is a UNESCO world heritage site and the birthplace of the ancient Olympic Games, was seriously endangered by a fast-moving wildfire. The local archaeological site contains the remains of the ancient stadium, temples, the museum and administrative buildings. The fire reached the hill overlooking ancient Olympia and it was stopped just before entering the archaeological site, but not before reaching a historic pine-covered hilltop above the renowned stadium.

Figure 1.1 Fire in Ancient Olympia

More recently in 2009, a multi-front wildfire raged the northeast of the greater Athens area and burnt 21,000 hectares of pine forest, olive groves, shrub land and farmland. Among the damaged areas was Marathon, site of one of history's most famous battlegrounds between the Greeks and the

Persians in 490 B.C. and an area of supreme natural beauty. The wildfire encircled the museum of Marathon and closed in on the archaeological site of Rhamnus, which is home to two 2,500- year-old temples, the Marathon battle site, the Tomb of the Marathon Warriors and the Tomb of the Plataeans. The antiquities linked to the battle of Marathon were not directly damaged; however the physical setting of the sites was destroyed. Earlier in 2009, a fire in Boeotia threatened the Mycenaean citadel of Gla (13th century BC).

Figure 1.2 Fire in the northeast of Athens area

Other archaeological and cultural heritage sites that were threatened by wildfires in the last decades include: the ancient Kameiros, Rhodes Island in 2008, the temple of Epikouros Apollo in 1998, three Monasteries of Mount Athos in 1990 and a large fire at mountain Olympus that burned the scenic scoots- pine forest and the Dion antiquities in 1994.

Figure 1.3 Fire in Mount Athos

Recent wildfires have caused significant damage to many archaeological and heritage sites in Turkey as well. In July 2007, the 2nd century BC theatre and the necropolis of the antique city of Notion (Ahmetbeyli, Aegean coast, 50 km south of Izmir) were partially destroyed by a wildfire. In February 2008, three houses in the Camiatik, a district of Kusadasi near Ephesus, were burned. These houses were classified as 1st degree heritage sites. A fire destroyed one hectare of pine trees in the Sulucahoyuk, which is an archaeological area in Nevsehir province in 2006. The site has been inhabited by people since the Neolithic age and it also contains remains from the Assyrian, Hittite, Phrygian, Hellenistic and late-Roman periods.

In June 2008, a fire destroyed 2km2 of land covered with shrubs in the ancient city of Laodikia in Denizli province. This fire also damaged some marble ruins. During summer of 2007 a forest fire broke out near the Ancient City of Ephesus and the House of the Virgin Mary (Mt. Koressos) at Selcuk Turkey. Luckily, fire fighters were able to control the fire and the ancient city of Ephesus did not suffer any harm.

As it is shown from all these incidents, wildfires are one of the main causes of the destruction of cultural monuments in recent years. The increase in seasonal temperatures has caused an explosion in the number of self-ignited wildfires in forested areas. Fanned by the dry winds, and fuelled by dry vegetation, some of these fires have become disastrous for many cultural heritage sites. Thus, beyond taking precautionary measures to avoid a forest fire, early warning and immediate response to a fire breakout are the only ways to avoid environmental and cultural heritage damages.

1.2 Wildfire risk

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 behaviour 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 modelling 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.

1.3 Fuel reduction

Fuel reduction has become an important tool for reducing fire hazard. This hazard is commonly defined as the fuel complex composed of volume, type, condition, arrangement, and location of fuels. In turn, this fire hazard combining with the favorite fuel moisture (affected by weather conditions) determines the degree of ease of ignition, spread and the resistance to fire control. Fuel reduction treatments are often implemented using prescribed burning, thinning, or a combination of the two treatments. Prescribed burning can reduce wildfire ignition and spread by consuming dead and live surface fuels. Thinning can reduce the likelihood of surface fires spreading into crown fires by removing the “ladder” fuels, including smaller fire-susceptible trees.

1.4 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.

1.5 Fire detection systems

There is a number of detection and monitoring systems in the world. These are in particular, observers, in the form of patrols or monitoring towers, aerial and satellite monitoring and increasingly promoted detection and monitoring systems based on optical cameras, different types of detection sensors or their combination. It turns out that the last mentioned are the most advanced technical solutions of forest fire monitoring in the future according to the practical experience.

Detection and monitoring systems are divided into two basic groups:

1. **land (terrestrial) systems** based on the tracking of ground monitoring stations,
2. **satellite-based systems**.

Different types of detection sensors can be used in terrestrial systems:

• Video-camera, sensitive to visible spectrum of smoke recognizable during the day and a fire recognizable at night,

• Infrared (IR), Thermal Imaging Cameras based on the detection of heat flow of the fire,

• IR spectrometers to identify the spectral characteristics of smoke

• Light Detection and Ranging systems - LIDAR (detection of light and range) that measure laser rays reflected from the smoke particles.

Use of the type of camera or sensor depends on the specific conditions of the operation but also on the financial resources available. Comparable infrared and laser systems are more sensitive and produce fewer false alarms than CCD (charge-coupled device) cameras. Another attribute of CCD cameras placed on the market today is their double sensitivity. These are color camera sensitive to visible spectrum during the day and monochrome cameras sensitive to IR spectrum at night. These features extend the possibility of their use. It has been proved that the ground systems based on CCD infrared cameras presents the best and the most effective solution for automatic monitoring and detection of forest fires at a present time. Currently, almost all countries with an increased risk of forest fires has been developing or designing at least one of such a system. All of these automatic fire detection systems are principally based on the recognition of smoke during the day and fire at night.

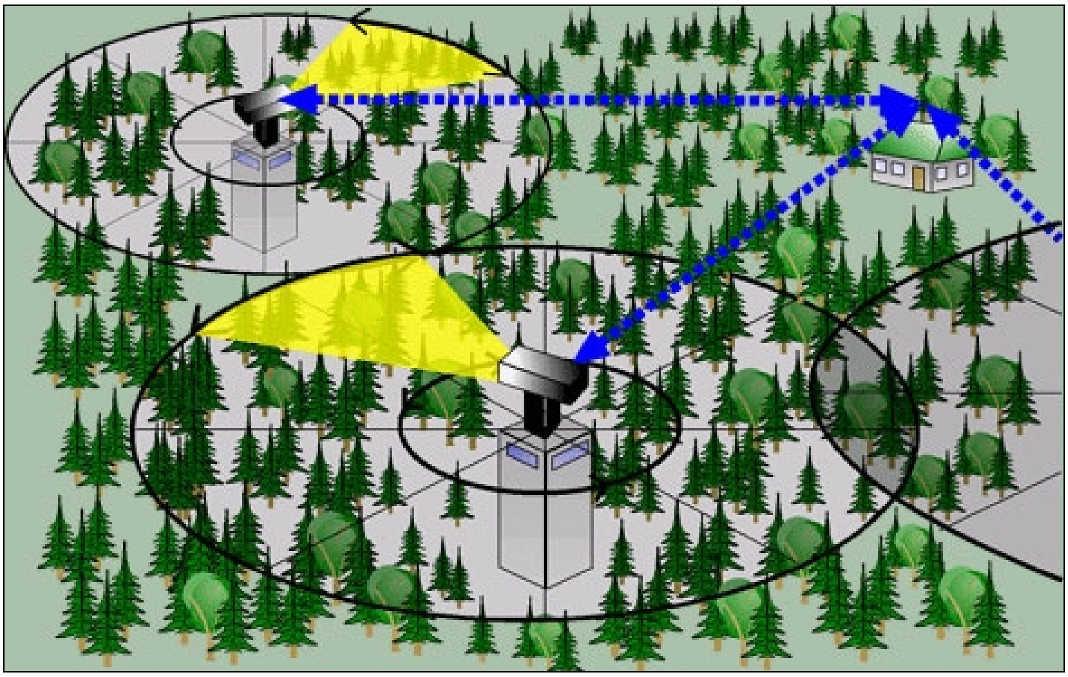

Figure 1.4 Scheme of a fire detection system in a forest area

2 THEOLOGICAL SCHOOL OF HALKI SETTING

The study area is the forest area located around the 11th- Halki seminary, the main Greek Orthodox seminary in Turkey and Theological Seminary of the Ecumenical Patriarchate of Constantinople. The Theological Seminary of the Ecumenical Patriarchate of Constantinople lies on top of a hill in the Heybeliada or Heybeli Ada (Greek: Χάλκη, Halki) island. Heybeliada is the second largest of the Prince Islands in the Sea of Marmara, near Istanbul. It is officially a neighborhood in the Adalar district of Istanbul, Turkey.

Figure 2.1 Heybeliada location within the Prens Adalari

Heybeliada has a length of 2.7 km from north to south and a width of 1.2 km from east to west. The highest peak of the Heybeliada is Değirmen Tepe (peak) (136 m). Taş Ocağı Tepe (128 m) is located on the eastern end of the Değirmen Tepe. The other mountains of the island are Umit Tepe (85m) on which Theological School Of Halki is located, and Makarios Tepe (98m), Makarios Monastery, on which located on top of the island.

The vegetation consists mainly from Calabrian pine (*Pinus brutia*) stands which forms dense complexes with the high, equal dense understory. The dense understory includes species like Wild asparagus, Sarcopoterium, Phillyrea, kermes oak and olive trees /shrubs.

Figure 2.2 Theological Seminary of the Ecumenical Patriarchate of Constantinople lies at the northern part of Heybeliada.

Figure 2.3 Sparse canopy forest around Theological School of Halki with the understory occupied by Turkish pine (*Pinus brutia*) and understory of terebinth (*Pistacia terebinthus*) (coordinates of photo X: 676549.984 meters Y: 4527792.018 meters).

Figure 2.4 Typical view of the forest around Theological School of Halki with the understory occupied by Turkish pine (*Pinus brutia*) and understory of terebinth (*Pistacia terebinthus*) (coordinates of photo X: 676442.509 meters Y: 4527885.840 meters).

Figure 2.5 Wild asparagus (*Asparagus acutifolius*)

Figure 2.6 Phrygana vegetation (*Sarcopoterium spinosum*)

Figure 2.7 Phillyrea (*Phillyrea latifolia*)

Figure 2.8 Kermes oak (*Quercus coccifera*)

Figure 2.9 Olive shrubs (*Olea europaea*)

The current forest situation around Halki, is at high risk of forest fire due to the dense fuel accumulation, illegal garbage dumps and the power lines passing through the forest canopy.

Figure 2.10 Electric power lines passing through individual pine crown represent a major fire risk and a possible source of ignition

Figure 2.11 The dense shrubland understory constitute a critical mass of ladder fuels located between the top surface of the fuel and lower parts of the overstory. Thus surface fires can develop into high intensity crown fires.

Figure 2.12 Urban garbage dumps increase the fire risk in the area.

3 OBJECTIVES OF THE PROPOSED PLAN/STUDY

The objectives of the current fire study are:

1) To estimate current fire risk components (Burn Probability, Fire Size, Conditional Flame Length and Crown fire activity) in the study area.

2) To propose and assess fuel treatments effects on the fire risk in the study area.

3) To propose fire detection spots in the study area by using a visibility analysis using GIS technology.

4) To describe and propose a wireless fire detection sensor system to be established in the study area.

4 CURRENT FIRE RISK

4.1 Fuel sampling

A field campaign was conducted in October 2013. The sampling method used a total of 40 circular plots with a 10 meter radius. In each plot, the mean height of the woody shrub layer and the cover of each species were visually assessed.

The diameter at breast height of every tree in the plot was measured. Total height and height to live crown base were measured with a Haga altimeter.

Canopy closure in each plot was estimated using a spherical densiometer.

The data were analyzed statistically to define stand inventory data and to estimate the shrub fuel characteristics against overstory variables. From the analysis it became obvious that shrub height and cover were decreasing as canopy closure increases. For that reason three different fuel types has been resulted according to the overstory canopy closure:

1. **Dense canopy closure (> 80%) with low height shrub layer (< 1 m)**
2. **Normal canopy closure (60 – 80%) with moderate height shrub layer (1-2 m)**
3. **Sparse canopy closure (< 60%) with high height shrub layer (>3 m).**

Figure 4.1 Fuel and tree measurements

a **b** **c**

Figure 4.2 Fuel types in the study area: a) Dense canopy with low shrubs, b) Normal canopy with moderate shrubs and, c) Sparse canopy with high shrubs

4.2 Datasets used in the study

In order to fulfill the aims of the study a variety of different kind of datasets were used. A Digital Elevation Model (DEM) was produced from 5 meters contours interval.

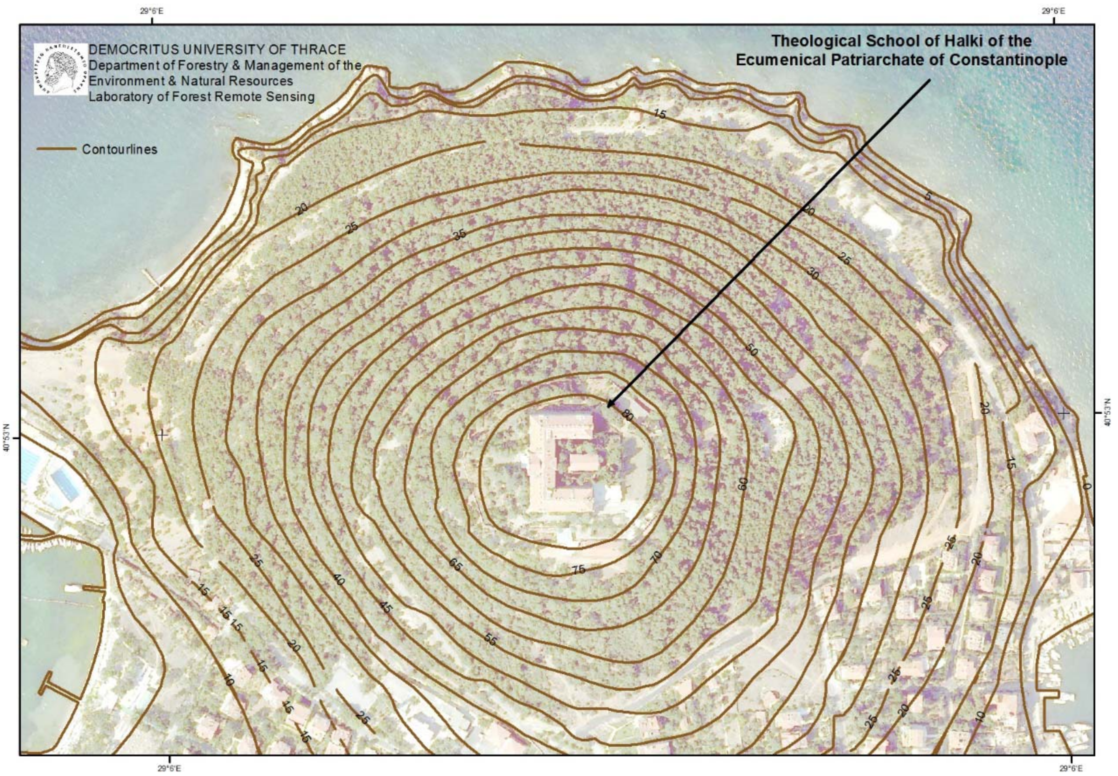

Figure 4.3 Contour lines used for developing the Digital Elevation Model, aspect and slope layers. The numbers indicate the altitude of points of equal elevation (height) above mean sea level.

Using the appropriate interpolation techniques and spatial algorithms, Digital Elevation Model (DEM), aspect and slope were produced.

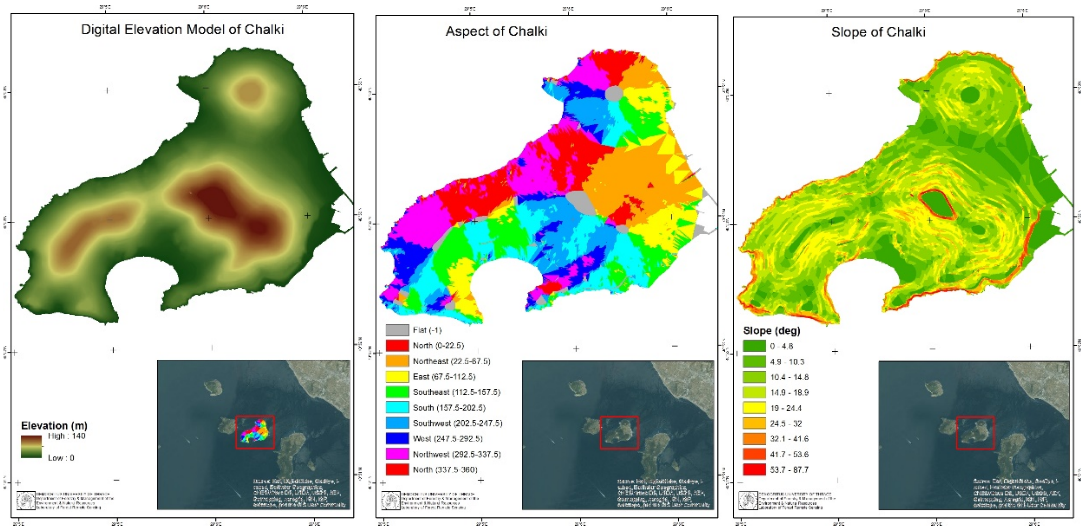

Figure 4.4 Digital Elevation Model, aspect and slope layers

A digital elevation model-DEM is a digital model or 3D representation of Earth, created from terrain elevation data. Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. The slope, or steepness, is the maximum rate of change in value from a cell to its immediate neighbors.

4.3 Fuel mapping

An automated object based procedure was followed for determining the extent of the different fuel types around Theological Seminar. The image was segmented and then classified automatically in order to delineate the classes of interest. To delineate individual meaningful objects, a multi-resolution segmentation algorithm was applied using the Trimble eCognition v. 9 software. With this segmentation technique, individual pixels are perceived as the initial regions, which are sequentially merged pairwise into larger ones with the intent of minimizing the heterogeneity of the resulting objects. Two levels of classification was developed-one upper for isolating water and land areas, and a second lower one for identifying land cover of interest.

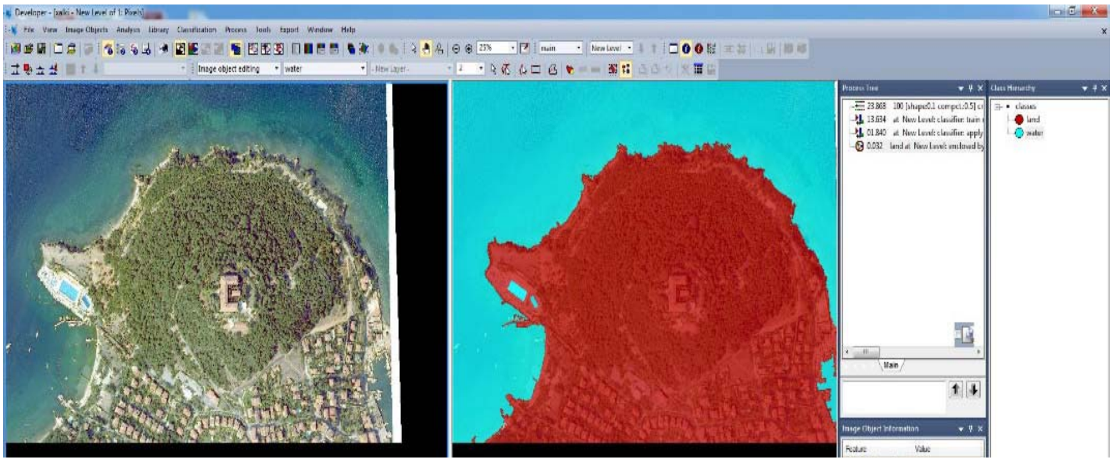

Figure 4.5 Isolating water (sea and pools) from mainland

At the end, we identified the following classes of interest:

- Dense canopy areas
- Normal canopy areas
- Sparse canopy areas
- Bare/artificial areas
- Roof (tile covered areas)
- Soil covered areas
- Pools (inland water)

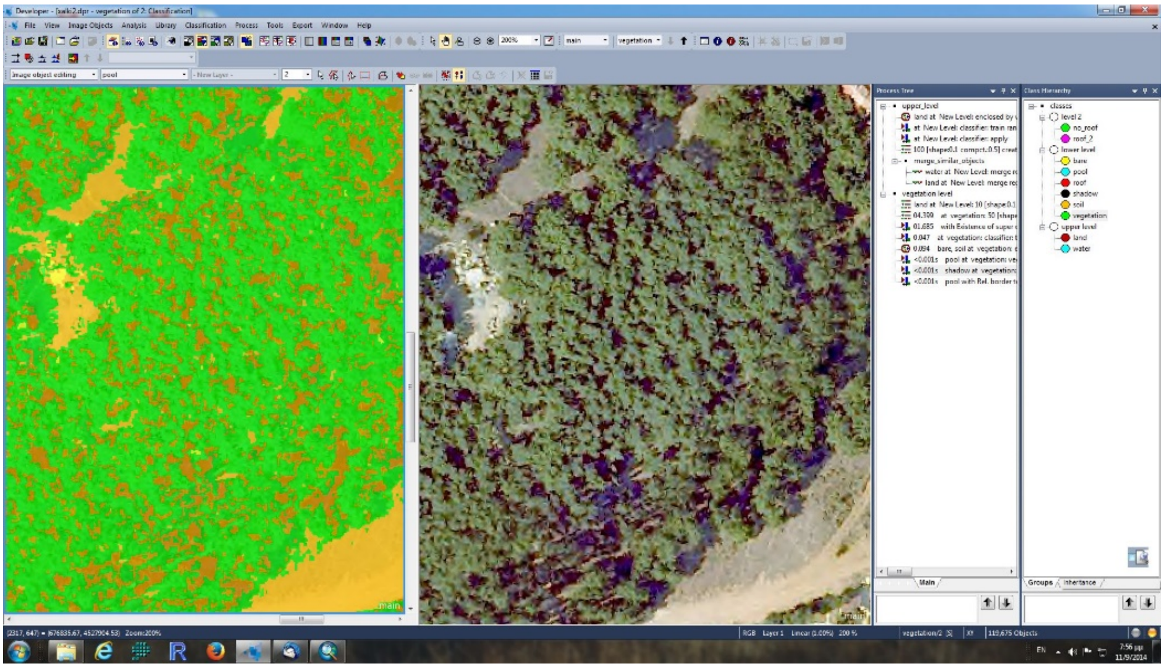

Figure 4.6 Fine scale classification of canopy (tree covered) areas from the other land cover classes

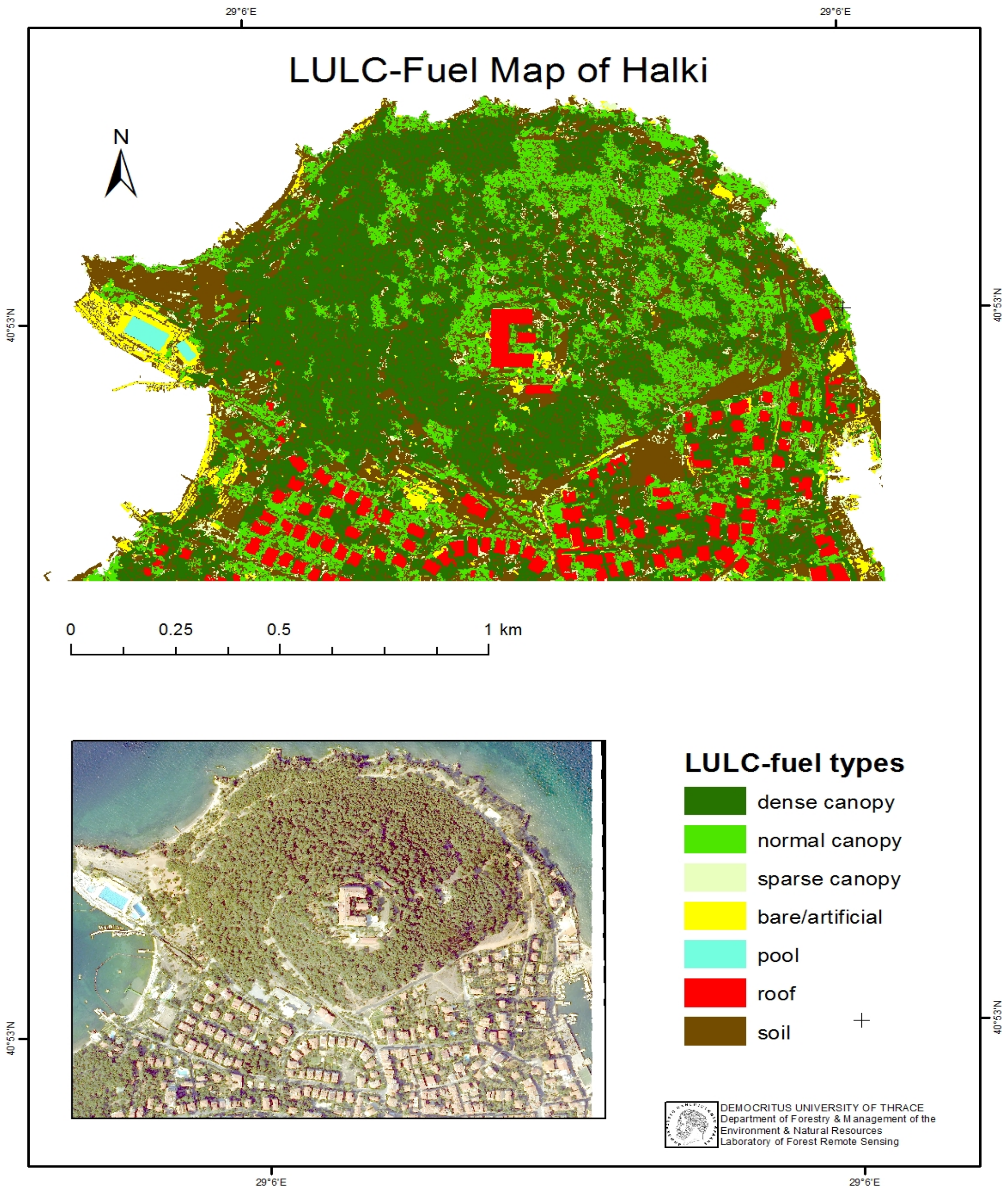

Figure 4.7 Final land cover / land use map of the site

4.4 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 MTT algorithm (Finney 2002), 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 2 m x 2 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 1000 random ignitions across the study area. The duration of all fires was set to 180 minutes (3 hours). Simulated fire behavior was performed by using the dominant weather and fuel moisture conditions obtained by the Turkish Meteorological Service (1-hr fuel moisture 8%, wind speed 25 Km/h and wind direction NE).

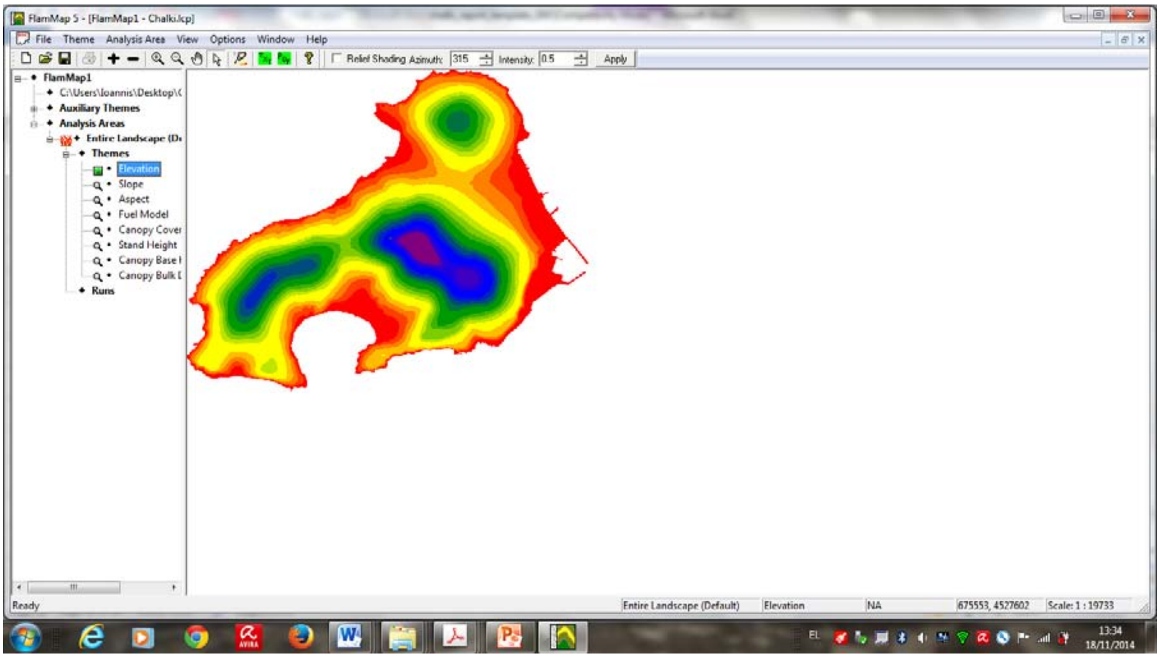

Figure 4.8 FlamMap user inteface

The outputs obtained for every simulation were burn probability (BP), conditional flame length (CFL) fire size (FS) and type of fire. 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 analyse spatial variation in fire size. Fire size (FS) refers to the average fire size (ha) for all fires that originated from a given pixel. Type of fire refers to the likelihood of a fire spreading in the shrub understory layer (surface fire), or burning individual tree crowns (passive crown fire), or propagating from crown to crown for a long time period (active crown fire).

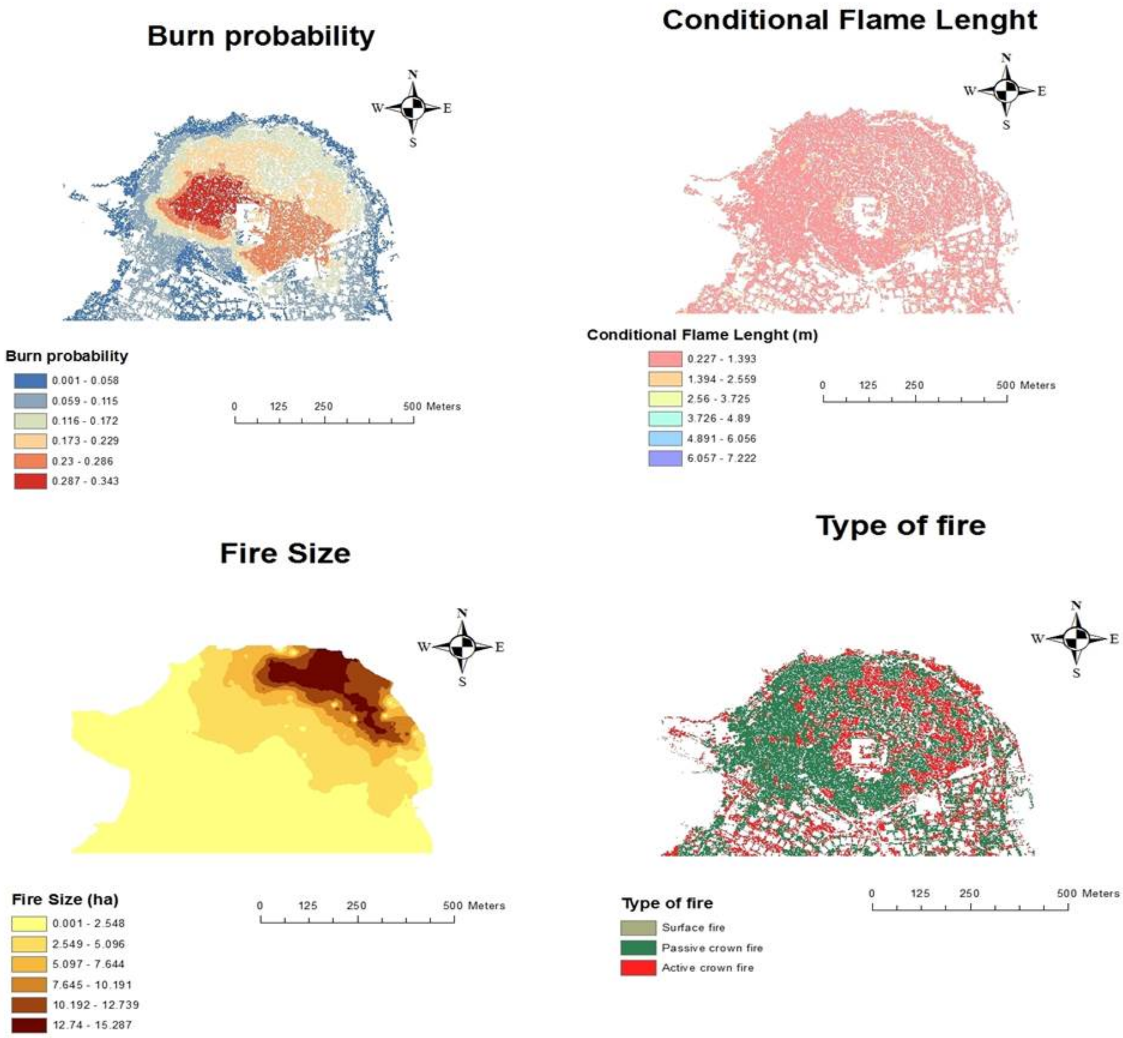

Figure 4.9 Current fire risk maps in the study area resulted from fire simulations

5 PROPOSED ACTIONS TO MITIGATE FIRE RISK

5.1 Fuel treatments

Three different fuel treatments (scenarios) were simulated using the FlamMap software for the study area:

- **Fuel Treatment Scenario A:** Overstory thinning (20% of the stand basal area) and pruning (increase crown base height 20%).
- **Fuel Treatment Scenario B:** Shrub fuel removal (50% of the shrub cover and height).
- **Fuel Treatment Scenario C:** Combination of Fuel Treatment Scenario A and Fuel Treatment Scenario B.

The surface and canopy fuel parameters, used in simulations, were adjusted according to the proposed fuel treatments scenarios.

Effects of each fuel treatment on fire risk components are shown in the following maps:

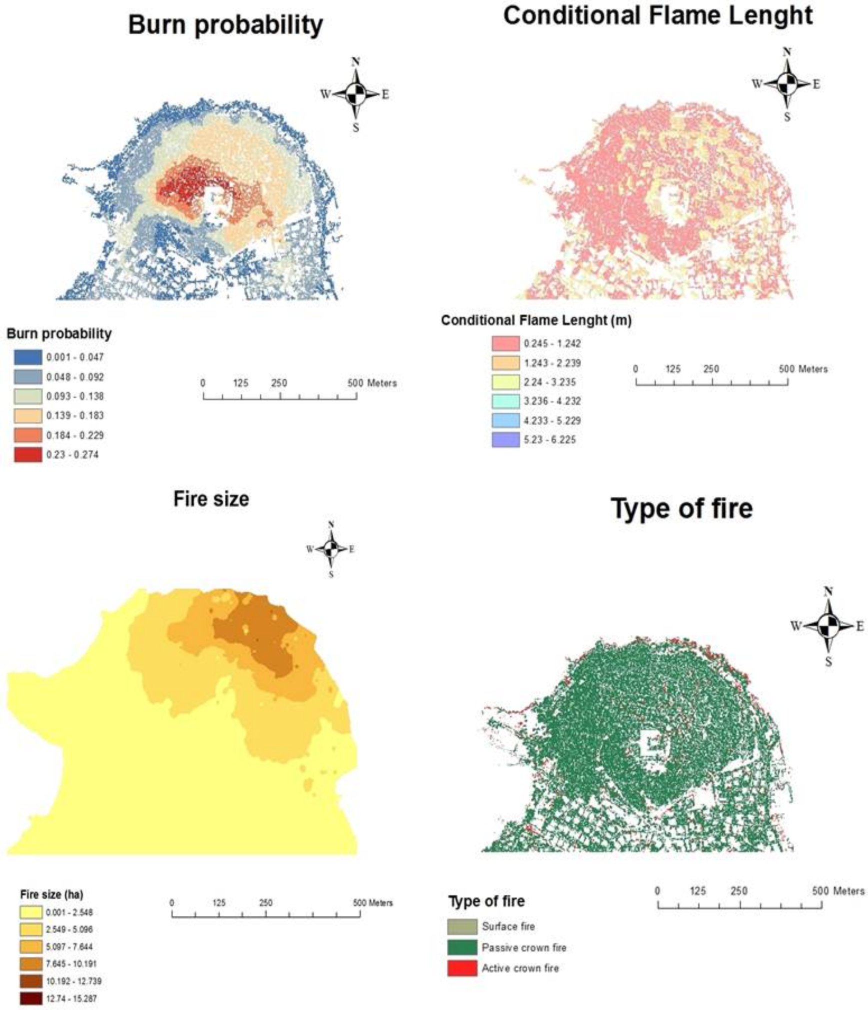

Figure 5.1 Fire risk maps under Fuel Treatment Scenario A

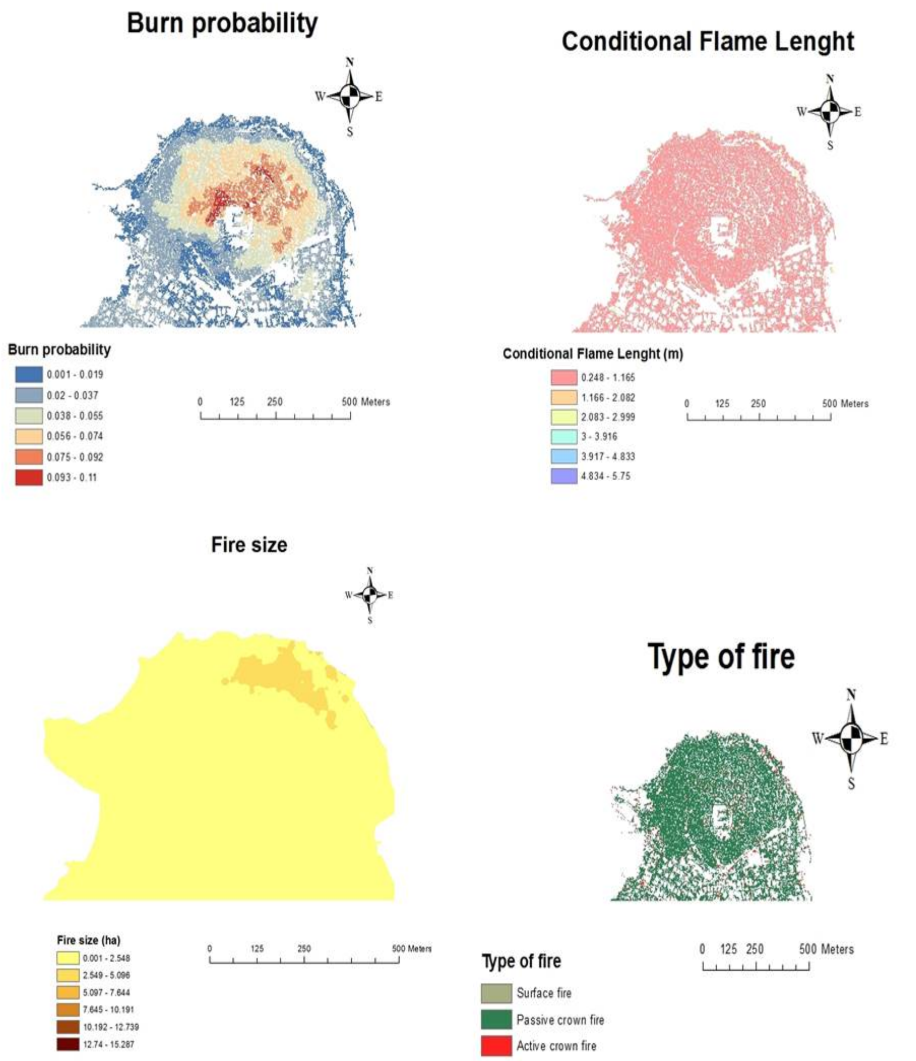

Figure 5.2 Fire risk maps under Fuel Treatment Scenario B

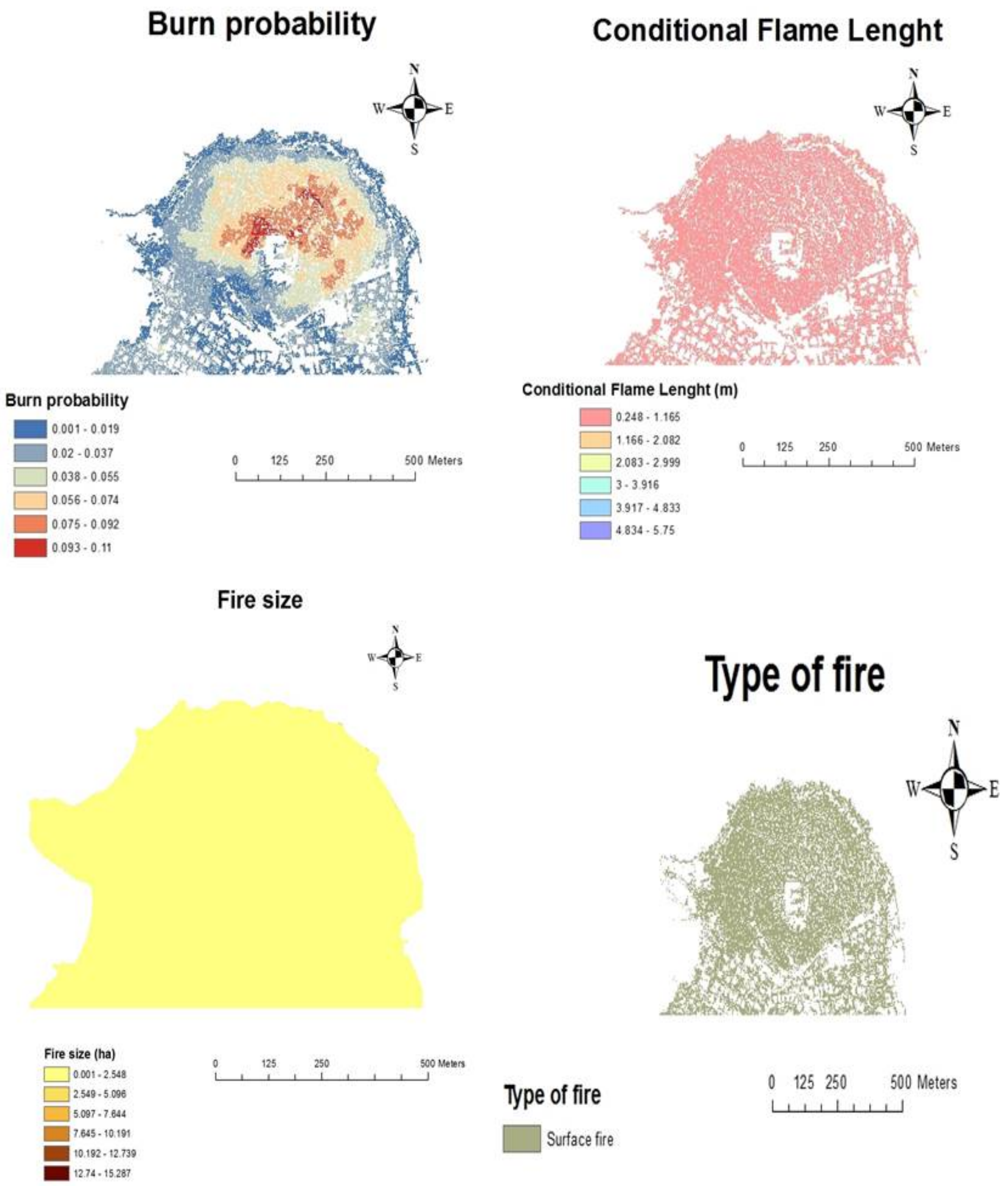

Figure 5.3 Fire risk maps under Fuel Treatment Scenario C

5.2 Silvicultural treatments

More than 80 years of fire research has led to the conclusion that the intensity and severity of a fire are determined by a combination of natural factors such as weather, topography and fuel and that fuel is the only factor susceptible to modification. Fuel management practices are known to dramatically affect fire behavior potential. Furthermore, the theoretical basis for methods of modifying the structure of fuel in order to reduce the risk of wildfire has long been established.

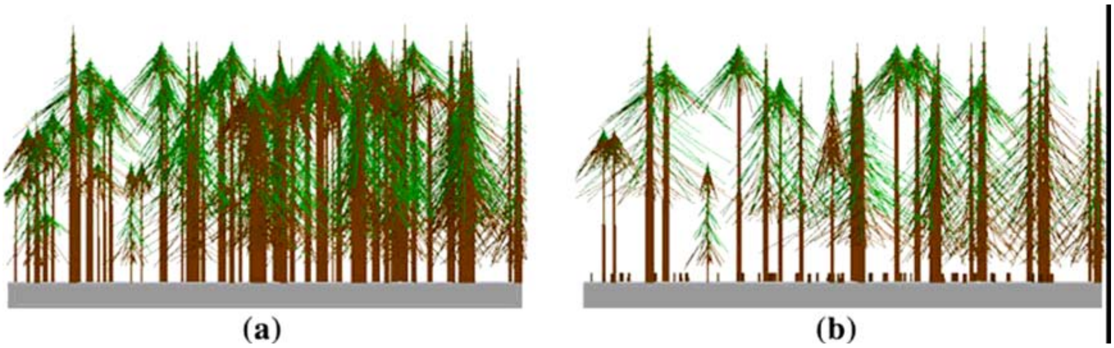

Figure 5.4 Forest stand before (a) and after (b) thinning treatment

Silvicultural treatments aiming at the reduction in the accumulated biomass and the interruption of its horizontal and vertical continuity focus on critical characteristics of the fuel structure. The traditional silvicultural treatments that can be implemented in a specific forest area in order to reduce the forest fire risk fall under three main categories:

i. Thinning In particular, removing a selected number of trees not aiming at increasing site productivity but in fire environment modification. Low thinning that includes the removal of smaller, weaker individuals to benefit the dominant individuals of the stand.

ii. Crown thinning (high thinning) where the dominant and co-dominant individuals are favored with the removal of a competitor, which includes individuals of the same diameter class.

iii. Selective thinning where, the dominant trees are removed in order to encourage individuals that are younger, but of great vitality.

Additionally, two other options can be added, aiming at the modification of the structure of the fuel layer:

iv. Free thinning, whereby selected individuals are released and the rest of the stand is left unmanaged. This method is presented as the most versatile, creating stands of varying structure.

v. Geometrical (mechanical) thinning, in which tree removal is based on their spatial arrangement, but it is not suitable for purposes other than timber production.

- Clearing which includes the cutting and removal of all vegetation, particularly grasses, shrubs and regeneration in pre-selected locations.

Figure 5.5 Clearing - cutting and removal of all vegetation, particularly grasses, shrubs and regeneration

- Pruning which includes the cutting, removal or fragmentation and dispersion of the lower parts of the tree crown, especially the dead ones.

Figure 5.6 Pruning increases the height from the ground to the base of the tree crown.

5.3 Implementation of silvicultural treatments for the Theological School of Halki

5.3.1 Principles for reducing fuels

The three principles of creating and maintaining as fire-resistant the forests around the Theological School of Halki are:

• Reduce surface fuels

• Increase the height to the base of tree crowns

• Increase spacing between tree crowns

Following these principles the following three goals for the forest around the Theological School of Halki will be accomplished:

- Reduction the intensity of a fire, making it easier for firefighters to suppress
- Increasing the odds that the forest will survive a fire. Small trees, shrubs, and other understory vegetation may be injured or killed, but larger trees in the stand will only be scorched, and soil damage also will be reduced.
- Reducing the extent of restoration activities needed, such as replanting or erosion control measures

Figure 5.7 Proposed treatment in Halki

5.3.2 Roads and paths considerations

In addition special consideration should be given for roads and paths access within the forest. More specifically trees and shrubs adjacent to the toad and paths of the Halki forest should be thinned and pruned.

Figure 5.8 Road (left) before and (right) after treatment

Also the gravel and dirt road around Theological School of Halki should be periodically graded to keep the surface in good shape, particularly when used heavily.

In addition, drainage structures such as water bars, ditches, and culverts should be regularly inspected to be sure they are clear of obstacles and able to function effectively. Blocked ditches and culverts can result in substantial damage to the road when water flows across it. Summer thunderstorms can both cause wildfires and damage roads at the same time due to intense rains and lightning.

Also, road cut-banks should be seeded with grass or other vegetation to stabilize the soil, prevent damage to the road from erosion, and minimize movement of sediment into nearby streams. Also, downed logs and other obstacles from the roadway and brush from the edges of the road should be cleared

5.3.3 Water Sources

Water sources are an important part of an overall fire protection strategy. However, it is less important than fuels reduction in most cases.

Developing and diverting spring water into a tank or cistern could provide a valuable water source for the protection of the forest around Theological School of Halki. For the purposes of firefighting, two high underground capacity tanks could be excellent.

Figure 5.9 Underground tanks

This tanks could be then linked to a sprinkler system wetting down surrounding fuels prior to the fire arrival and creating a humid microclimate. Set up overlapping sprinkler heads to wet down the structure, surrounding forest fuel. A gas powered portable pump should be used in the event of power interruptions or loss.

Figure 5.10 Sprinklers for increasing fuel moisture

Figure 5.11 High pressure Sprinkles for increasing fuel moisture and creating a "humid fire break"

5.4 Camera identification for real-time monitoring

Visibility analysis based on viewsheds is one of the most frequently used GIS analysis tools. Viewshed is created over a DTM using an algorithm that estimates the difference in elevation in the observer's cell and the target cell. Visibility analysis is often used to determine areas that are visible from a specific location, and its applications range from the military field to modelling of environmental changes generated an integrated geospatial system, which provides a series of software tools for the assessment of the propagation and combating of forest fires. The interface integrates GIS technologies under the same data environment that would serve as a useful tool for forest fire prevention, planning and management.

The Visibility function provides answers to two basic questions:

- What places are visible from the given observation place?
- How many observation places is the given object/place visible from?

5.4.1 Implementation of visibility analysis for the Theological School of Halki

In order to collect spatial information from field, a mobile mapping system was used. This consists of a GPS (Global Positioning System) coupled to a pocket computer with GPS applications for field cartography. We sampled candidate cameras positions and recorded their coordinates.

Once the spatial information about the six ground points was obtained, this was superimposed on the elevation digital model by use of the “visibility” application in the topographical analysis of the ArcGIS software.

The visibility algorithm was applied considering the criteria of altitude above sea level and above ground level (watchtower height) and visual cover of 360°, and with no restrictions regarding the maximum visualization range. The area of visibility was thus generated. The next step consisted of determining the combination of watchtower locations that would maximize the area of visibility, with the smallest possible number of ground locations (watchtowers), as a restrictive condition, through a trial and error procedure.

The optimum solution identified relates to the positioning of 3 cameras position in order to ensure and maximize the identification of hotspots and fire ignition points.

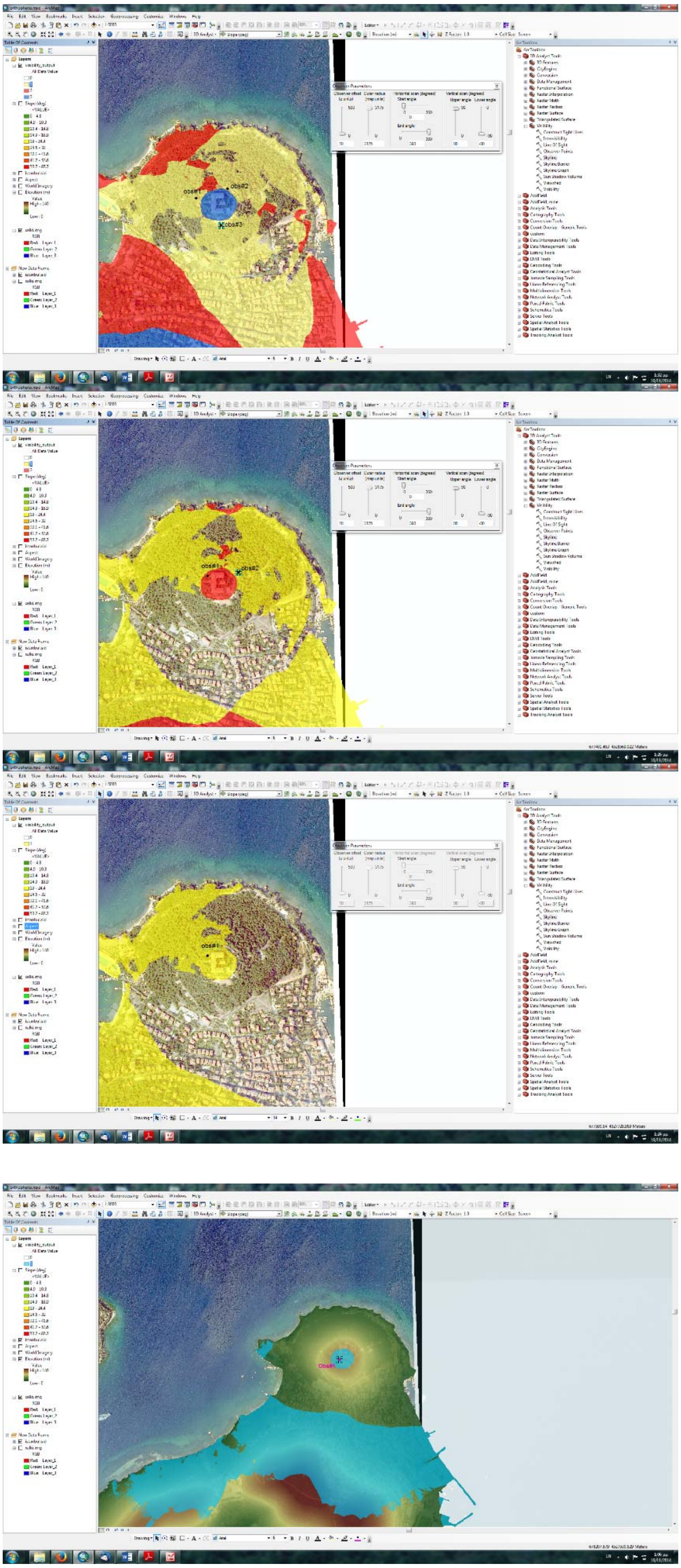

Figure 5.12 Trial and error procedures for identifying areas of maximum visibility

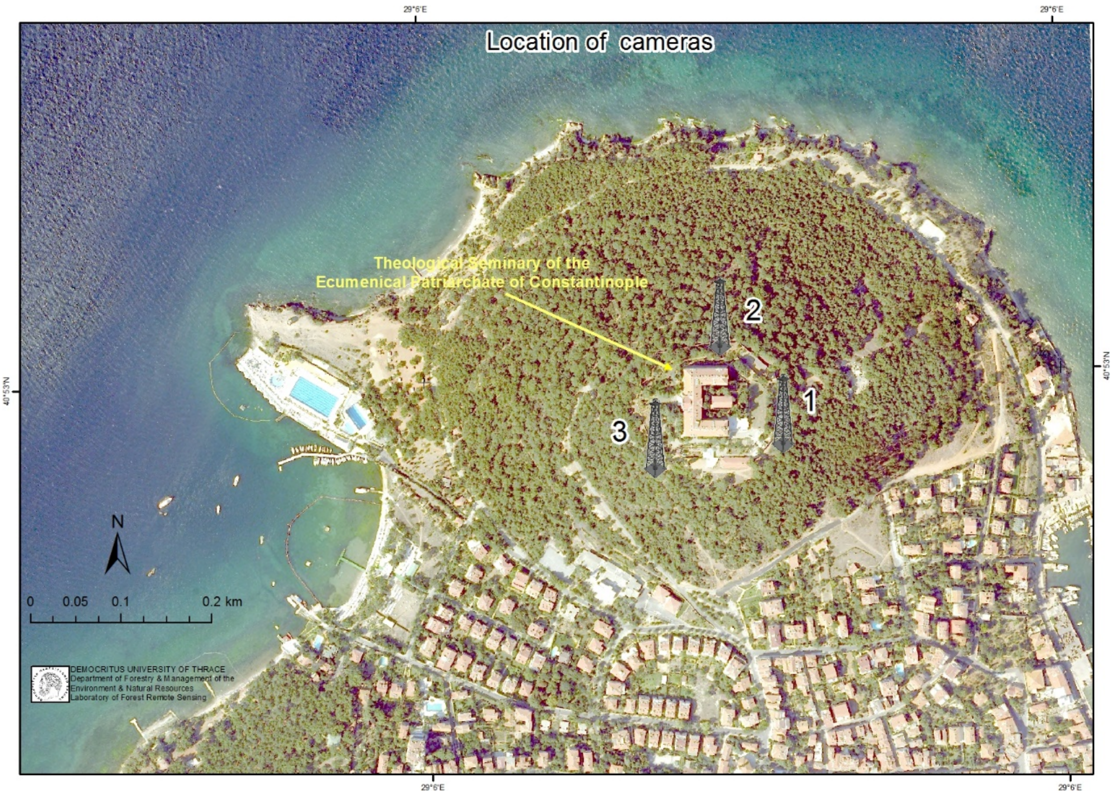

Figure 5.13 Identified suitable locations (3) for implementing the monitoring cameras

At this point we should mention that it might feasible (or even preferable) to locate the cameras along the coastline in order to achieve equally satisfactory results or even better considering that the same task could be completed with event two camera positions. However, this approach is considered operationally as non-optimum due to the remote and isolated distance of the cameras from the main Seminary facilities.

The three-dimensional view constructed by superimposing the natural color orthoimages over the Digital Elevation Model of the island, clearly depicting the visibility and locations that could be inspected by each camera.

Figure 5.14 Visible forest area from the 1st proposed position

Figure 5.15 Visible forest area from the 2nd proposed position

Figure 5.16 Visible forest area from the 3rd proposed position

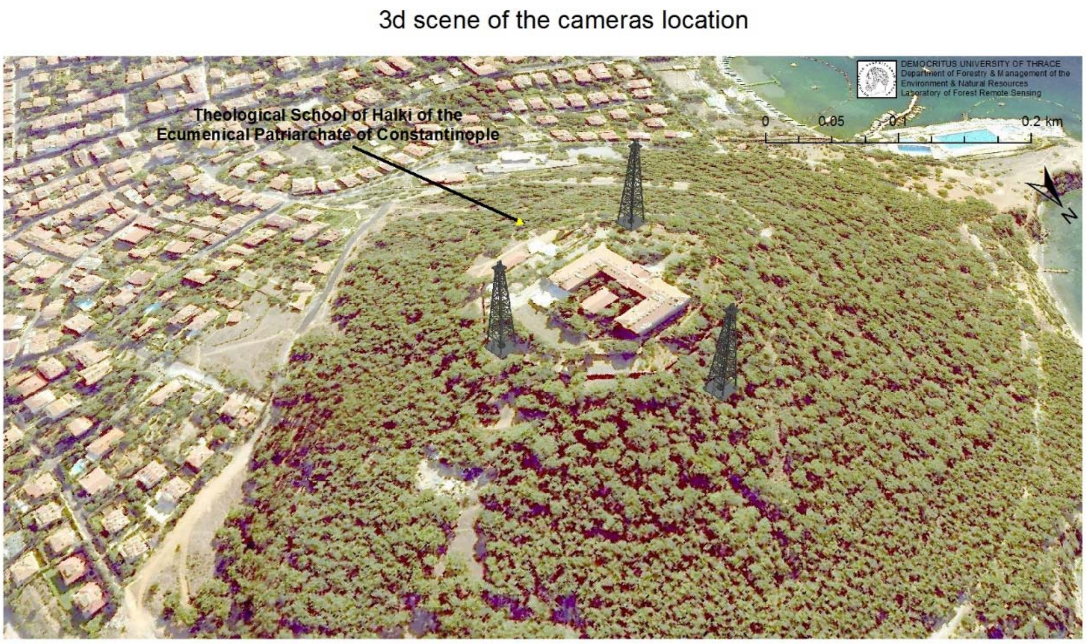

Figure 5.17 Three-dimensional realization of the proposed camera locations

5.5 The proposed fire detection system

The Halki Theological School is surrounding by a high fire risk forest. The proposed fire detection system should include a Wireless Sensor Network (WSN), capable of monitoring temperature and smoke, and optical and infrared cameras on the deployment site. The signals collected from these sensors will be transmitted to a monitoring center, which will employ intelligent computer vision and pattern recognition algorithms as well as data fusion techniques to automatically analyse sensor information. The system should be capable of generating automatic warning signals for local authorities whenever a dangerous situation arises.

There is a number of detection and monitoring systems in the world. These are in particular, observers, in the form of patrols or monitoring towers, aerial and satellite monitoring and increasingly promoted detection and monitoring systems based on optical cameras, different types of detection sensors or their combination. It turns out that most them have been developed by the most advanced technical solutions of forest fire monitoring in the future according to the practical experience. Commercial available systems can be found in full package (a system as a whole) or custom (adjusted to end user needs and requirements). A list of manufactures of fire detection systems can be found in Appendix A.

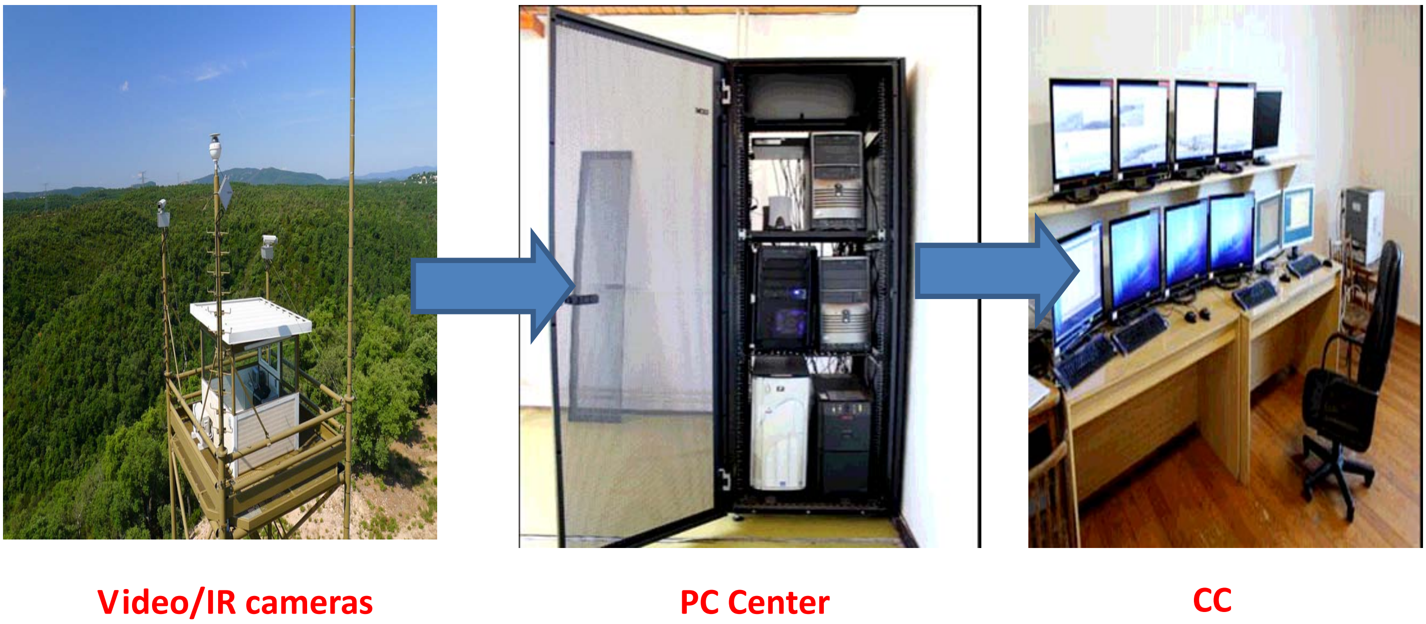

Figure 5.18 Architecture of the proposed fire detection system. Video/IR Cameras, PC center and Control Center (CC)

6 CONCLUSIONS AND FIRE MANAGEMENT IMPLICATIONS

This study assessed the current fire risk regime of the Theological School of Halki surrounding forest area and investigated the potential effects of fire risk under three different fuel treatment scenarios. Three localized fuel models have been developed based on extensive fieldwork and they have been subjected to landscape fire simulation runs in order 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 area under the current fire risk situation. From the analysis it became obvious that the combination of shrub removal and overstory thinning and pruning can be used to reduce wildfire risk hazard in the Theological School of Halki surrounding forest under dominant summer meteorological conditions for the area. The proposed methodology presents an integration of fuel sampling, very high fuel mapping resolution, and landscape fire behavior simulation for fire management planning across the natural and cultural landscapes in Mediterranean ecosystems.

Furthermore, this study conducted a novel visibility study for identifying optimal locations for establishing an automatic early warning system to remotely monitor the study area from the risk of fire. The proposed system will take advantage of recent advances in multi-sensor surveillance technologies, using a wireless sensor network capable of monitoring different modalities, as well as optical and infrared cameras on the deployment site. The signals collected from these sensors are transmitted to a monitoring center, which employs intelligent computer vision and pattern recognition algorithms as well as data fusion techniques to automatically analyze sensor information. The system is capable of generating automatic warning signals for local authorities whenever a dangerous situation arises.

Fuel treatment plans and fire detection systems should be essential components of forest management in forests surrounding cultural monuments in order to reduce fire hazard.

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