ASSESSING VULNERABILITY OF GREEK FORESTS TO FIRES WITHIN THE CONTEXT OF CLIMATE CHANGE

A. Karali[1], C. Giannakopoulos[1], A. Roussos[1], G. Lemesios[1]

[1]*Institute of Environmental Research and Sustainable Development, National Observatory of Athens, GR-15236, Athens, Greece*

Presenting author e-mail: akarali@noa.gr, telephone number: +30 2108109151

Abstract

Greece, being part of the eastern Mediterranean basin, lies within an area particularly vulnerable to climatic change regarding temperature rise and increased fire risk. The aim of this study is to assess the vulnerability of Greece to fire risk occurrence due to climate change within the framework of EU Project CLIM-RUN. The vulnerability of Greek forests to the future climatic changes is assessed in terms of their sensitivity, exposure and adaptive capacity based on the available quantitative and qualitative data for Greece. In order to assess exposure to forest fires, maps depicting the days with elevated fire risk (FWI>30) both for the control (1961-1990) and the first future period (2021-2050) were examined. For assessing the sensitivity factor, a fire hazard map including static information (topography and vegetation) was created. Finally, a Multi-Criteria Analysis (MCA) tool was implemented, so as to assess the adaptive capacity of Greek forests and to select the most appropriate adaptation options for Greece. It was found that eastern lowlands are more exposed to fire risk followed by eastern high elevation areas. Lowlands were found to be the most sensitive areas. As for the overall vulnerability eastern lowlands were found to be the most vulnerable followed by western lowlands and eastern high elevation areas.

Keywords: climate change, vulnerability, forest fires, FWI

1. Introduction

Greece, being part of the eastern Mediterranean basin, is an area particularly vulnerable to climatic change regarding temperature rise and increased fire risk [5]. Since the mid-1970s most regions of Greece experience significant positive temperature trends that are more pronounced in summer [4], while at the same time, Greece entered a prolonged period of drought that led to a significantly high number of fires and burnt area [3]. RCM projections for Greece indicate longer and more intense summer droughts that even extend out of season. In connection to this, the frequency of forest fire occurrence and intensity is on the rise.

The word 'vulnerability' is usually associated with natural hazards like floods, droughts, forest fires and social hazards like poverty etc. Recently, it is extensively used in climate change literature to denote the extent of damage a region is expected to be affected by various factors influenced by climate change. In the context of climate change there are many studies on vulnerability and its definitions vary according to the perception of the researchers.

For the purpose of the current study, the IPCC Third Assessment Report was followed. According to this, vulnerability is defined as "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" [10]. Thus as per this definition, vulnerability has three components: exposure, sensitivity and adaptive capacity. These three components are described as follows [8].

- Exposure can be interpreted as the direct danger (i.e. the stressor), and the nature and extent of changes to a region's climate variables (e.g. temperature, precipitation, extreme weather events).

- Sensitivity describes the human–environmental conditions that can worsen the hazard, ameliorate the hazard, or trigger an impact.
- Adaptive capacity represents the potential to implement adaptation measures that help avert potential impacts.

The first two components together represent the potential impact and adaptive capacity is the extent to which these impacts can be averted. Thus, vulnerability is potential impact minus adaptive capacity. Under this framework, a highly vulnerable system would be a system that is very sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and for which the ability to adapt is severely constrained.

According to the ATEAM (Advanced Terrestrial Ecosystem Analysis and Modelling) Project, high potential impact and low adaptive capacity constitutes a high degree of vulnerability for the system [1]. Adaptive capacity according to Brooks [2] has no direct implications to current vulnerability and can only diminish future vulnerability. IPCC [9] defines adaptive capacity as the ability of a human-environment system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities and cope with the consequences.

This study is part of the European Project CLIM-RUN (www.climrun.eu) which aims to provide an important instrument for the development of a Mediterranean-wide network of climate services that would eventually confluence into a pan-European network. Differently from current approaches, CLIM-RUN will develop a bottom-up protocol directly involving stakeholders early in the process with the aim of identifying well defined needs at the regional to local scale. The aim of this study is to assess the vulnerability of Greek forests to fire risk occurrence within the context of climate change in terms of their sensitivity, exposure and adaptive capacity based on the available quantitative and qualitative data for Greece.

2. Methodology and results

The vulnerability of Greek forests to the future climate changes is assessed in terms of their sensitivity, exposure and adaptive capacity according to the aforementioned definitions. In particular, exposure is defined as the degree to which forests will be affected by climate change, sensitivity is the degree to which forests are exposed to land hazard that will be discussed later in detail, while the adaptive capacity is defined by the ability of forests to adapt to changing environmental conditions which is also enhanced by the measures implemented in the country, in order to mitigate the adverse impacts of climate change on this sector.

2.1. Assessment of Exposure

Exposure reflects both the direct danger and the extent of changes to a region's climate variables. For the Mediterranean-type ecosystems, fire occurrence strongly depends on the drought conditions that drastically increases flammability during summer period, on the temperature reached during this period as well as on the amount of fuel load [12]. In order to study the exposure of Greek forests to forest fires, climatic indices and the meteorologically based Fire Weather Index (FWI) were examined.

Fire Weather Index (FWI) is a daily meteorological-based index used worldwide to estimate fire danger in a generalized fuel type. Although it has been developed for the Canadian forests, several studies have shown its suitability for the Mediterranean basin [6, 11]. The FWI System provides numerical ratings of relative fire potential based solely on weather observations. The meteorological inputs to the FWI System are noon values of temperature, air relative humidity, 10m wind speed and precipitation during the previous 24 hours [16].

In order to calculate FWI, daily output from the high resolution regional climate model RACMO2 developed at KNMI (Netherlands) within the framework of the EU ENSEMBLES project was used (www.ensembles-eu.org). The model has a horizontal resolution of 25 km × 25 km and use the A1B greenhouse gases emissions scenario

[13]. Present day simulations cover the period 1961-1990 and used here as reference for comparison with future projections for the periods 2021-2050 (near future) and 2071-2100 (distant future). Tables 1-2 present mean control values as well as the changes in the near and distant future of indices relevant to forest fires for Greece. Greece was divided into four sub-regions following geographical and climatological criteria, in order for our results to be presented in a more comprehensive and illustrative way.

Table 1: Values of indices with particular relevance to forest fire risk for Greece for the control period (1961-1990).

	Eastern lowlands	**Eastern high elevation areas**	**Western lowlands**	**Western high elevation areas**
No of dry days (P<1mm)	290-310	270-310	250-270	210-250
Max length of dry spell (days)	80-120	70-90	70-90	30-70
No of days with Tmax>35 °C	20-40	5-20	5-15	10
Average summer Tmax (°C)	31-35°C	27-30°C	29-32°C	25-27°C

Table 2: Potential future changes in indices with particular relevance to forest fire risk for Greece for the near (NF) and distant (DF) future periods.

		Eastern lowlands	**Eastern high elevation areas**	**Western lowlands**	**Western high elevation areas**
No of dry days (P<1mm)	**NF**	+5-15	+5-15	+5-10	+5-10
	DF	+15-20	+15-30	+12-15	+12-15
Max length of dry spell (days)	**NF**	+10-30	+5-30	+10-20	+10-20
	DF	+20-50	+15-30	+20-30	+15-25
No of days with Tmax>35°C	**NF**	+15-25	+5-15	+10-15	+5-10
	DF	+35-60	+25-40	+40-60	+25-35
Average summer Tmax (°C)	**NF**	+1.5-2.5°C	+1.5-2.5°C	+1.5-2.5°C	+1.5-2.5°C
	DF	+3.5-5.5°C	+4.5-5.5°C	+4.5-5.5°C	+4.5-5.5°C

As shown in Table 2, the number of dry days is expected to increase in the entire domain up to 15 and 30 days in the near and distant future, respectively. Maximum increases are expected for the eastern parts of Greece. In the near future, the increases in the maximum length of dry spell may vary between 5-30 and 10-20 additional days per year in the eastern and western part of Greece, respectively. In the distant future, this increase will be up to 50 additional days for the eastern and up to 30 additional days per year for the western parts. Moreover, the average summer maximum temperature is expected to increase up to 2.5°C in the near future for the entire domain. At the end of the century this increase will reach 5.5°C in western and northern parts of Greece.

In order to study the present and future exposure of Greek forests to forest fires, fire weather index (FWI) indicators both for the control and the first future period, namely the period 2021-2050, was examined. As FWI is based solely on meteorological variables the aforementioned changes in temperature and precipitation patterns will be reflected in the FWI patterns throughout the domain of study.

As shown in Figure 1, the number of days with elevated fire risk (i.e. FWI>30), in both periods, are higher for the lowlands in the eastern part of Greece. In particular, the Greek domain can be divided into 4 sub-regions of different fire risk behaviour and exposure. These sub-regions are the eastern lowlands and high elevation areas as well as the western lowlands and high elevation areas. As depicted in the figures, the eastern lowlands are more exposed to fire risk followed by eastern high elevation areas. This means that they present a high number of days with elevated fire risk, both for the control and the future period. The western lowlands and high elevation areas are the least exposed regions, as they depict few days with elevated fire risk both for the control and the future period.

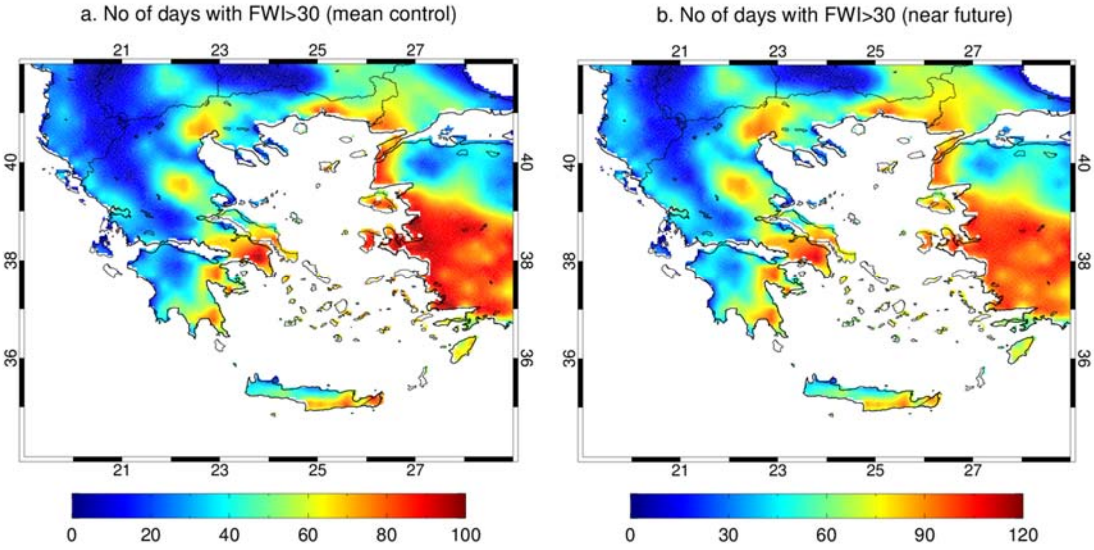

Figure 1: Mean number of days with increased fire risk (FWI>30) for a) the reference period (1961-1990) and b) the near future period (2021-2050) for Greece.

2.2 Assessment of Sensitivity

The sensitivity factor describes the human–environmental conditions that can worsen or ameliorate the hazard. In the current study, static information concerning fire affecting factors, namely topography and vegetation, was used to create a fire hazard map in order to assess this factor.

Starting with static information, Hardy [7] notes that fire hazard expresses the potential fire behaviour for a fuel type, regardless of the fuel type's weather-influenced fuel moisture content. This means that based solely on vegetation information a sensitivity map of an area can be produced. In order to create such a map, vegetation was categorized in fuel type categories, denoting how much combustible material the vegetation would be able to provide in a possible fire event.

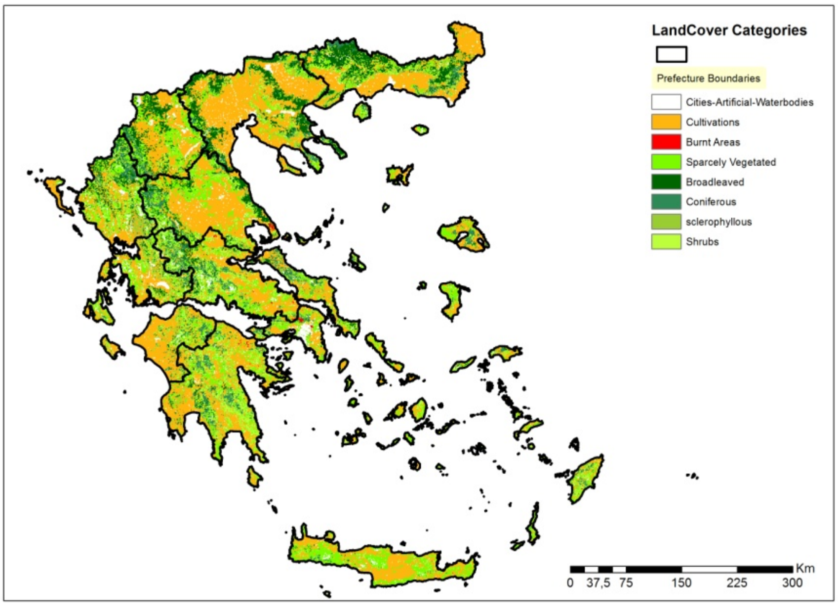

Figure 2: Land cover categories map for Greece.

For this information layer, raw data pertaining to land cover types in Greece for the year 2007, which have resulted from the processing of Landsat satellite imagery, through the implementation of automated grading model were used. Original data were obtained from WWF Greece (www.wwf.gr) and were developed by the Laboratory of Forest Management and Remote-Sensing of the Faculty of Forestry and Natural Environment at the Aristotle University of Thessaloniki in Greece. Categorized data are shown in Figure 2. On the categories shown in Figure 2, certain weights were given to each (not shown), according to their evaluated fuel load and combustibility. For example, shrubs and sclerophyllous vegetation were assigned the higher weights contrary to the burnt areas and agricultural cultivations that were given much lower weights. Cities, artificial constructions and water bodies were assigned zero weights.

It is also known that topography affects forest fires, in terms of aspect, slope and altitude. Aspect generally refers to the horizontal direction to which a mountain slope faces. As south and west aspects are generally hotter and drier than the adjacent north ones in any given area of Greece, this affects vegetation as well. This means that south facing slope vegetation is usually drier and more fire prone than north facing slopes. Altitude is an inhibiting factor to forest fires, that is, the higher the altitude, the more difficult is for fires to break out or to propagate. Furthermore, slope affects mainly fire behavior rather than ignition in the way that the steeper the slope, the faster fire spreads. However, one should consider that that steeper slopes (especially over 67%) are less likely to be vegetated than milder ones.

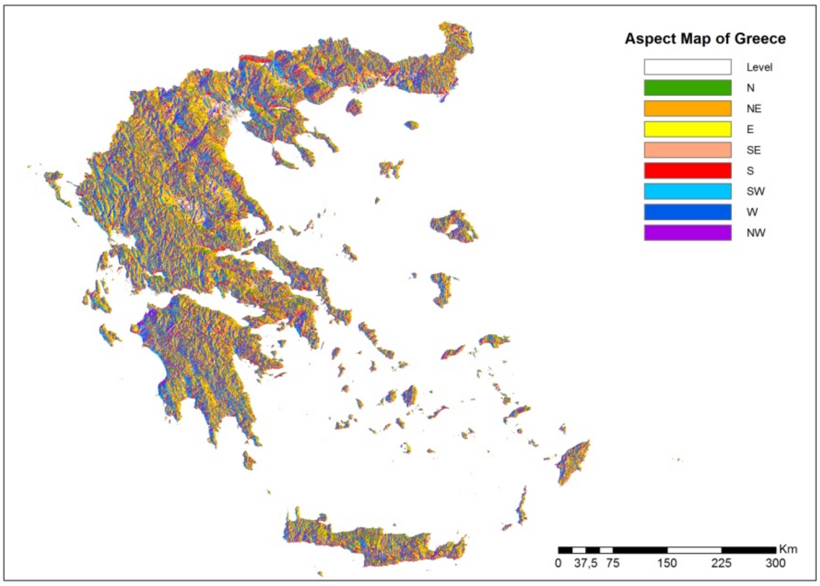

Figure 3: Aspect map of Greece.

Topographic information deriving from a digital elevation model (DEM) developed at the National Oceanic and Atmospheric Administration's National Geophysical Data Center (http://www.ngdc.noaa.gov/mgg/topo/globe.html), available at a 30-arcseconds (approximately 1 km) resolution, was used. The final Fire Hazard map was constructed by combining the two information layers of fire affecting static information mentioned above (land cover, aspect and altitude) and giving certain weights to each of their categories. The last step was to categorize the final Fire Hazard Map in six different classes, from the lowest possible one that is found inside cities, artificial constructions and water bodies to the very high level of the south and west oriented vegetated areas of low altitude. The final results for the entire Greek domain are depicted in Figure 4 (which combines information from Figures 2-3). As shown in Figure 4, the low to medium elevation south or west facing continental areas can be characterized as "high" fire hazard areas while the cultivated lowlands can be characterized as "low" and "medium" fire hazard areas.

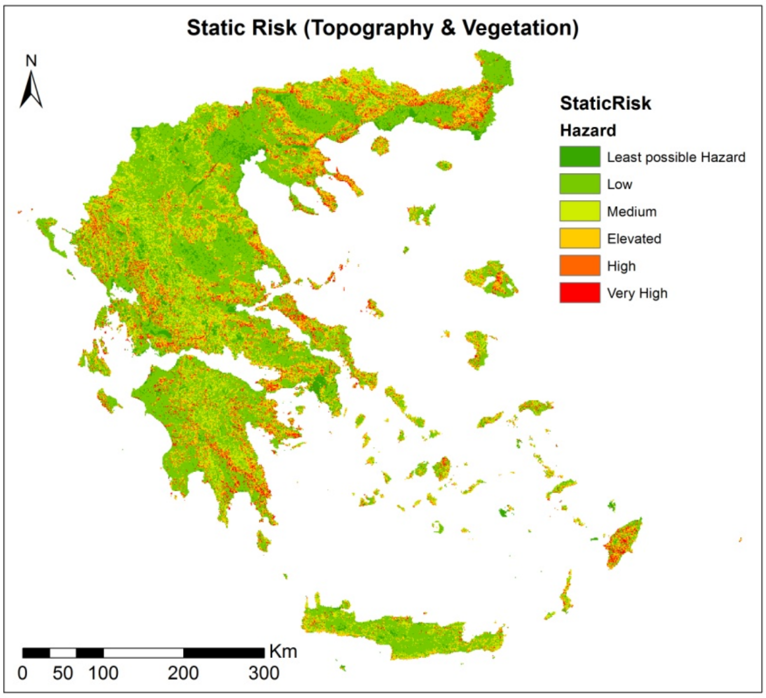

Figure 4: Final Hazard map for Greece.

2.3 Assessment of adaptive capacity

Adaptive capacity is a significant factor in characterizing vulnerability. In climate change literature, adaptive capacity is similar or closely related to other commonly used concepts such as adaptability, coping ability, management capacity, stability, robustness, flexibility, and resilience [14]. According to Brooks [2], the adaptive capacity of a system reflects its ability to modify its characteristics or behavior in order to better cope with existing or anticipated external stresses and changes in external conditions. IPCC [8] describes adaptive capacity as the potential or ability of a system, region, or community to adjust to the effects or impacts of climate change (including climate variability and extremes). The capacity to adapt is context-specific and varies from country to country, from community to community, among social groups and individuals, and over time [8, 14]. Adaptive capacity is considered to be "a function of wealth, technology, education, information, skill, infrastructures, access to resources, and stability and management capabilities [10].

In order to assess the adaptive capacity of Greek forests and to select the most appropriate adaptation options for Greece, a Multi-Criteria Analysis (MCA) approach has been used like in CYPADAPT project (http://uest.ntua.gr/cypadapt/). Multi-criteria analysis is proposed as the most appropriate method to accomplish decision making in the field of adaptation to climate change. MCA can accomplish handling of all available technical information and incorporation of different stakeholder views.

This method is used to evaluate options based on a set of criteria. Stakeholder analysis and expert judgment provides identification of all possible decisions/options. In the following, relevant criteria are selected in order to prioritize alternative adaptation options. Through weights and scores, the performance of each adaptation option is measured against criteria. This step in particular, reflects the preferences of the decision makers. Finally, the weighted sum of the different criteria is used to rank the different options [15].

The evaluation criteria which are chosen and used in the framework of the CLIM-RUN Project for the case study of Greece are the following:

- Efficiency of the Measure
- Environmental Friendliness
- Supporting the Prevention of Climate Impacts
- Urgency for Implementing the Measure
- Usefulness of Implementation Irrespective of Climate Change
- Technical Viability
- Economic Viability
- Social Acceptance

As has already been mentioned, each adaptation measure performance was scored against each of those criteria. Each measure was scored against each criterion on a scale from 0 to 100. In this scale 1 represents the least preferred option and 100 is associated with the most preferred option. After the implementation of the MCA method, the proposed adaptation measures for Greek forests in descending order of priority are the following:

- Fire Prevention measures
- Inclusion of the private forest covered areas in the fire fighting schemes of the Department of Forests
- Classification of forests according to the risk of fire, designation of high-risk areas
- Vital national resources and the implementation of a national fire protection plan
- Reforestation of burnt areas
- Immediate reforestation / restoration of areas destroyed by fire and implementation of appropriate silvicultural measures
- Fire suppression measures
- Infrastructure to improve forest resilience to fires
- Set up of infrastructure in the private forest areas for protection from fires
- Planning and development of forest ecosystems that would make the start and speed of expansion of fires more difficult

Finally, the SET (stakeholder expert team) taking into account the opinion of the local stakeholders concluded that when vegetation information and changes in meteorological conditions due to climate change are combined, forests of northern and western Greece are expected to be more adaptive than their eastern counterparts. That is mainly due to the fact that the aforementioned areas receive greater amounts of precipitation, together with less human activities due to lower population density, compared to southern and eastern areas of Greece (e.g. Attica or Crete). The already predominating vegetation species are not certain to survive the projected climate change, yet the forecasted conditions are most likely to be able to support a tall forest ecosystem, assuming that no major environmental catastrophe will occur in the meantime.

2.3. Assessment of overall vulnerability

As has already been mentioned, vulnerability can be defined as potential impact minus adaptive capacity. This can be described by the following mathematical equation:

$$Vulnerability = Impact - Adaptive\ capacity$$

where

$$Impact = \sqrt{Sensitivity * Exposure}$$

Sensitivity, exposure and adaptive capacity are evaluated on the same 6-degree qualitative scale ranging from “least” to “very high” (Table 3). “Impact” and “Adaptive capacity” should be evaluated on the same scale (1-6). For this to be achieved, the square root of “Sensitivity * Exposure” was used.

Taking into account the findings of sections 3.1 and 3.2, the overall vulnerability of Greek forests to forest fires, was estimated. The results are summarized in Table 4. For ecosystems in the eastern part of the country the vulnerability is medium while lower vulnerability exists for the ecosystems in the western part of the country. In particular, western Greece lowlands have the lowest vulnerability values followed by the higher elevation areas.

Table 3: Degree of sensitivity, exposure, adaptive capacity and vulnerability.

Degree of sensitivity and exposure & adaptive capacity		**Degree of vulnerability**		**Legend**
Least	1	Least	V≤1	⬜
Low	2	Low	1<V≤2	🟩
Medium	3	Medium	2<V≤3	🟨
Elevated	4	Elevated	3<V≤4	🟨
High	5	High	4<V≤5	🟧
Very high	6	Very high	5<V≤6	🟥

Table 4: Overall vulnerability assessment of forests to climate change in Greece.

	Eastern Greece		**Western Greece**	
	Lowlands	**Medium to high elevation areas**	**Lowlands**	**Medium to high elevation areas**
Sensitivity	High	Medium	High	Medium
Exposure	Very High	High	Elevated	Elevated
Adaptive Capacity	Low	Low	Medium	Medium
Vulnerability	Elevated	Low	Low	Least

3. Conclusions

In this study an assessment of the vulnerability of Greek forests to fire risk occurrence within the context of climate change was performed. The vulnerability of Greek forests was assessed in terms of their sensitivity, exposure and adaptive capacity based on the available quantitative and qualitative data for Greece according to the definitions of IPCC. In particular, exposure was interpreted as the direct danger and the nature and extent of changes to a region's climate variables. In order to assess exposure to forest fires, maps depicting the days with elevated fire risk (FWI>30) both for the control and the first future period, namely the period 2021-2050, were examined. It was found that eastern lowlands are more exposed to fire risk followed by eastern high elevation areas, for both the control and future period.

Furthermore, the term sensitivity describes the human–environmental conditions that can worsen or ameliorate the hazard. In this study static information concerning fire affecting factors, namely the topography and vegetation, was used to create a fire hazard map in order to assess the sensitivity factor. Land cover types for the year 2007, obtained from the WWF Hellas, were combined with topographic information deriving from a digital elevation model (DEM) in order to produce these maps. Lowlands were found were found to be the most sensitive areas followed by the medium to high elevation continental areas in both the Eastern and Western Greece.

The adaptive capacity is defined by the ability of forests to adapt to changing environmental conditions which is also enhanced by the measures implemented in the country, in order to mitigate the adverse impacts of climate change on this sector. In order to assess the adaptive capacity of Greek forests and to select the most appropriate adaptation options for Greece, a Multi-Criteria Analysis (MCA) tool was implemented. The major proposed adaptation measures for Greek forests include fire prevention measures, the inclusion of the private forest covered areas in the fire fighting schemes of the Department of Forests, the classification of forests according to the fire risk as well as the designation of high fire risk areas.

Finally, as far as the overall vulnerability of Greek forests is concerned, when combining all the aforementioned factors, eastern lowlands were found to be more vulnerable to climate change followed by western lowlands and eastern high elevation areas.

Acknowledgements

This work was supported by the EU project CLIM-RUN under contract FP7-ENV-2010-265192.

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