Advances in Forest Fire Research

DOMINGOS XAVIER VIEGAS

EDITOR

2014

A fire effects index for overall assessment of wildfire events in Greece

Kostas Kalabokidis, Palaiologos Palaiologou, Nikolaos Athanasis

Department of Geography, University of the Aegean, GR-81100 Mytilene, GREECE.
kalabokidis@aegean.gr

Abstract

Greece is faced with increased wildfire activity on an annual basis. Large-scale wildfires along with limited economic resources do not allow application of rehabilitation measures for the vast majority of burned areas, and when restoration takes place it is not based on sound scientific evidence. A scientific approach is missing based on wildfire classification and overall assessment of fire effects. Severity of a wildfire is perceived by the authorities only from the total area burned. These facts prompted our research thoughts about the need for introducing a new ranking method that will be based on expert judgment, with scientific evaluation of what has happened and what it is expected to occur based on several fire related aspects and parameters. The backbone of our proposed Fire Ranking and Effects Index (FIRE Index) is the Analytical Hierarchical Process (AHP) that is used to combine the scores of seven categories and 56 criteria that comprise them. These categories form two groups of effects: Environmental Fire Effects with three categories (Landscape and Vegetation; General Environment Impacts; Regeneration Potential/Vegetation Recovery); and Socioeconomic Fire Effects with four categories (Casualties and Fatalities; Destructions/Damages on Infrastructure; Economic Losses; Firefighting/Wildfire Confrontation). Each of the 56 criteria, along with four different general multipliers, describes a different anticipated fire effect. The magnitude of the effects is estimated by one or more persons/ assessors in a multi-level evaluation procedure. Then, AHP pair-wise comparisons are applied in two levels, i.e. within the criteria of each category and among the seven categories. Weighted scores of criteria are summed and normalized in a 0-100 scale; and the same procedure is applied on categories to calculate the final FIRE Index value. End-users are thus able to estimate the FIRE Index in a user-friendly, web-based platform that provides all the necessary feedback and literature justification, while conducting all the necessary calculations in the background.

***Keywords**: Wildfire Effects Evaluation; Analytical Hierarchical Process; Fire Index; Greece*

1. Introduction

Increased frequency and intensity of wildfire events for the past two decades in the Mediterranean Basin resulted in millions hectares of burned land, causing hundreds of fatalities and extensive losses on socioeconomic and natural resources (Moreira *et al.* 2011). There are several explanations for this large wildfire breakout, ranging from climate change (Trigo *et al.* 2006; Founda and Giannakopoulos 2009) to socioeconomic reasons, but it is generally agreed that human activities is the main cause for their geometrical increase (Pausas 2004). Either from arsons, negligence or need, the human-ignited fires are constantly destroying forest lands, accelerating phenomena such as erosion, desertification, land use changes, species extinction and degradation of the natural environment (Shakesby and Doerr 2006; Pausas *et al.* 2008; Moreira *et al.* 2011). Furthermore, the cost of rehabilitating the landscape, repairs on infrastructures and properties and economic compensations burden the national budgets (Butry *et al.* 2001; Steelman and Burke 2007). Societies are forced to spend vast amounts of economic and human resources to confront these events and to mitigate their catastrophic effects. Inability of evaluating each wildfire event from the importance of the causing effects usually leads to overestimate or underestimate of the real situation that emerged after the event, resulting in enforcing either a wrong recipe for post-fire management or do nothing.

Our proposed Fire Ranking and Effects Index (FIRE Index) in this study adds to the current fire effects evaluation procedures a comprehensive methodology that allows the classification of wildfires based on an evaluation of multiple fire effects categories and criteria. Its primary evaluation principle considers the social perspective of wildfires, by incorporating into the evaluation procedure a logic derived from how people understand fire effects during their lifetimes. The social perspective of wildfires dominates most of the criteria but co-exists with the ecological perspective of others. In the case of a conflict between those two approaches, the social always prevails. The above indicate that the assessor must rate the criteria based on what is important for human beings and societies, as well as, how they understand and experience ecology and environment.

2. Materials and Methods

The main tools used for the conceptual design and implementation of the proposed FIRE Index are based on approaches and applications used to estimate and assess burn severity and first order fire effects on the field (Composite Burn Index - CBI) from Key and Benson (2006); in conjunction with ranking the academic performance of world universities (The World University Rankings - Thomson Reuters[1]). The backbone of the ranking method among the different fire effects is the Analytical Hierarchical Process (AHP) (Saaty 1977). The FIRE Index has been designed for fire events that occur in Greece, but, given the necessary modifications and inputs can be expanded to other countries and regions.

The first level of wildfire evaluation is the *Fire Effect Category* (FEC: seven in total). Each category is composed of *Criteria* (56 in total). Each criterion has its own set of *Choices*, defining the magnitude of fire effects it describes on a scale of 0 (No effect) to 100 (High effect) (Table 1). The choices for each criterion were derived by the detailed study of the relevant local and international literature (wildfire and ecology studies) for several wildfire incidents as well as from the knowledge and experiences gained from several case studies across Greece. These choices portray the significance of the effects and outcomes caused by the wildfire. The assessor has the ability to provide any value through the predefined scale, with the exception of those values for certain choices that have been excluded or are not available by the initial criterion design. For example, if a criterion has two available choices that can both describe a certain fire effect with values 100 and 60, then the assessor can choose either the middle values of the two choices (80) or, a value that is closer to one choice depending on his judgment for the current situation (70 or 90).

Table 1. Fire effects evaluation scale from 0 (none) to 100 (high)

No Effect		Low		Moderate		High
0	10	20	40	60	80	100

Two criteria were assigned with *Additive Terms* (AT) that can aid in a more detailed description of the fire effects. The criterion score is modified by the AT value, but, eventually the final score will fall in the range of 0 to 100, due to an average estimation of the scores. For example, a forest under protection status will receive the highest value if it is an old-growth forest that comprises more than 50% of the burned area. Another concept in the evaluation procedure is the *Criterion Descriptor* that allows the attribution of a percentage value to each choice to achieve a better description of what has happened on a landscape level. For example, the assessor can describe the percentage of area occupied by pine trees or other vegetation types, achieving a more detailed allocation of the criterion value. The sum of all the values of criterion descriptor should not exceed 100%.

Some of the FEC's (five out of seven) were assigned with a *General Multiplier* (GM) that is evaluated on a scale of 0.5 to 3 having a 0.5 interval. These GM's were derived from evaluation of important

[1] http://www.timeshighereducation.co.uk/world-university-rankings/2013-14/world-ranking/methodology

wildfire attributes and characteristics, such as fire size, ecological condition and protection status, and post-fire vegetation condition. They provide the ability to decrease (by selecting a value from 0.5 to 0.9), keep it the same (values equal to 1) or increase (values greater than 1) the overall FEC score based on the assessor's answer. AT's were also assigned to two GM's and their value is defined by the average of all answers. The majority of criteria and multipliers can be evaluated by simply selecting one from the available choices or provide a user defined score; but there are some that have a particular logic behind them that it is noted in their description.

2.1. Prioritization of Categories and Criteria

For each category and criterion, weights were derived to achieve a prioritization among them based on their relative importance at the category and final index levels, by using the AHP method developed by Saaty (1977). Initially, a pair-wise comparison matrix is designed (Equation 1), where the relative importance between two criteria is measured according to a numerical scale from 1 to 9, where 1 denotes equal importance and 9 denotes that the first is absolutely more important than the second criterion.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & & a_{2n} \\ \vdots & & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \tag{1}$$

where, $\alpha_{jk} = 1/ a_{kj}$ and k,j = 1, …., *n*.

Once the matrix is built, it is possible to derive a normalized pair-wise comparison matrix (i.e. A_{norm}) by making equal to 1 the sum of the entries on each column. Each entry $\bar{a}_{jk}$ is computed by Equation 2:

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \tag{2}$$

Then, the criteria weight vector w (that is an m-dimensional column vector) is built by averaging the entries on each row of the A_{norm} matrix with Equation 3 (results were checked to ensure that they are consistent):

$$\mathrm{w_j} = \frac{\sum_{\mathrm{l=1}}^{\mathrm{m}} \bar{\mathrm{a}}_{\mathrm{jl}}}{\mathrm{m}} \tag{3}$$

To conduct all the necessary calculations for the final FIRE Index estimation, the calculation of all criteria and multipliers scores is required. Each criterion is weighted and then summed with the others from the same category. If a GM exists, it is applied on the weighted sum. Then, a normalization of the outcome is performed on a scale of 0 to 100 by using the higher and lower value that each category can achieve with the Equation 4:

$$x_i = \frac{(R_i - R_{min})}{(R_{max} - R_{min})} * SR \tag{4}$$

where, R_i is the outcome weighted value of the category i, R_{min} and R_{max} are the lower and higher values respectively the category can achieve, and SR is the standardized range.
Finally, the value from each of the seven categories is also weighted and then summed with the others to derive the final FIRE Index value on a scale of 1-100.

3. Results

3.1. Categories and Criteria of Fire Effects

By studying several wildfire case studies that occurred during the past 40 years in Greece, seven general wildfire effects categories were derived, forming two groups: the Environmental Fire Effects (Figure 1) and the Socioeconomic Fire Effects (Figure 2). The first fire effects category is the "Effects on Landscape and Vegetation" and examines the wildfire consequences on the landscape in terms of air quality and soil condition. It also examines the vegetation type, rarity, protection status based on a social perspective of the prioritization of forest resources. It is composed by five criteria and one GM. Initially, the assessor must define the landscape type in which the wildfire took place, by choosing among flat terrain/agricultural land, highlands, wildland-urban interface and mountainous areas. Then, in the criterion "Dominant Land Use/Land Cover types" (LULC), the vegetation composition inside the burned area is defined by providing the percentage estimation of its cover. The available choices are: bare soil; grass or short shrub; shrubland; agricultural land or orchard; mixed or broadleaf forest; and conifer forest. Then, the percentage fraction provided for each choice is multiplied by its relevant score. If the choices involve either "Mixed/Broadleaf forest" or "Conifer forest", then the two AT are activated, defining the vegetation types that exist inside the fire perimeter. For the case of mixed/broadleaf forest types, the available choices are: *Quercus* spp. or *Olea sylvestris*; *Fagus* spp. or *Juglans regia* or *Castanea* spp. or Cold Climate Broadleaf Evergreens; and mixed conifer/broadleaf forest. For the case of conifer forest types the available choices are: *Pinus brutia* or *Pinus halepensis*; *Juniperus* spp. or *Cupressus* spp.; *Pinus nigra* or *Pinus pinea*; and *Abies* spp. or mixed Fir/Pine forest or *Pinus sylvestris* or *Pinus heldreichii*. The assessor must provide the type of each forest and, depending on what is chosen, the AT score is multiplied by the fraction of cover for this particular LULC, summed with the initial LULC score and then averaged. The final criterion value is derived by summing the scores of each LULC type, including the average values derived by the possible usage of AT.

The next criterion defines if the burned area is under Greek or international conservation and protection status of forested areas and on what percentage it is inside the fire perimeter. The choices are: lake or seashore forests; recreational forests; national parks; and old-growth forest. If the assessor chooses a value different from "None" (which means a zero value for the criterion), he must then define the percentage that this protected area type is occupying inside the burned area. The two scores are then summed and averaged to derive the final criterion value. The effects on air quality are defined by providing information that describes the size and type of the affected populated areas and to what extent (Sastry 2002; Vedal and Dutton 2006). The available choices are: away from settlements; small-scale visibility reduction and smoke impacts near small villages; visibility reduction inside medium/large sized populated areas; and severe smoke impacts inside medium/large sized populated areas. Finally, the last criterion describes the probabilities to occur land degradation, erosion and soil losses phenomena (none; low; moderate; high) (Robichaud 2000; Parsons *et al.* 2010). The assessor must also define the percentage of area that is expected to have those probabilities. The percent fraction is then multiplied with the score of each choice and summed to derive the final criterion score. Upon the completion of the above criteria, the size of burned area must be defined to act as the category's GM. Based on a detailed study of the frequency, size and number of fire events on Greece, the available choices are: fire size <10 ha; 10 to <100 ha; 100 to <500 ha; 500 to < 2,000 ha; 2,000 to <7,000; and >7,000 ha.

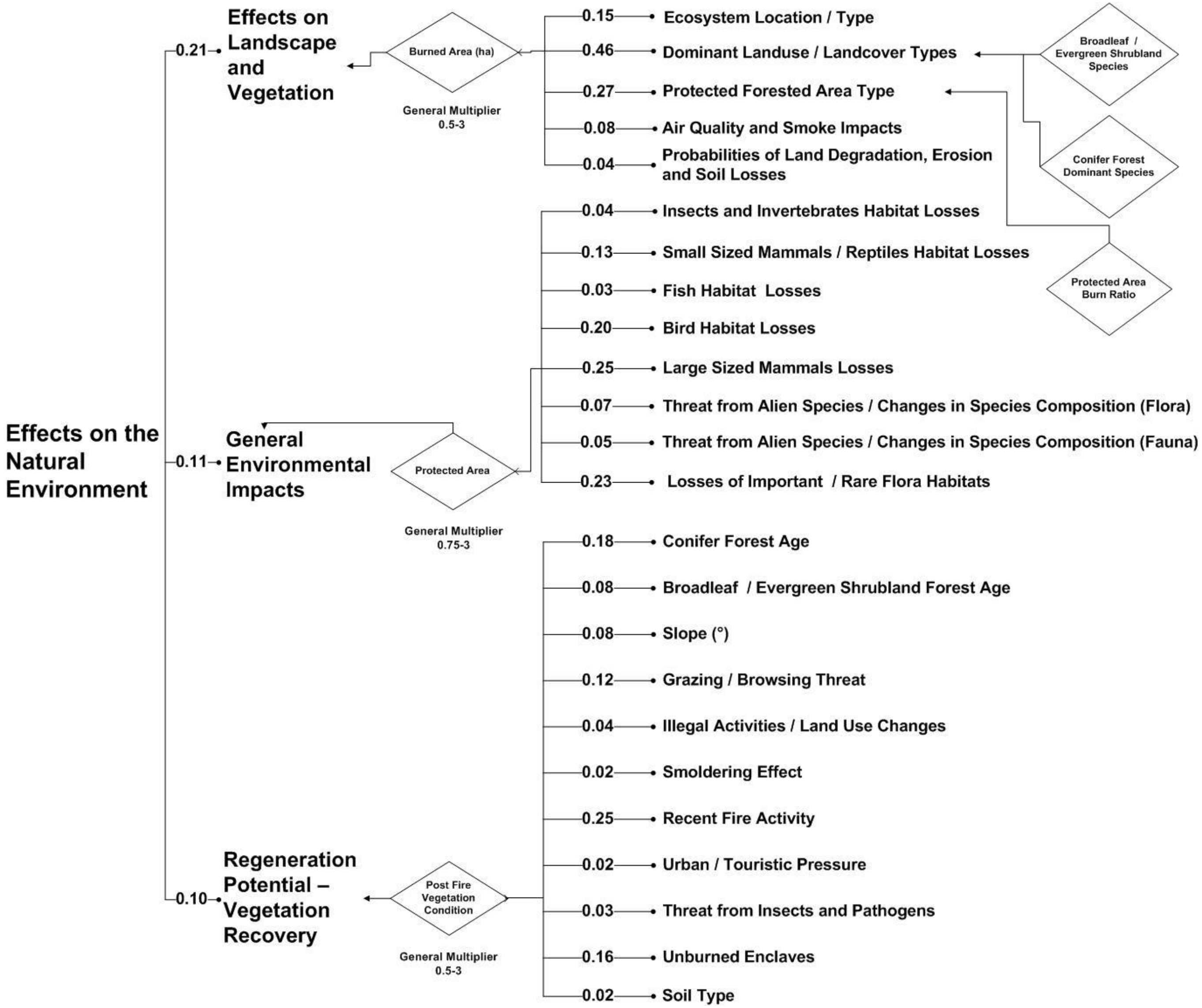


Figure 1. Structure of criteria and categories with their attributed weights for natural environment fire effects evaluation

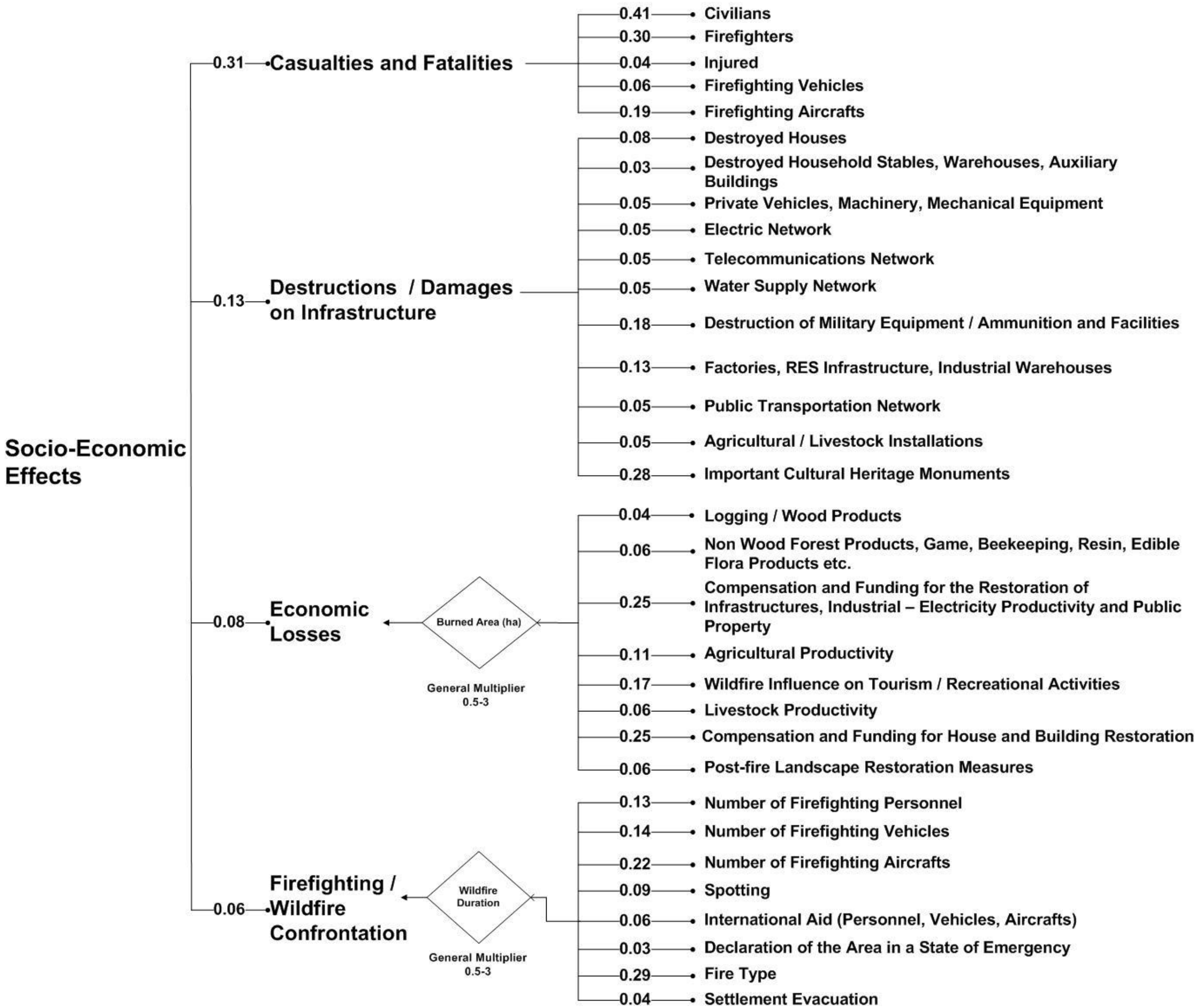


Figure 2. Structure of criteria and categories with their attributed weights for socioeconomic fire effects evaluation

The second category is the "General Environmental Impacts" that evaluates the wildfire effects on the fauna and flora of the affected area, as well as on the environmental quality and biodiversity. It is composed of eight criteria and one GM. Initially, the assessor must define the losses (if any) on important fauna habitats for five criteria (insects and invertebrates; small mammals/reptiles; fish; birds; and large-size mammals) (Smith 2000). The available choices are: none; few; several; and extended. The assessor must, prior to any judgment, acquire knowledge about the species composition of the area, their vulnerability to wildfires, their projected population response, their rarity and the extent of their habitat on the broader area. The sixth criterion evaluates the losses and possible endangering of important/rare flora species (Phitos *et al*. 1995; Brown and Smith 2000; Georghiou and Delipetrou 2010). The available choices for the assessor include: zero losses due to the lack of important/rare species; few losses with regeneration potential; extended losses with alteration on habitat conditions and strong population stresses; and intense, with possible species extinction or disappearance from the area. The next two criteria estimate the threat for exotic species invasion or the modification of the current abundance of local fauna and flora species. The available choices for both criteria are: none; local; extended; and intense. The assessor must gain knowledge about possible exotic species/invaders that reside inside or adjacent to the affected area that can encroach into it and to estimate if there will be any changes in species abundance and composition (Vitousek 1990; D 'Antonio and Vitousek 1992; Daehler and Strong 1994; Wilcove *et al*. 1998; Pimente 2002). Finally, one GM with an AT will define if the affected area is under any protection status and to what extent (Dimopoulos 2005; Mazaris *et al.* 2008). The available choices for the assessor are: none; wildlife habitats/NATURA 2000 areas; protected natural areas; areas of complete and strict protection; and biogenetic/biosphere reserves. If the choice is different than "None" (score = 1), the percentage of burned area that belongs to the selected type should be defined on the AT. The two scores are summed and averaged to derive the final GM score.

The third category is the «Regeneration Potential/Vegetation Recovery» and examines the fire behavior, pre-fire landscape and vegetation conditions, fire history and human pressures on the affected area. It is composed of 11 criteria and one GM. Initially, the assessor must define the age of conifer species that existed in the area prior to the fire (if present). The available choices are: not applicable; >100 years; 60-100 years; 20-60 years; 15-20 years; and <15 years. It is assumed that the younger the conifer forest is the more difficult it is to regenerate (Thanos and Daskalakou 2000; Tapias *et al*. 2001; Ne'eman *et al.* 2004; Climent *et al.* 2008). In the second criterion, the age of broadleaf species/evergreen shrublands must be defined (if present). The available choices are: not applicable; 10-15 years; 15-20 years; 20-60 years; 60-80 years; and >80 years or <10 years old. It is assumed that the older (or very younger) the broadleaf forest/evergreen shrublands is the more difficult it is to regenerate (Johnson and Godman 1983; Stroempl 1983). For these two criteria, it is important to define the age of the dominant vegetation types across the landscape instead of a detailed approximation at a stand level. The next criterion describes the topography of the area in terms of slope, and the assessor must calculate and provide information about the portions of the landscape that have a certain slope choice. The available choices are: 0-5°; 5-10°; 10-15°; 15-20°; 20-30°; 30-45°; and >45°.

The imminent threat from grazing must be evaluated by understanding the amount of livestock that resides inside or on the periphery of the burned area. It is assumed that as the grazing is increased in frequency and range, the conditions for potential successful vegetation regeneration are dramatically reduced (Perevolotsky and Haimov 1992; Campbell and Donlan 2005). The available choices are: none; partial; extended; and intense. The recent fire activity is an important parameter that has a substantial effect on regeneration. It is assumed that there are more chances for a successful regeneration if the fire return interval is large (Agee 1990). The available choices are: >100 years; >50 years; >30 years; and <30 years. It is frequent that post-fire vegetation recovery is depended on unburned forest patches and individual trees, providing a seed bank to colonize and repopulate the burned area, and it is assumed that the more dispersed and abundant these unburned patches are, the better is for regeneration (Lentile *et al.* 2005; Arianoutsou *et al.* 2010). The available choices are:

many (dispersed); many (gathered); few (dispersed); few (gathered); none. Illegal activities that may cause land use changes or interference into formerly vegetated areas can have a substantial negative effect, so the assessor must identify if there is any evidence that such activities have happened in the past (e.g. illegal logging, construction of buildings, roads and houses, conversion of forests into agricultural lands, etc.) (Tacconi *et al.* 2003). The available choices are: none; partial; extended; and intense. Another important criterion is the influence humans can have into the burned area by applying urban or touristic pressures. This can usually take the form of frequent tourist trips into the burned forests and people visits for recreational activities (Kuvan 2005). These pressures are usually performed into the wildland urban interface environment (Atmiş *et al.* 2007). The available choices are: none; partial; extended; and intense.

Fire smoldering effect can cause serious implications in vegetation recovery, mainly by modifying significant soil properties that prevent seeds from growing or resprouting (Ryan and Noste 1985). The assessor must have evidence if smoldering has happened and to what extent. The available choices are: none; partial; extended; and intense. Another important threat is the outbreak of diseases or harmful insect's population expansion that can cause negative effects on areas that survived the fire (de Dios 2007; Hansen 2008). Often, seeds and genetic material is transferred from these areas to other nearby burned parts, colonizing the landscape and reestablishing vegetation. If those surviving areas or individuals are affected, then the process of forest regeneration can be halted or lead to vegetation alterations (Winder and Shamoun 2006). The available choices are: none; partial; extended; and intense. Finally, the soil type plays an important role on resprouting and seed germination ability. This criterion assumes that deep soils with small amount of rocks are more preferable compared to shallow skeletal soils (steep slopes or exposed parent material) (López-Soria and Castell 1992; Minotta and Pinzauti 1996; Spanos *et al.* 2001). The available choices are: deep soils with small amount of rocks; deep soils with moderate amount of rocks; moderate depth soils with small amount of rocks; moderate depth soils with moderate amount of rocks; shallow soils with moderate amount of rocks; and shallow exposed soils with large amount of rocks. The GM is composed of three parts that must be evaluated and averaged. In particular, the assessor must define the percentage of burned, scorched and unburned vegetation (black, brown and green), in a similar way to CBI estimation for the overstory vegetation condition (Key and Benson 2006). The sum of the percentage choices from the three answers should not exceed 100%.

The main operational priority for most firefighting agencies across the world is focused on the protection of civilian and personnel lives, followed by the protection of firefighting infrastructure, properties and the natural environment. Societies often evaluate the importance of a wildfire from the number of fatalities it has caused and the total burned area (Haynes *et al.* 2010). Thus, a category with criteria able to estimate what has happened in terms of casualties is extremely important. The category «Casualties and Fatalities» determines the human death toll caused by the fire, along with the number of injured individuals and the number of destroyed firefighting vehicles and aircrafts. This category is composed of five criteria; three of them describe the fire effects on human lives and two on firefighting infrastructure. The last two criteria were selected for that they are caused due to the operational activities of firefighting forces and can be seen as causalities (Mangan 2007).

To include the proper choices on each criterion, a detailed study on the number of fatalities caused during the past 40 years from fire events across Greece was conducted. The available choices for the civilian fatalities criterion are: 0; 1; <5; 5 to 10; and >10. The available choices for firefighting personnel deaths criterion are: 0; 1; 2 to 3; 4 to 5; and >5. Usually, the firefighting personnel losses are less compared to civilians from a single fire event. The available choices for injured people criterion are: 0; 1; <5; <10; 10 to 20; 20 to 30; and >30. It is more common to have destroyed firefighting vehicles compared to aircrafts, thus, the available choices for firefighting vehicles losses criterion are: 0; 1; 2; 3; 4 to 5; and >5. Finally, the available choices for firefighting aircraft losses criterion are: 0; 1; 2; and >2.

The fire effects Category «Destructions/Damages on Infrastructure» is composed of 11 criteria and estimates the magnitude of destructions and damages caused by the fire event on property, public infrastructures, monuments and capital. Initially, the assessor must provide data regarding the destroyed houses due to the fire activity, providing their absolute number by selecting among these choices: 0; 1; 3; 5; <10 and >10. Based on the same logic, the number of destroyed household stables, warehouses or auxiliary buildings must be provided by selecting among these choices: 0; 1; 3; 5; <10; <20; and >20. The following eight criteria are evaluated based on their repair or acquisition cost. The assessor must provide estimation of the cost required to replace or restore this infrastructure to its pre-fire working condition. The third criterion estimates the fire damage cost caused on mobile property such as cars, machinery and other equipment. For the next four criteria, the fire damage cost on transportation, electric, water supply and telecommunication networks is estimated. The available choices for the above criteria are: no damages; minor costs <15,000€; small cost <30,000€; medium cost <100,000€; and important high cost damages >200,000€. The next three criteria examine the cost of damages on military facilities, ammunition and equipment; on factories, renewable energy sources (RES) installations and industrial warehouses; and on Agricultural/Livestock installations. The available choices for the above criteria are: no damages; minor costs <50,000€; small cost <100,000€; medium cost <200,000€; and important high cost damages >300,000€. Finally, it is very important to assess if there were any damages or destruction of important cultural heritage monuments, and if so, the assessor must select a monument category that is based on time. The following choices are available: no damages; recent monuments aged <200 years; historic monuments aged >200 years; and world heritage sites and monuments.

The category «Economic Losses» accounts for the changes that are expected to occur on the local or regional economic structure, emphasizing on the market price drop of some valued items/products, the inability to produce or collect them and the amount of money that will be spent for productivity restoration or compensations (Donovan and Rideout 2003; Calkin *et al.* 2007). It also estimates the relative cost of post-fire landscape treatment measures that are going to be applied on the affected area. The main difference with the previous category is that it does not just account the costs of damages and destructions the fire has caused, but the cost of anticipated rehabilitation measures and future economic losses. It is composed by eight criteria and one GM.

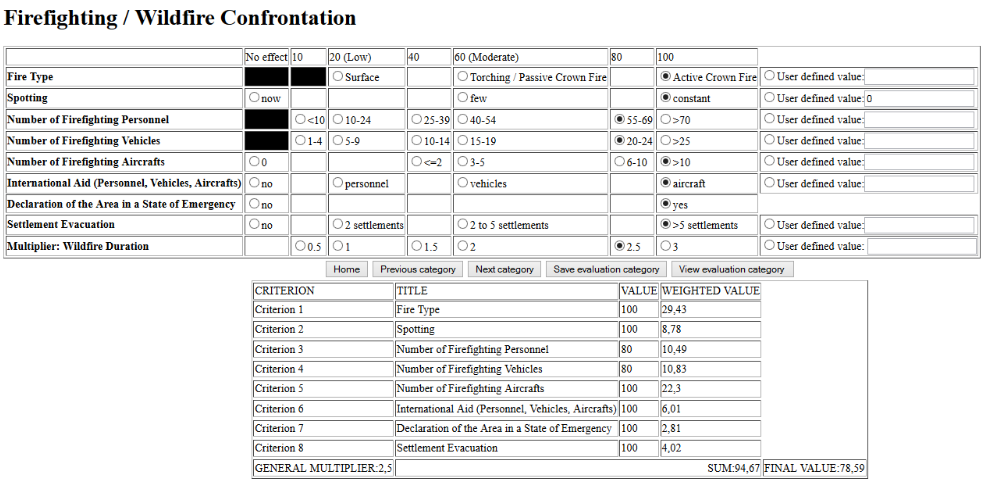
Initially, the assessor must provide information about the timber production and wood harvesting practices of the affected area. If the area was under a management status with frequent or upcoming timber harvesting then it is very probable that some kind of economic losses might occur. Several individuals or industries exploit the non-timber forest/nature products, such as game, honey production, resin extraction, pharmaceutics and medicine products, wild food, etc. These lead to the development of a small scale local or regional economy around these activities. The assessor must evaluate which were the fire effects on them and if economic losses have already happened or is expected to occur in the future. In Greece, it is very often for a wildfire to cause negative effects on agricultural and livestock production (Henderson *et al.* 2005; Moreira *et al.* 2011). This is usually done by destroying the means to produce income from these activities (animal deaths, burning of crops or orchards, destruction of infrastructure such as greenhouses, etc.). The cost includes possible compensations and future revenue losses from the inability to produce (e.g. in case of destroyed orchards). The assessor must assess those costs for these criteria. The available choices for the four criteria are: non productive area; minor; small; moderate; high economic losses; and total destruction. To restore the industrial and electric production, or to repair infrastructures and public property, compensations or funding must be paid from the state or insurance companies, otherwise negative effects can arise for the whole society. The same applies for houses and buildings. The available choices for these two criteria are: no cost; minor; small; moderate; and very high costs. The next criterion assesses the fire effect on tourism by evaluating the aesthetic, recreational and tourist infrastructure potential of the area (Kuvan 2005). The assessor must understand how large the touristic value of the area is and what kind of activities take place in the broader affected landscape. A link

must also be established between the values of the burned area and how important is for selecting it for tourist purposes, along with the predicted economic losses it might be caused. The available choices are: non touristic area; seashore related tourism area, scenery landscape close to intensely developed touristic areas; and forested area used for recreational/touristic purposes. The last criterion estimates the cost of landscape rehabilitation measures that are expected to be applied on the affected area. Usually, the type and range of their application depends on the available money the state is willing to spend. It is assumed that as the type changes and range of application increases, so does the cost (Napper 2006). The available choices are: no measures; small; medium; or high scale reforestations/counter-erosion/counter-flooding measures. Finally, one GM will define the size of burned area, assuming that as the fire size increase so does the overall economic losses.
The last category is the «Firefighting/Wildfire Confrontation» and evaluates the wildfire effects caused during firefighting activities and the wildfire confrontation strategy implemented. The category is composed of eight criteria and one GM, defining the general firefighting context and its operational costs. Furthermore, it considers the equipment and machinery wear, as well as the personnel fatigue. In the first criterion, the assessor must describe the fire behavior type that occurred in the majority of the burned area. This information can be derived either from observations or from the firefighting personnel. The available choices are: surface fire; torching/ passive crown fire; and active crown fire. Next, it must be defined if any spotting of fire re-bursts occurred. The available choices are: none; few; constant. The next three criteria count the number of people and vehicles that participated during the firefighting operations, to figure out confrontation difficulty. The available choices for the number of people/ firefighting personnel are: <10; 10-24; 25-39; 40-54; 55-70; and >70. The available choices for the number of ground vehicles are: 1-4; 5-9; 10-14; 15-19; 20-25; and >25. The available choices for the number of firefighting aircrafts are: 0; ≤2; 3-5; 4-5; and >5. All the above choices were derived by the study of several past wildfire events of Greece and are in proportion with their severity and confrontation costs. The international aid and reinforcements on personnel, vehicles and aircrafts add substantially to the firefighting operations, but is an indicative fact of the wildfire suppression difficulty, as well as of the costs associated with them. The available choices are: none; personnel; vehicles; and aircrafts. The declaration of the area in a state of emergency has two options (either no or yes), and is another indicative criterion of the wildfire difficulty. The evacuation of settlements adds a very complex parameter in the whole operation, increasing the costs and difficulty of operation. The available choices are: none; <2; 2 to 5; and >5 settlements. Finally, the category has one GM which accounts for the fire duration, providing the following choices: 0-2; 3-15; <24; <48; <72; and >72 hours.

3.2. **Web-Based Software Architecture**

To easily calculate and account for the complex interactions between and among criteria and categories, it was necessary to design a web-based software/ platform that will enable the assessor to provide inputs in a user-friendly Graphical User Interface (GUI), thus automating the calculation procedures and return the intermediate and final FIRE Index values (Figure 3). Furthermore, users can instantly test several different choices and options and understand their influence on the final index value (Figure 4). A detailed help section exists inside the GUI covering all the aspects of the methodology, providing explanation and documentation about what is being evaluated and the logic behind the available provided choices.

Figure 3. Initial evaluation screen and selection among categories



Firefighting / Wildfire Confrontation

	No effect	10	20 (Low)	40	60 (Moderate)	80	100	
Fire Type			Surface		Torching / Passive Crown Fire		Active Crown Fire	User defined value:
Spotting	now				few		constant	User defined value: 0
Number of Firefighting Personnel		<10	10-24	25-39	40-54	55-69	>70	User defined value:
Number of Firefighting Vehicles		1-4	5-9	10-14	15-19	20-24	>25	User defined value:
Number of Firefighting Aircrafts	0			<=2	3-5	6-10	>10	User defined value:
International Aid (Personnel, Vehicles, Aircrafts)	no		personnel		vehicles		aircraft	User defined value:
Declaration of the Area in a State of Emergency	no						yes	
Settlement Evacuation	no		2 settlements		2 to 5 settlements		>5 settlements	User defined value:
Multiplier: Wildfire Duration		0.5	1	1.5	2	2.5	3	User defined value:

Home | Previous category | Next category | Save evaluation category | View evaluation category

CRITERION	TITLE	VALUE	WEIGHTED VALUE	
Criterion 1	Fire Type	100	29,43	
Criterion 2	Spotting	100	8,78	
Criterion 3	Number of Firefighting Personnel	80	10,49	
Criterion 4	Number of Firefighting Vehicles	80	10,83	
Criterion 5	Number of Firefighting Aircrafts	100	22,3	
Criterion 6	International Aid (Personnel, Vehicles, Aircrafts)	100	6,01	
Criterion 7	Declaration of the Area in a State of Emergency	100	2,81	
Criterion 8	Settlement Evacuation	100	4,02	
GENERAL MULTIPLIER:2,5			SUM:94,67	FINAL VALUE:78,59

Figure 4. Web-based fire effects evaluation for the firefighting/wildfire confrontation category

4. Discussion and Conclusions

This version of FIRE Index is the first and has the primary goal of defining an evaluation context by creating a hierarchy among the categories, criteria and choices and by setting the rules that determine the combination of scores. Given its limitations and assumptions, the FIRE Index attempts to reveal an aspect of reality that allows people to evaluate possible scenarios that might happen in the future or to better understand what is been happening during the present time or to discover what has happened in the past. The FIRE Index does not portray or explains with full detail all the complexity, interrelationships and multivariate range that appear after a wildfire but, rather, it can quantify and record systematically what has happened for a large number of fire effects, while for some others can estimate what is going to happen.

There is a large number of criteria, AT's and GM's (approximately 1/3 of the total number) that can be evaluated by providing spatial data together with their descriptive information. The usage of Geographic Information Systems (GIS) in a next version of the FIRE Index can perform the necessary spatial queries and interactions that are required to provide answers for several criteria. For example, the size of burned area and their boundaries can be provided in a very short time after the wildfire event by EFFIS[1]. These data can be used to derive information from other spatial layers such as the LULC types or the location of protected areas. Spatial data from satellite products or other study methods (such as burn severity, erosion and soil type maps) can also be included in the process if they are provided. The assessor then just has just to accept, reject or apply corrections on the derived choices.

There are several limitations and assumptions in the FIRE Index evaluation context. The main assumption is that each fire effect can be evaluated by a single criterion that has predefined choices on a scale from 0 to 100, thus providing a numerical value for its significance. This is not a problem for criteria like "Burned Area", but for example applying scores on fatalities may cause misinterpretations, disagreement and confuse. However, choices were derived from detailed studies of hundreds of fire events. The way those choices have been placed on the scale is more a descriptive/ qualitative approach rather than a numerical one. The current approach scales the choices from lower to higher impacts, and thus, the assessor should rate them with this logic. The numerical values are used primarily for the calculations, but their meaning lies on the way the assessor chooses them on the predefined scale. Another assumption that has been made for the "Destructions/Damages of Infrastructure" category, where there are several criteria on which a market value has been applied. The main limitation on this approach is that the total damage cost can greatly exceed the predefined choices and the assessor is limited on the higher ranked choice, without the ability of inserting this extra amount on the procedure. The evaluation context of the FIRE Index is designed to catch the variability between and among the different wildfires and not to actually portray everything that has happened and with absolute detail. The last assumption, that is simultaneously a limitation, is the usage of AHP method to derive criteria and categories weights. The AHP method requires user inputs to set a hierarchy among criteria and categories, thus, it is vulnerable to subjective judgment. Different people can consider differently their importance and this will lead to alterations in weights. The AHP was evaluated by the authors of this study by considering the social perspective of fire effects as the most important issue that determines the FIRE Index value, followed by environmental and economic perspectives.

By combining the scores of criteria for each category and by producing a total score for the wildfire event, public authorities and societies will be able to understand if during this event more or less serious effects have happened to one or more environmental and socioeconomic attributes; an approach that is beyond a simple measure of the burned area. This will allow a shift to occur in the current perspective of wildfires in Greece (and maybe elsewhere) and will enable the introduction of a scientific approach in the evaluation of each wildfire. It is anticipated that fire effects will be seen as an overall sum of negative and positive consequences that should be dealt either combined or individually to mitigate their impacts on nature and humans. It will also enhance the public awareness and will provide a comprehensive information source regarding several aspects of wildfires. The FIRE Index will not substitute a thorough study for the wildfire event with well established methods and techniques for the estimation of first and second order fire effects, but, in contrary, it will be enhanced by those studies that can provide the necessary inputs, with scientific evidence, and increased detail and accuracy.

[1] http://forest.jrc.ec.europa.eu/effis/applications/current-situation/

5. Acknowledgments

This work has been funded by the research project "AEGIS: Wildfire Prevention and Management Information System" {Code Number 1862}, which is implemented within the framework of the Action ARISTEIA of the Operational Program "Education and Lifelong Learning" (Action's Beneficiary: General Secretariat for Research and Technology), and is co-financed by the European Social Fund (ESF) and the Greek State.

6. References

Agee, J.K., 1990. The historical role of fire in Pacific Northwest forests. In: Natural and prescribed fire in Pacific Northwest forests. (eds. Walstad, J.D., Radosevich, S.R., Sandberg, D.V.), pp. 25-38. (Corvallis: Oregon State University Press).

Arianoutsou, M., Christopoulou, A., Kazanis, D., Tountas Th, G. E., Bazos, I., and Kokkoris, Y., 2010. Effects of fire on high altitude coniferous forests of Greece. In: 6th international conference on forest fire research, 15-18 November 2010, Coimbra, Portugal.

Atmiş, E., Özden, S. and Lise, W., 2007. Urbanization pressures on the natural forests in Turkey: an overview. *Urban Forestry and Urban Greening*, **6(2)**, 83-92.

Brown, J.K. and Smith, J.K., (Eds.) 2000. Wildland fire in ecosystems: effects of fire on flora. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42-vol. 2. (Ogden, UT).

Butry, D.T., Mercer, E.D., Prestemon, J.P., Pye, J.M. and Holmes, T.P., 2001. What is the price of catastrophic wildfire? *Journal of Forestry*, **99(11)**, 9-17.

Calkin, D.E., Hyde, K.D., Robichaud, P.R., Jones, J.G., Ashmun, L.E. and Loeffler D., 2007. Assessing post-fire values-at-risk with a new calculation tool. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-205. (Fort Collins, CO).

Campbell, K.J and Donlan, C.J., 2005. A review of feral goat eradication on islands. *Conservation Biology*, **19(5)**, 1362-1374.

Climent, J., Prada, M. A., Calama, R., *et al*., 2008. To grow or to seed: ecotypic variation in reproductive allocation and cone production by young female Aleppo pine (Pinus halepensis, Pinaceae). *American Journal of Botany*, **95(7)**, 833-842.

Daehler, C.C., and Strong, D.R., 1994. Native plant biodiversity vs. the introduced invaders: status of the conflict and future management options. In: Biological Diversity: Problems and Challenges. (Eds. Majumdar, S.K., Brenner, F.J., Lovich, J.E., Schalles, J.F. and Miller, E.W.), pp. 92- 113. (Easton, PA: Pennsylvania Academy of Science).

D'Antonio, C.M. and Vitousek, P.M., 1992. Biological invasions by exotic grasses the grass/fire cycle, and global change. *Annual Review Of Ecology And Systematics*, **23**, 63-87.

de Dios, V.R., Fischer, C., and Colinas, C., 2007. Climate change effects on Mediterranean forests and preventive measures. *New forests*, **33(1)**, 29-40.

Dimopoulos, P., Bergmeier, E., Theodoropoulos, K., Fisher, P. and Tsiafouli, M., 2005. Monitoring Guide for Habitat Types and Plant Species in the Natura2000 Sites of Greece with Management Institutions. University of Ioannina and Hellenic Ministry for Environment, Physical Planning and Public Works.

Donovan, G.H. and Rideout, D.B. 2003. A reformulation of the cost plus net value change (C+ NVC) model of wildfire economics. *Forest Science*, **49(2)**, 318-323.

Founda, D. and Giannakopoulos, C., 2009. The exceptionally hot summer of 2007 in Athens, Greece – a typical summer in the future climate? *Global and Planetary Change*, **67**, 227-236.

Georghiou, K. and Delipetrou, P., 2010. Patterns and traits of the endemic plants of Greece. *Botanical Journal of the Linnean Society*, **162**, 130-422.

Hansen, E.M, 2008. Alien forest pathogens: Phytophthora species are changing world forests. *Boreal Environmental Research*, **13**, 33-41.

Haynes, K., Handmer, J., McAneney, J., Tibbits, A. and Coates, L., 2010. Australian bushfire fatalities 1900–2008: exploring trends in relation to the 'Prepare, stay and defend or leave early'policy. *Environmental Science & Policy*, **13(3)**, 185-194.

Henderson, M., K. Kalabokidis, E. Marmaras, P. Konstantinidis, and M. Marangudakis. 2005. Fire and society: a comparative analysis of wildfire in Greece and the United States. Human Ecology Review, **12(2)**,169-182.

Johnson, P.S. and Godman, R.M., 1983. Precommercial thinning of oak, basswood, and red maple sprout clumps. In: Silviculture of established stands in north. Stier, Jeffrey C. (Ed.). SAF Region V Technical Conference, Duluth, Minnesota. Society of American Foresters, pp. 124-142. (Washington, DC: USA).

Key, C.H. and Benson, N.C., 2006. Landscape assessment: Sampling and analysis methods. In: FIREMON: Fire effects monitoring and inventory system. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-164-CD. (Fort Collins, CO).

Kuvan, Y., 2005. The use of forests for the purpose of tourism: the case of Belek Tourism Center in Turkey. *Journal of environmental management*, **75(3)**, 263-274.

Lentile, L.B., Frederick, W.S. and Wayne, D.S., 2005. Patch structure, fire-scar formation, and tree regeneration in a large mixed-severity fire in the South Dakota Black Hills, USA. *Canadian Journal of Forest Research*, **35(12)**, 2875-2885.

López-Soria, L., and Castell, C., 1992. Comparative genet survival after fire in woody Mediterranean species. *Oecologia*, **91(4)**, 493-499.

Mangan, R., 2007. Wildland firefighter fatalities in the United States: 1990–2006. National Wildfire Coordinating Group. *Safety and Health Working Team, National Interagency Fire Center,* NWCG PMS, **841**.

Mazaris, A.D., Kallimanis, A.S., Sgardelis, S.P. and Pantis, J.D., 2008. Does higher taxon diversity reflect richness of conservation interest species?: the case for birds, mammals, amphibians, and reptiles in Greek protected areas. *Ecological indicators*, **8(5)**, 664-671.

Minotta, G. and Pinzauti, S., 1996. Effects of light and soil fertility on growth, leaf chlorophyll content and nutrient use efficiency of beech (Fagus sylvatica L.) seedlings. *Forest Ecology and Management*, **86**, 61-71.

Moreira, F., Viedma, O., Arianoutsou, M., *et al.*, 2011. Landscape–wildfire interactions in southern Europe: implications for landscape management. *Journal of Environmental Management*, **92(10)**, 2389-2402.

Napper, C., 2006. Burned area emergency response treatments catalog. USDA Forest Service, National Technology and Development Program, Watershed, Soil, Air Management, 0625 1801—SDTDC. (San Dimas: CA).

Ne'eman, G., Goubitz, S. and Nathan, R., 2004 . Reproductive traits of Pinus halepensis in the light of fire — a critical review. *Plant Ecology,* **171**, 69-79.

Parson, A., Robichaud, P.R., Lewis, S.A., Napper, C. and Clark, J.T., 2010. Field guide for mapping post-fire soil burn severity. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-243. (Fort Collins, CO).

Pausas, J.G., 2004. Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean basin). *Climatic change*, **63(3)**, 337-350.

Pausas, J.G., Llovet, J., Rodrigo, A. and Vallejo, R., 2008. Are wildfires a disaster in the Mediterranean basin? – A review. *International Journal of Wildland Fire* **17**, 713-723.

Perevolotsky, A. and Haimov, Y., 1992. The effect of thinning and goat browsing on the structure and development of Mediterranean woodland in Israel. *Forest ecology and management*, **49(1)**, 61-74.

Phitos, D., Strid, A., Snogerup, S. and Greuter, W., 1995. The red data book of rare and threatened plants of Greece. World Wide Fund for Nature (WWF).

Pimentel, D., 2002. Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species. (CRC Press: Boca Raton, Florida).

Robichaud, P.R., 2000. Fire effects on infiltration rates after prescribed fire in Northern Rocky Mountain forests, USA. *Journal of Hydrology*, **231-232**, 220-229.

Ryan, K. and Noste, N., 1985. Evaluating prescribed fires. In: Symposium and Workshop on Wilderness Fire. USDA Forest Service Intermountain Forest and Range Experiment Station, General Technical Report INT-182, pp. 230-238. (Lotan, J.E., *et al*. (tech. coord.).

Saaty, T., 1977. A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, **15 (3)**, 234-281.

Sastry, N., 2002. Forest fires, air pollution, and mortality in Southeast Asia. *Demography*, **39(1)**, 1-23.

Shakesby, R.A. and Doerr, S.H., 2006. Wildfire as a hydrological and geomorphological agent. *Earth-Science Reviews*, **74**, 269-307.

Smith, J.K., (Ed.) 2000. Wildland fire in ecosystems: effects of fire on fauna. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42-vol. 1. (Ogden, UT).

Spanos, I.A., Radoglou, K.M. and Raftoyannis, Y., 2001. Site quality effects on post-fire regeneration of Pinus brutia forest on a Greek island. Applied vegetation science, 4(2), 229-236.

Steelman, T.A. and Burke, C.A., 2007. Is wildfire policy in the United States sustainable? *Journal of Forestry*, **105(2)**, 67-72.

Stroempl, G., 1983. Thinning clumps of northern hardwood stump sprouts to produce high quality timber. In: Forest Research Information Paper, Canadian Ministry of Natural Resources (Maple: Ontario).

Tacconi, L., Boscolo, M. and Brack, D., 2003. National and international policies to control illegal forest activities. *Report for the Ministry of Foreign Affairs, Government of Japan. CIFOR, Bogor, Indonesia*.

Tapias, R., Gil, L., Fuentes-Utrilla, P. and Pardos, J.A., 2001. Canopy seed banks in Mediterranean pines of southeastern Spain: A comparison between *Pinus halepensis* Mill, *P. pinaster* Ait, *P. nigra* Arn. and *P. pinea* L. *Journal of Ecology*, **89**, 629-638.

Thanos, C.A. and Daskalakou, E.N., 2000. Reproduction in Pinus halepensis and P. brutia. In: G. Ne’eman and L. Trabaud [eds.], Ecology, biogeography and management of Pinus halepensis and P. brutia forest ecosystems in the Mediterranean Basin, 79 – 90. Backhuys Publishers, Leiden, Netherlands.

Trigo, R.M., Pereira, J., Pereira, M.G., Mota, B., Calado, T.J., Dacamara, C.C. and Santo, F.E., 2006. Atmospheric conditions associated with the exceptional fire season of 2003 in Portugal. *International Journal of Climatology* **26**, 1741-1757.

Vedal, S. and Dutton, S.J., 2006. Wildfire air pollution and daily mortality in a large urban area. *Environmental research*, **102(1)**, 29-35.

Vitousek, P.M., 1990. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Oikos, **57**, 7-13.

Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A. and Losos, E., 1998. Quantifying threats to imperiled species in the United States. *BioScience*, **48**, 607-615.

Winder, R.S. and Shamoun, S.F., 2006. Forest pathogens: friend or foe to biodiversity. *Canadian Journal of Plant Pathology*, **28**, 1-7.