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«CLIMATE CHANGE & FOREST FIRES OF MEDITERRANEAN»
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ABSTRACT

The Mediterranean region, characterized by warm and dry climate, is located in a transitional zone between the humid/cold temperate zone and the hot arid zone and due to this fact, it presents high vulnerability to environmental changes. Shifts of few degrees in temperature may cause dramatic changes in environment such as desertification in regions with wet climate. Forest fires are today the most important enemy of Mediterranean forests because they can completely destroy large areas of forest vegetation in a very short time. A changing climate will profoundly affect the frequency, size and severity of fires in many regions and ecosystems in response to factors such as earlier snowmelt and severe or prolonged droughts, it will alter the growth, structure and composition of existing vegetation, with resulting changes in fuel structure and dead fuel loads. Increased fuel flammability due to hotter and drier conditions, is the main response of fire to climate change. The activity and intensity of fires are favored by fuel under suitable climatic conditions. Studies have analyzed the extent and intensity of the climate impact on forest fire regime and the conclusion is that maximum temperature and decrease in rainfall and relative humidity can trigger forest fires easily during summer period, resulting in higher forest fire risk.
INTRODUCTION

The Mediterranean region is one of the areas that are heavily affected by climate change. In this area, 50,000 forest fires have a significant impact on forests destroying 400,000 hectares per year on average (San Miguel Ayanz et al., 2013). Alterations in ease of ignition and extent of burnt areas are mainly related to the presence, quantity and structure of fuel, as well as fuel moisture content (Pausas and Ribeiro, 2013).

In several studies, scientists support that climate change is the primary factor of fire variability in Mediterranean forest ecosystems (Moritz et al., 2012). «A changing climate will profoundly affect the frequency, size and severity of fires in many regions and ecosystems in response to factors such as earlier snowmelt and severe or prolonged droughts, it will alter the growth, structure and composition of existing vegetation, with resulting changes in fuel structure and dead fuel loads» (Sommers et al. 2011). «Weather and climate are the most important factors influencing the geographical distribution of wildfires and fire activity and these factors are changing due to anthropogenic climate change» (Flannigan et al. 2006). Increased fuel flammability due to hotter and drier conditions, is the main response of fire to climate change. The activity and intensity of fires are favored by fuel under suitable climatic conditions (Moritz et al., 2012).

Forest fires are strongly related to drought during the summer period in the countries of the Mediterranean climate zone. In these countries, prolonged drought and strong winds combined with high heat and low precipitation are considered as the main factors of forest fire occurrence (Camia and Amatulli, 2009; San Miguel Ayanz et al., 2013).
CHAPTER 1 CLIMATE AND FOREST ECOSYSTEMS OF THE MEDITERRANEAN REGION

1.1. CLIMATE CLASSIFICATION
Geographically, the Mediterranean region extends from the European Alps to the Sahara and from the Atlantic Ocean to the Caspian Sea. It includes 25 countries divided into four groups: south-west Europe (France, Italy, Portugal and Spain), south-eastern Europe (Albania, Bulgaria, Greece, Cyprus, Malta, Romania and Slovenia, southern region (Algeria, Egypt, Libyan Arab Jamahirya, Morocco, Sudan and Tunisia) and the eastern part of the Mediterranean (Israel, Jordan, Lebanon, Saudi Arabia, Arab Republic of Syria and Yemen (Ramadé, 1991).

Mediterranean macroclimate has its origination in seasonal alternation of frontal cyclones that are related to polar atmospheric masses during the winter and subtropical high pressure systems originated from maritime and continental tropic air masses during the summer. Continental flows of air masses coming from African and Middle East region during the summer, lead to prolonged hot and dry conditions in the area of Anatolian Peninsula (Tatli and Türkeş, 2014; Türkeş et al, 2009, 2011).

During the winter season, the weather and climate conditions in the Mediterranean region are controlled by the combination of mid-latitude and Mediterranean cyclones, originating from Northeast Atlantic with subtropical anticyclones originating from Azores (Tatli and Türkeş, 2014).

According to the Köppen-Geiger climatic classification system, parts of the Mediterranean basin of 25-60° latitude are characterized by a mild and warm climate
(Peel et al., 2007). The Maritime (Temperate meso-thermal) Climate where the mean temperature of the colder month is greater than 0 °C is represented by the Latin letter C while the Continental meso-thermal Climate where the mean temperature is less than 0 °C is denoted by the letter D. The average temperature of the cooler month of the Marine and Continental climates should not exceed 18 °C, but the warmer month (July) should be above 10 °C (Tatli and Turkes, 2014).

Both, Maritime and Continental Climates are characterized by equal an uneven distribution of annual precipitation, since some months are wetter and some others are drier. In the Köppen-Geiger climatic classification system, the dry season is determined by the rainfall of the hottest month of the year due to the stronger evaporation during the warm season. If the mean midday height of the hottest month is less than 30mm, defined as the cut-off limit of dry or non-dry summer, the climate is classified as dry or continental with dry summer. Dry summer is represented by the second letter (s), and therefore Cs and Ds are denoting the Maritime climate with a dry summer and the Continental climate with dry summer, respectively. (http://www.meteoclub.gr/images/stories/weerman/klimatiki-katataksi-elladas.pdf).

Mediterranean Cs climate is mainly characterized by high temporal variability which is influenced by several factors (Tatli and Türkeş, 2014):

- it extends to an area between temperate and cold latitudes, such as subtropical zone
- it faces significant alterations in circulation between winter and summer season and
- it has connection with many oscillation atmospheric patterns, such as North Atlantic Ocean (NEA), Mediterranean (MO) oscillation phenomenon as well as El Niño (ENSO) and the NCP (North Sea-Caspian Climatic Model).

An additional feature of Cs climate is the occurrence of half of annual precipitation in the winter opposed to the fact that the summer season is characterized by drought. Temperatures during the winter are unusually mild in mid-latitude regions except for some in the east and the interior. Temperatures during the summer period range from high to very high with bright sunshine without cloudiness. Also, the influence of the ocean interaction with the atmosphere during the year is of great importance (Tatli and Türkес, 2014).

If precipitation exceeds 30mm, the climate is characterized as wet Maritime or Continental. The absence of dry summers is represented by the letter f and particularly, the wet Maritime and Continental Climate are represented by Cf and Df respectively (Fig. 1) (http://www.meteoclub.gr/images/stories/weerman/klimatiki-katatakisi-elladas.pdf).

The letter w represents the dry period during the winter, where the precipitation of the driest month during the coldest half of the year should be less than 1/10 of the precipitation height of the wettest month in the warm season (Laiaki, 2013).

The third letter of the code in climate classification can be:

a: which is used for very hot summer climates where the temperature of the hottest month should be equal to or greater than 22 °C.
b: which is used for hot summer climates where the temperature of the hottest month should be less than 22 °C but there should be at least four warmer months of an average monthly temperature greater than 10 °C.

c: which is used for climates with cool summer where the temperature of the warmest month should be less than 22 °C and the temperature of 1-3 months being 10 °C or above (Laiaki, 2013).

Figure 1. Geographical distribution of climatic types in the Mediterranean macroclimatic region based on the first, second and third letter of the Köpper-Geiger classification system (Tatli and Türkesh, 2014).

Type B climates refer to dry climates of high or low temperatures, not only rainfall but also seasonal distribution is taken into account (Laiaki, 2013).

Type B dry climates are classified according to rainfall amounts in two types:

type S steppe climate which is a characteristic of areas with vegetation and high precipitation 350-700mm and type W desert climate in areas of lower rainfall amounts (<250mm) (Figure 1) than the type s climate (Tatli and Türkesh, 2014).
With regard to the third Latin letter of the classification, depending on the average annual temperature, type B climate is distinguished in h-warm climate of an average annual temperature greater than 18 °C and in k-cold climate of an average annual temperature of less than 18 °C (Laiaki, 2013; Tatli and Türkeş, 2014).

1.2 DIVERSITY AND EXTENT OF FOREST ECOSYSTEMS
Mediterranean Basin presents a great diversity of vegetation due to altitude changes. Forests are one of the most important ecosystems in the Mediterranean, as they harbor unique biodiversity and provide socio-economic and environmental benefits such as soil retention, aquifer enrichment, biomass production, microclimate stabilization and tourism development. Forests have many interconnected functions-social, economic and environmental. They offer raw materials for industry and the production of renewable energy. Forests protect the soil, settlements and infrastructure; they regulate freshwater supply and preserve biodiversity. From a climatic point of view, during their development, forests act as “carbon dioxide-absorbing depots”, the gas that contributes most to the greenhouse effect, but when they are burnt or destroyed by harmful organisms, they are source of CO₂ release (Geotechnical Chamber of Greece, 2010).

The following types of vegetation can be observed in different altitudes: subalpine zone of coniferous forests, mountainous zone of deciduous forests, Mediterranean zone of evergreens and coniferous forests and the lower and driest altitude zone of scattered forests (Fig. 2)

In 2010, the estimated forest area was over 85 million hectares, representing 2% of the world’s forest area (FAO, 2010). Forests are distributed unevenly in the Mediterranean Basin with significant differences between countries (Fig. 3). For example, France, Turkey and Spain represent over 50% of the total forest area, while the rest countries account for only 4% of the total Mediterranean area, although it represents 20%, 19% and 13% of the total area in Greece, Spain and Turkey respectively. The forest areas of the Mediterranean countries increased by almost 12 million hectares between 1990 and 2010, an average of 0.68% per year, except Albania, Bosnia, Algeria and Herzegovina where there was a loss of forest land (FAO, 2013).
Figure 3. Extent of forest areas in Mediterranean region (FAO, 2013)

Forest growing stock is defined as the volume of living trees and it is a key factor and a basis for carbon stock and biomass estimation. In 2010, the total forest growing stock in Mediterranean countries was estimated at 9.623 million m$^3$, of which 41% was coniferous and 58% were broadleaved forests. Bulgaria, Turkey, France, Italy and Spain present the highest volume of growing stock (Fig. 4) (FAO, 2013).
Forest biomass is an important measure of ecosystem productivity and is used to quantify the role of forests in the carbon cycle and the potential of woody biomass for energy production. Mediterranean countries showed an increase in growing stock by 2 billion tones during 1990-2010 due to total forest area expansion. Woody biomass was increased due to abandonment of forests especially in the northern Mediterranean countries and rarely due to good forest management, and the result is an increase in risk of fires. Forest fires lead to severe damages which can be prevented by using biomass appropriately (FAO, 2013).

Regarding carbon stock, carbon is captured by forests during their development, thus there is plenty of carbon stock in dead organic matter, biomass and soil.

The total amount of carbon presents fluctuations depending on forest management practices and climate conditions. Therefore, forests can contribute to mitigation of climate change as a reservoir or source of atmospheric carbon. The carbon stock of forests in the Mediterranean region increased by 1.2 billion tones from 1990-2010, with an annual growth rate of 1.3%, which contrasts with the global reduction in the carbon stock over the same period (FAO, 2010).

Unusual geographic and topographical variability as well as the intense climatic seasonality have influenced the richness and distribution of forest species in the
Mediterranean region which is highly endemic (Myers et al., 2000). Fig. 5 represents the main ecological zone for the distribution of Mediterranean forests: dry subtropical forests, subtropical steppe and subtropical mountain systems (FAO, 2013).

Figure 5. Ecological zones in Mediterranean region for the distributions of Mediterranean forests (FAO, 2013).

Mediterranean forests have almost double the number of woody species compared to those in central and northern Europe (247 instead of 135). In the Mediterranean region, 34 genuses of forests appear instead of 7 European forests. Typical examples are the seven endemic species of maple (A. pseudolatanus, A. platanoides, A. opalus, A. campestre, A. monspessulanum, A. lobelii and A. peronai) and nine species of fir (Abies pinsapo, A. marocana incl A. tazaotana, A. numidica, A. cephalonica including A. borisii-regis, A. cilicica, A. equi-trojani, A. nebrodensis and A. alba), nine species

Several areas of Mediterranean region are covered with a variety of forest species. Cupuliferae, including beech, oak and chestnut trees are found in many areas of the Mediterranean region and they cover a large area. Chestnut forests (S. sativa) cover several million hectares in the Mediterranean countries while oak forests comprise a genus of the following species Q. robur, Q. petraea, Q. pubescens, Q. frainetto, Q. vallonea, Q. cerris, Q. ilex Q. cocifera και Q. suber.

There is a remarkable number of deciduous species including Q. afares, Q. euboica, Q. vulcanica and Arbutus pavarii in Mahreb, Greece (Euboia), Turkey and Libya respectively. Endemic species are located in the Mediterranean islands and particularly Phoenix theophrastii in Crete and Anatolia and Chamaerops humilis is present in central Mediterranean areas as Spain (FAO, 2013). Fig. 6 presents the coverage of Greece by category and species of forests comprising 25% of the land surface of the country. The evergreen broadleaved species cover almost half of the total area, the deciduous broadleaved 30% and the conifers 22% of the forests of Greece. The oak and beech forests, among the broadleaved species, occupy a big part of them, while halepium-trachea pine and the pine-tree coniferous spruce and black pine trees are dominant in coniferous forests (EMEKA, 2011).
CHAPTER 2 FOREST FIRES IN MEDITERRANEAN

2.1 THE PHENOMENON OF FOREST FIRES

Forest fires are today the most important enemy of Mediterranean forests because they can completely destroy large areas of forest vegetation in a very short time (Markalas, 1996). For many terrestrial ecosystems, fire is an important and determining ecological factor (Daniel et al., 2007) where it occurs at almost regular periods of time. The determination of forest fire as an ecological factor is based on the fire-induced or fire-adaptive capacity of the majority of the species constituting the Mediterranean ecosystems (pyrophylla species). It is worth mentioning that the Mediterranean ecosystems have the ability to recover after fire when the elapsed time between the occurrences of two incidents in the same area is over 30 years (Pancyprian Union of Foresters, 2016). However, when the percentage of accumulated fuel is higher than the recycled one, then there is an increase in fires (Tabakis and Karanikola, 2015).
Fire, of course, as an ecological disorder occurs in all terrestrial ecosystems. Conservation of fire is important for communities that depend on it to remain in the natural environment (Miller, 2000). Forest fires have become more frequent and more destructive in recent years and this causes great concern (Tabakis and Karanikola, 2015).

Generally, the problem that occurs in the Mediterranean countries is not the fire itself, which have been always present. The real problem is the systematic and rapid reduction of periods of reoccurrence of forest fires (Tabakis and Karanikola, 2015). The phenomenon of recurrent high frequency forest fires in ecosystems is a fact related to the imbalance that is observed between the percentage and the rate of fuel accumulation in ecosystems in relation to the rate at which it is recycled (fuel storage>recycle rate) (Kalabokidis et al., 2002). Much more, the increased number of fires causes great concern. Forest fires have become more frequent and catastrophic the last years (Tabakis and Karanikola, 2015).

Forest fires and fires in general, is the result of combustion, a chemical reaction involving fuel, heat and oxygen (fire triangle, Fig. 7). All three elements are necessary to burn, while the removal of only one element results in the extinction of fire (Tabakis and Karanikola, 2015).
In the case of forest fires there are a number of additional factors/parameters that determine its evolution, which are distinguished in seven conditions that affect the behavior of fire:

- Condition 1: Types of fuel (flammable, heavy, green)
- Condition 2: fuel condition (fuel moisture)
- Condition 3: meteorological precipitations
- Condition 4: relative air humidity
- Condition 5: air temperature
- Condition 6: wind (speed)
- Condition 7: topographic layout

The conditions that determine the evolution of forest fires are grouped into three main categories: fuel, weather and topographical conditions (Fig. 8).
The spread of fire is likely when the ignition has occurred and when the amount of heat transferred from the pre-existing flame to neighboring combustible material is high enough to cause its ignition (Dupuy, 2009).

The development and evolution of forest fires consist of a series of successive phases characterized by high temperature and release of great energy units. The procedure of fuel combustion begins with the preheating of the material, a phase in which the fuel (needles/leaves, branches, dry vegetation) is dried, losing some of the moisture content of the material as well as part of its remaining volatile substances (~190 °C). In the second stage, the loss of volatile substances continues and the ignition of fuel (~280 °C) begins, and in the third and final stage the volatile substances burn between 380 °C and 425 °C (Pancyprian Unit of Foresters, 2016).

Figure 8. Diagram of the factors affecting the fire triangle for the development and evolution of fire (modified from Pancyprian Union of Foresters, 2016).
During woody material combustion, high temperatures lead to the burning of woody material and cause its chemical decomposition and production of flammable gases (Fig. 9). The combustion steps of woody matter are distinguished in:

i. evaporation of wood moisture (up to 100 °C),

ii. gasification of volatile substances (from 95 °C to 150 °C or above),

iii. surface charring and slow removal of flammable gases (150 °C – 200 °C),

iv. faster exhaust of flammable gases, followed by ignition and glow (200 °C – 370 °C) and

v. rapid ignition of flammable gases and formation of incandescent carbon (370 °C – 500 °C) (Pancyprian Unit of Foresters, 2016; Tabakis and Karanikola, 2015).

Figure 9. Burnt forest in which woody vegetation has reached the final burning stage (Pancyprian Unit of Foresters, 2016).
Fuel in forest fires is the dead or living plant tissues and it is divided into two categories depending on the position it occupies in the forest: a) Ground fuel, which includes all the fuel contained on the surface of the ground up to 1.5m. The main forest fuel materials are peat, tree roots, dry grass, young trees and shrubs, perennial vegetation as well as thinner or thicker branches, standing trunks and stumps, and b) aerial fuel, comprising all fuel at height of 1.5m and above (Tabakis and Karanikola, 2015).

The main meteorological factors that affect the development and spread of forest fires are temperature, relative humidity, precipitation and wind. Air temperature has a direct effect on forest fires, as it helps to dry and preheat fuel. Relative humidity of air is the ratio of the mass of air vapor to the mass to water vapor required to make the air saturated at the specified temperature by one hundred. When the relative humidity of air is low, then the vegetation is strongly dried, especially with the simultaneous influence of the wind (low relative humidity at noon). However, when there is relative humidity in air, the humidity of the fuel is increased (high relative humidity early in the morning). As a general rule, when the relative humidity in the air is 50-55%, there is low occurrence of forest fires and those that light up do not spread, especially in case of low wind speed. The amount of rainfall directly affects the moisture content of the fuel. The periods of rainfall are of great importance. The wind has a severe impact on forest fires because it determines the fire propagation direction and the speed of its spread. The dry wind causes the drying of the fuel. The main characteristic of the winds that blow in the summer is that they cease usually at night and in the morning hours making it easier to be extinguished.
The most common type of forest fire is the surface fire. It represents the most familiar propagation regime and consists in rapidly burning fire consuming dry grass, low vegetation, shrubs and herbs. This category includes shrub fires, which are considered dangerous and of high frequency. Diffusion takes place very fast due to the abundance of air and oxygen, dry fuel, flame and suitable temperature (Aplada et al., 2007). In specific conditions, a surface fire may lead to the next type of forest fires, the crown fires which affect the crowns of woody vegetation (Gabban et al., 2008). In this case, the crowns of forest trees are burned with rapid transfer from one to another, especially when the forests are dense (Aplada et al., 2007). These fires are very destructive as they can act decisively in large forests (http://www.ethelontismos.gr/attachments/070_%CE%94%CE%B1%CF%83%CE%B9%CE%BA%CE%AD%CF%82%20%CE%A0%CF%85%CF%81%CE%BA%CE%B1%CE%B3%CE%B9%CE%AD%CF%82.pdf).

Moreover, a fire could develop below the terrain, it is called ground fire and it consists in flameless fire that burns slowly through thick surface of organic matter. Regarding ground fires, it is very difficult to be detected and controlled and they can become surface fires with flame if they are not properly treated (Gabban et al., 2008).
Type of mixed fires is a combination of above fire categories. With the coexistence of crown and surface fire, a flame front is formed from the ground up to a height above the top of trees with destructive effects on the vegetation (http://www.ethelontismos.gr/attachments/070_%CE%94%CE%B1%CF%83%CE% B9%CE%BA%CE%AD%CF%82%20%CE%A0%CF%85%CF%81%CE%BA%CE% B1%CE%B3%CE%B9%CE%AD%CF%82.pdf).

Figure 10. Fire development, spread and decay (Gabban et al., 2008)

2.3 CAUSES AND IMPACTS OF FOREST FIRES

2.3.1 Causes
The causes of forest fires are either natural (lightning) or due to human who intentionally (malicious arson and pasture improvement), negligence (field burning, cigarettes, outdoor workers, hunters, trash etc.), from accidental events (engine sparks, explosives and artillery missiles) as well as unknown causes can cause forest fires (Tabakis and Karanikola, 2015).
Lightning distribution is not accidental. It follows specific standards and it is higher when there is humidity in the atmosphere. In addition, lightning density increases in proportion to altitude. The correlation of lightning with high moisture content or rainfall reduces the possibility of a lightning-induced fire. In the Mediterranean countries, in areas that are far from the sea, the combination of drought conditions in the summer season with incidents of increasing lightning activity, which may occur with the passage of a strong cold front, may contribute to the occurrence of a lightning-induced fire. (Balafa, 2013)

Any cause of fire can lead to disaster, as long as there are “appropriate” conditions. These conditions refer to one or more of the critical factors mentioned above. Unfavorable weather conditions combined with increased vegetation provide the potential for extreme fire behaviors. Ineffective fire detection and initial suppression attempt provide the opportunity for the fire to spread intensely enough to stifle all suppression efforts (Balafa, 2013).

For fires due to anthropogenic causes, there is a possibility of spreading and evolving into catastrophic fires, but the question that arises, as part of the improvement in fire prevention planning, is whether the possibilities are the same for all types of fires. According to available information, Mediterranean region is characterized by an intense prevalence of forest fires that are induced by human. Fig. 11 presents the cause of forest fire in five Mediterranean countries in 2010. The “unknown” represents 51% of the total (Algeria 88%, Bulgaria 14% and Turkey 12%) (FAO, 2013).
The Italian State Forest Service has established a new method to investigate the causes of forest fires, considering possible causes and observed facts. Once the cause is found, then the following procedure includes deep search and analyses of the reasons and motivations (in case of intention). Fig. 12 presents the main cause of forest fires (68%) in Italy in 2010 which was intentional (FAO, 2013).

Figure 11. Causes of forest fire in five countries in Mediterranean region (FAO, 2013).

Figure 12. Causes of forest fires in Italy, 2000-2010 (FAO, 2013).
The Italian method has lead to the development of new classification (Fig. 13) for causes of forest fires in European countries, managed by Cemagref (French Research Institute for Agricultural and Environmental Engineering) and EFFIS (European Forest Fire Information System).

Figure 13. New classification for causes of forest fires (FAO, 2013).
2.3.2 Impacts

Forest fires have impacts on vegetation, fauna, soil properties and air characteristics. Over 2.6 million hectares of forest land have been destroyed by fires in the Mediterranean region in the period 1989-1993. The most affected countries are Greece, Italy, Portugal and Spain. In the Mediterranean region, over 50,000 forest fires occur annually, destroying approximately 600,000 hectares of forest land. Over 127,940 hectares of coniferous forest land in Spain, 70,027 hectares in Italy, 109,967 hectares in Portugal were destroyed by forest fires in 1998. However, some tree species develop resistance mechanisms to forest fires, such as Pinus banksiana and Pinus contorta, which have their seeds protected in a cone-shaped some that releases them on the ash-carpet at the time of forest fire incident. Many species of plant vegetation and trees can resprout after the effects of forest fires under certain conditions (SCBD, 2001).

Moreover, forest fires can have impact on the composition, structure and shaping of animal habitats through direct mortality. Forest vegetation which is a natural shelter for wildlife, is easily altered having impact on life and reproduction of the animal kingdom. Deadwood on the ground is an important and basic habitat for birds and mammals including bears (Jhariya and Raj, 2014). Forest fires can cause displacement of birds and mammals, leading to local unbalance and ultimately to the loss of wildlife (Nasi et al., 2002). After the destructive forest fire of Parnitha in Greece in 2007, the most affected animals were those that did not have the ability to escape as Testudo marginata turtles. The effect was also great on animals such as Lepus europaeus and deer Cervus elaphus. Numerous reptiles such as Gusters, failed to escape the fire that destroyed a large area of forest carpet. However, in some cases,
some species of reptiles may have a positive effect from the fire and therefore increase their population (Aplada et al., 2007).

Fire forests have remarkable impact on physical and chemical properties of soil. The color and texture of soil are altered after severe soil burning. The soil changes its color to red after exposure at high temperatures (600 °C) for 45min due to transformation of iron oxides into hematite and magmatite and due to complete removal of organic matter (Zavala et al., 2014), while it is covered by an ash layer of gray or black color in case of small forest fires (Verma and Sayakumar, 2012). Thermal effect of forest fires causes increase of soil pH due to the denaturation of organic acids. However, this occurs only at temperatures above 500 °C with the release of basic compounds during full combustion (Certini, 2005).

The main effect of forest fire on soil is the reduction in water retention capacity due to reduction of porosity. High temperatures cause incineration of organic matter leading to vapors that move vertically and turn into water resistant soil particles (Verma and Sayakumar, 2012). The phenomenon is more intense in areas that have been burnt in moderate or high intensity while attenuating with depth (Mc Donald and Huffman, 2004).

Additionally, forest fires have an impact on the macronutrients of soil, causing their loss through volatility at high temperatures. At 500 °C, half of the nitrogen contained in the organic matter is possible to evaporate. Combustion can increase the nitrogen concentration of the residual matter and affect the state of nutrients in the soil by directly adding nutrients or indirectly by altering the soil environment (Verma and Sayakumar, 2012).
Forest fires affect abundance, species composition and invertebrate habitats change (Jhariya and Raj, 2014). The fire direct effects on soil-borne invertebrates are less intense than those of microorganisms and unlike plants, they can be removed from the fire. Invertebrate’s mobility increases with size but varies in cases of the same size (Verma and Sayakumar, 2012).

Forest fires have direct and indirect impact on water quality due to the introduction of harmful chemical formed by fires, through precipitation or sedimentation. Ash can cause direct pollution of the water surface, while pollution can spread indirectly over long distances through air (Foldi and Kuti, 2016). Forest fires cause increase in suspended sediment concentration and turbidity as result of erosion and land flow due to increased stream flow and accumulation (Neary et al., 2005). There have been reported observations of varying levels of chloride and sulphate ions released after the fire. According to observation by Ferreira et al (2005), after a fire in coniferous forest in Portugal, the amount of released sulphate ions was 278 times higher (18.1kg/ha per year) than the unburnt mass.

Turbidity and sediment deposition may have a direct impact on aquatic organisms (clogging) and their natural habitat, resulting in a decrease in their population, species variability and increased mortality. The impact of biodiversity varies considerably depending on the particle size of the sediment and the ability to disperse the affected species (Ryan, 2001). Increased concentrations of nutrients, especially nitrogen and phosphorus, contribute to eutrophication resulting in increased growth of aquatic plants and algae (Smith et al., 2011).

Incomplete combustion of forest fires releases a large amount of organic microparticles that cause air pollution into the atmosphere. Huge amounts of carbon
dioxide enter the atmosphere due to forest fires, resulting in the growing trend on greenhouse gas which is responsible for global warming. The result of forest fires is the low photosynthetic capacity of the forest and vegetation. Due to incomplete combustion, carbon monoxide enters the atmosphere causing health problems in living organism. Also, toxic derivatives of incomplete combustion are released into the atmosphere and they can be transported via atmospheric motion even at 50-100km (Foldi and Kuti, 2016).

2.4 OCCURRENCE OF FOREST FIRES IN MEDITERRANEAN
Available forest fire data for Mediterranean countries as Greece, Italy, Portugal, Spain and France are provided by EFFIS, while data for northern African countries are provided mostly by local authorities and partly by EFFIS. The analysis of spatial distribution of forest fires in Mediterranean region includes the classification of countries as western Mediterranean, eastern Mediterranean and southern Mediterranean and investigation data consisting in number of fires (NF), burnt forest area (BFA), fire size and total burnt area in the period 2000-2010 and particularly 2006-2010.

Over 85% of total fires occurred in five Mediterranean countries during 2006-2010 with the total number of fires reaching 269,000. Fig. 14 (left) shows that over 81% of total fires developed in western Mediterranean countries, while Fig. 14 (right) presents the number of fires during 2000-2010 in countries with complete data. According to referred data by Portugal, the country is characterized by the highest number of fires during 2006-2010 due to climatic and socioeconomic reasons (Fig. 15) (FAO, 2013).
Figure 14. Left: Distribution (%) of forest fires in Mediterranean region. Right: Total number of forest fires in Mediterranean countries with complete data, 2006-2010 (FAO, 2013).

Figure 15. Highest number of fires in Portugal in 2006-2010 (FAO, 2013).

Four Mediterranean countries represent about 80% of the “total burnt area” in 2006-2010. Over 2 million hectares of land were burnt in the Mediterranean region. Fig. 16 and 17 show that 78% of total burnt area was located in Greece, Spain, Portugal and Italy (FAO, 2013).
Figure 16. Burnt forest area in Mediterranean countries that provided complete data (FAO, 2013).

Figure 17. Burnt area (ha/yr) in Mediterranean countries (grey color indicates that these countries had not provided complete data) (FAO, 2013).

MODIS (Moderate Resolution Imaging Spectroradiometer) is a satellite imagery system that provides data for the estimation of land burnt (>40ha) by forest fires in
Mediterranean region. Forest fires that occur in southern European countries affecting more than 40ha account for 75% of the total burnt area (Fig. 18) (FAO, 2013).

Figure 18. Burnt area per year and per 1000ha by forest fires in Mediterranean countries, 2008-2010 (FAO, 2013).

Forest fires in the Mediterranean region have three peak activity rates; the highest occurring in the summer during June, July and August and sometimes extends until September. The second maximum activity value appears in spring, partly due to seasonal agricultural work. Finally, a third maximum activity value occurs in mountainous areas in winter. This is due to dry periods and the premature melting of snow in February and March associated with the phenomenon “Foehn”, resulting in the heating of dried air coming from a mountain and descanting (San-Miguel-Ayanz and Camia, 2009).
CHAPTER 3 IMPACT OF CLIMATE CHANGE ON FOREST FIRES IN MEDITERRANEAN COUNTRIES

3.1 CLIMATE CHANGE IN GLOBAL, EUROPEAN AND MEDITERRANEAN LEVEL

3.1.1 EVIDENCE AND PROJECTIONS OF GLOBAL CLIMATE CHANGE

Climate change, as defined by the Intergovernmental Panel on the Climate Change (IPCC), refers to a change in a state of the climate which can be determined using statistical controls, by the changes in the mean or the variability of its properties and it is maintained for a long time, usually for ten or more years. This definition refers to any change in climate over time, whether due to natural variability or as a possible result of human activity (IPCC, 2007a). In contrast, the United Nations Framework Convention on Climate Change defined climate change as:

‘the change of climate that is attributed directly or indirectly to human activity, that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods’ (UN, 1992).

Anthropogenic GHG emissions are largely responsible for climate change in the last decades. As Fig. 19 shows, GHG emissions reached 49Gt CO$_2$eq per year in 2010 with CO$_2$ (in total) representing 76Gt; 16% came from CH$_4$ and 6% from N$_2$O (IPCC, 2014).
A climate change scenario as defined by the Data Distribution Center (DDC) of IPCC is a coherent and plausible description of a possible global climate situation. A scenario is not a prediction but an alternative theory of how the future might evolve. Despite the disagreement about the final result and the timing of the change, most of the world scientific community agrees that the main cause of this change is human activity (IPCC, 2007a).

In the framework of the Third Report of the UNIPCC, a large number of scenarios (a total number of 40 scenarios) related to future evolution of GHG emissions, were developed by scientific groups. The formulation of these scenarios was based on a number of key axes related to the evolution of the global population, the policies to be followed on energy issues, economic development rates, future technological development, and whether economic decisions are taken about social and environmental issues in regional or global level. Based on the importance of
mentioned factors, the various emission scenarios were classified into six scenario groups, each of them including similar emission scenarios. These categories are:


Table 1 shows the characteristics of each scenario category:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A1 scenario</strong></td>
<td>Very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). Rapid increase of CO₂ emissions reaching 850ppm in 2100.</td>
</tr>
<tr>
<td><strong>A2 scenario</strong></td>
<td>A very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines. Intense increase of CO₂ reaching 720ppm in 2100.</td>
</tr>
<tr>
<td><strong>B1 scenario</strong></td>
<td>A convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives. Moderate increase of CO₂ emissions reaching 550ppm in 2100.</td>
</tr>
<tr>
<td><strong>B2 scenario</strong></td>
<td>A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels. Slow rate of CO₂ increase reaching 550ppm in 2100.</td>
</tr>
</tbody>
</table>

According to the recent IPCC Fifth Assessment Report (AR5), published in 2014, global warming of the climate system is a real fact and the proof is the warming of the
oceans and atmosphere, the snow and ice melting, as well as the sea level rise and the increase in concentrations of GHG. The statement ‘virtually certain’ was used for the warming of the upper 700m of the world’s oceans during 1971-2010. There was ‘likely’ warming of the depth of the oceans below 3000m during 1992-2005. Additionally, glaciers shrinking is of ‘high confidence’ in Greenland and Antarctic and the acceleration of ice loss in Greenland the past twenty years is of ‘very high confidence’ (IPCC, 2014). The IPCC AR5 Report stated that the global warming due to anthropogenic activities is ‘extremely likely’ in contrast with the previous IPCC AR4 Report that gave the characterization ‘very likely’ (IPCC, 2014, IPCC, 2007).

According to the IPCC AR5 Report, global warming will continue to persist in 21st century; it is projected that concentrations of CO$_{2eq}$ will reach 430ppm by 2030 and 1300ppm CO$_{2eq}$ by 2100. The increase of global mean surface temperature is projected to be 3.7-4.8 °C in 2100 compared to previous levels. In the IPCC AR5 Report, there was consideration of four scenarios of ‘representative concentration pathways’ (RCPs) for the study and assessment of global projections of climate change impacts. These RCPs present radiative forcing values of 2.6, 4.5, 6.0 and 8.5 W/m$^2$ corresponding to GHG concentrations of 450, 650,850 and 1379ppm CO$_{2eq}$ respectively by 2100. Figure 20 shows the projections of the four RCPs by the year 2100 (IPCC, 2014).
The driving factors that contribute to future climate change are the existing and future GHG due to human emissions and the climate variability. Figure 21 presents the temperature projections according to IPCC AR5 RCPs (IPCC, 2014): “The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs, and will likely be in the range 0.3°C to 0.7°C (medium confidence). This range assumes no major volcanic eruptions or changes in some natural sources (e.g., methane (CH4) and nitrous oxide (N2O)), or unexpected changes in total solar irradiance”. It is ‘virtually certain’ that hot temperature extremes and heatwaves will be more frequent and durable in the future while cold temperature extremes will be less frequent. Global surface temperature change (2081-2100) is projected to increase up to 1.5°C for RCP4.5, RCP6.0 and RCP8.5 scenarios, while the increase reaches 2°C for RCP2.6 (IPCC, 2014).
3.1.2 EVIDENCE OF CLIMATE CHANGE IN MEDITERRANEAN REGION

The Mediterranean region, characterized by warm and dry climate, is located in a transitional zone between the humid/cold temperate zone and the hot arid zone and due to this fact, it presents high vulnerability to environmental changes. Shifts of few degrees in temperature may cause dramatic changes in environment such as desertification in regions with wet climate (Regato et al., 2008).

According to the observations of the WWF study “Climate change impacts in the Mediterranean resulting from a 2 °C global temperature rise” by Giannakopoulos et al. (2005), significant trends of temperature and precipitation in the Mediterranean region with spatio-temporal variability is a fact:

- During the second half of 20th century, there was a significant increase in temperatures during the summer and winter in several Mediterranean areas and decrease in precipitation. However, due to high differentiation in areas...
and periods of occurrence, there is high uncertainty in the observed patterns (Giannakopoulos et al., 2005).

- The findings of the research by Giorgi (2002) show the temperature raise of 0.75 °C, particularly in winter and summer.

- Areas of the west Mediterranean region experienced a temperature increase of 3 °C/50yr during the summer period from 1920-1950 and from 1970 onwards. In contrast, areas of eastern basin experienced cooling (Brunet et al., 2002; Galan et al., 2001). Cooling of Mediterranean winter Sea Surface Temperatures was observed by Xoplaki et al. (2003), east of 20°E during 1950-1999, while the areas in the western part of basin experienced increased temperatures.

- Winter precipitation decrease of 20% was observed since 1970 and during the period 1900-2005 (Solomon et al., 2007; Giorgi, 2002). In some areas such as western Iberia and southern Turkey, rainfall increases were observed during autumn, while rainfall decreases occurred during winter and spring (Jacobeit, 2003).

- There is a decrease in frequency of raining days and an increase in intensity in some Mediterranean parts such as Italy and Spain.

- There is a higher tendency in increased rates of maximum temperatures than minimum temperatures.

There is “high confidence” that many environmental incidents in Mediterranean region as directly associated with anthropogenic climate change, as several findings from scientific researches present (Regato, 2008):
• There is evidence of rapid glaciers melting in Spain: 27 glaciers in Pyrenees were decreased to 10 by 2000 which corresponds to a decrease of 85% of total area (290 hectares instead of 1,779 hectares in 1894). Similarly, in Turkey the most recent glacier retreat occurred at the beginning of the 20th century (Regato, 2008).

• Extreme climatic incidents (heat waves, drought, and heavy storms) in Mediterranean region are strongly associated with climate change: There is an increase in intensity and frequency of heat waves in many Mediterranean areas (very hot days with strong winds and low humidity in the air) and falling of numbers of very cold days in the last 30 years (Regato, 2008). Drought events (low precipitation for long periods) in the western Mediterranean are related to the “blocking effect of the North Atlantic subtropical high pressure fronts”. There is an increase in drought frequency and intensity which can be higher with less precipitation incidence and higher temperatures. In 2005, a severe drought event occurred which influenced Mediterranean countries such as Portugal, Libya, Morocco, Spain, Syria and Italy. Drought incidents have impacts on ecosystems that release additional carbon in the atmosphere resulting in increased carbon fluxes. Large scale droughts can cause problems in recovery of ecosystems and increasing carbon emissions for a long period of time (Regato, 2008).

3.2 PROJECTIONS FOR CLIMATE CHANGE IN MEDITERRANEAN

In recent decades, Mediterranean areas have presented much more increased temperatures than other places in the world. According to projections based on climatic models, the temperatures will continue to rise with prominent drought, increase of number of heatwaves and reduced precipitation (Lionello et al., 2014).
Based on the climate change assessment report presented by European Environment Agency (EEA, 2012), the Mediterranean region is challenged to have:

- Temperature rise higher than European average
- Reduced annual precipitation and river flow
- Increasing risk of forest fire, desertification and biodiversity loss
- Increase in mortality from heatwaves

Climate change research projects are conducted in order to offer knowledge and projection through findings regarding climate change and its impacts on natural and human systems. The ENSEMBLES project provides scientists, businesses and public with the climate information obtained by multiple climate models to improve accuracy of prediction analyses (Van der Linden and Mitchell, 2009).

The ENSEMBLES project presents projections on changes in annual mean surface air temperature the period 2021-2050 (Fig. 22 right) and during the period 2071-2100 (Fig. 22 left) where the latter shows an increase trend. Fig 23 (left) shows the projected changes in precipitation (%) which are higher than those projected in Fig, 23 (right) for the period 2021-2050 (Van der Linden and Mitchell, 2009).
Figure 22. Projected climate changes in annual mean surface air temperature (A1B scenario and multi model ensemble mean of RCMs) for the period 2071-2100 (left) and 2021-2050 (right) relative to 1961-1990 (Van der Linden and Mitchell, 2009)

Figure 23. Projected changes in annual precipitation (%) under the A1B scenario, ensemble model RCMs for 2071-2100 (left) and 2021-2050 (right) (Van der Linden and Mitchell, 2009).

In the frame of the MedCLIVAR project (Lionello, 2012) which’s subject was climate conditions and climate change projections, Dubrovsky et al. (2014) presented the findings of 16 global circulation models for temperature and precipitation projections which showed that temperature increased in space and time all over the Mediterranean region (Fig. 24) and precipitation was found to decrease in all areas during summer (Fig.25). The findings by Dubrovsky et al. (2014) were as following:

“Temperature is projected to increase in all seasons and for all parts of the Mediterranean. The largest increase occurs in summer, and the smallest increase happens in winter and spring. Considering the spatial pattern, the largest increase is projected for the Balkan and Iberian peninsulas (above 6 C in their interiors in
summer) and the smallest (below 2.8 C in spring and winter) over the Mediterranean Sea”, and

“Precipitation is projected to increase north of this band (in the Mediterranean area, this applies only to its northernmost parts during winter) and decrease south of the band. In winter, the band of high uncertainty (STD/MED >2) affects major parts of the Mediterranean (minor areas of high uncertainty occur in summer in the eastern Mediterranean). During the other three seasons, the Mediterranean lies mostly south of this band and experiences moderate (spring and autumn) to high (summer) decreases in precipitation. The largest decrease (reaching a 45 % reduction) may be expected in summer across the southern Balkan region (and adjacent Aegean Sea area) and southwest Iberian Peninsula (and adjacent sea area between Spain and Morocco). In terms of the annual change, the Mediterranean area may expect to see a 5–30 % (from north to south) precipitation decrease, and an even higher decrease in its western most and easternmost parts”.

Figure 24. Changes in summer and winter temperatures based on SRES-A2 emission scenario during 2070-2099 (vs. 1961-1990) (Dubrovsky et al., 2014).
Figure 25. Changes in summer and winter precipitation sum based on SRES-A2 emission scenario during 2070-2099 (reference 1961-1990) (Dubrovsky et al., 2014).

The scientific report “Environmental, economic and social impacts of climate change in Greece” prepared for the Bank of Greece (2011), presents the results of the study of climatic projections on Greek areas:

- The mean annual air temperature during 2021-2050 and 2071-2100 compared to the reference period 1961-1990 will increase in all parts of Greece.

Fig. 26 shows the changes in the mean annual air temperature of the periods 2021-2050 and 2071-2100 compared to the reference period 1961-1990 based on the mild scenario A1B. All regions of Greece are expected to have about 1.5 °C higher average annual temperatures during 2021-2050 (Fig. 26 left). The rise in temperature will be relatively higher in summer and less in winter (EMEKA, 2011).
Based on the results of climate simulations, precipitation will be reduced during the year in the future across the Greek territory for the case of all three emission scenarios for which estimates of change have been made. The decrease of the precipitation is estimated to be particularly important in the case of A2 and A1B scenarios and milder in case of scenario B2.

Fig. 27 shows the percentage changes of the average annual precipitation during the periods 2021-2050 and 2071-2100 compared to the reference period for the A1B scenario. The height of precipitation in the territory during the period 2021-2050 will be reduced compared to the reference period. The percentage decline in the average annual precipitation during 2021-2050 is projected to be higher in Crete and Peloponnese, where it will reach 15%, while it will range between 5% and 10% in the remaining regions of Greece (Fig. 27 left). The reduction of the precipitation will be higher across the territory at the end of the 21th century. More specifically, for Greece as a whole, the average mean annual precipitation for the period 2071-2100 (A1B
scenario) is projected to fall by 16% in winter, by 26.5% in spring, by 37% in summer, by 12.5% in autumn and by 19% for the whole year. The percentage decrease in the average annual precipitation is expected to be higher in Crete and Peloponnese, where it will approach 25%, while in other areas will be around 20% and will be less than 15% in North Aegean (Fig. 27 right) (EMEKA, 2011).

![Percentage change of mean annual precipitation](image)

**Figure 27.** Percentage change of mean annual precipitation between 2021-2050 and 1961-1990 (left), 2071-2100 and 1961-1990 (right), based on A1B scenario (EMEKA, 2011).

In case of B2 scenario, the reduction of precipitation over the period 2071-2100, compared to the reference period, will be lower. In winter and spring, a 10% reduction is projected only for southern Greece. During autumn, the high of precipitation will drop only in Western Greece (approx. 8%), while precipitation is projected to increase up to 10% in the Greek islands. Finally, in summer, rainfall will decrease significantly across Greece. However, in absolute numbers, the precipitation decrease will be remarkable only in Northern Greece (EMEKA, 2011).
The impacts of climate change may be more severe due to change of extreme weather events than due to a long-term change of the “average” climate. All Greek regions are expected to have about 1.5 °C and 3.5 °C higher minimum temperatures in winter during 2021-2050 and 2071-2100 respectively. These results are in agreement with large-scale findings, according to which there has been a significant upward trend in the minimum temperatures over the past decades. This temperature rise will be higher in the most mountainous areas, mainly in the mountainous region of Pindos and Northern Greece. There, the increase will reach 2 °C during 2021-2050 and 4 °C in 2071-2100. In addition to the high temperatures, flash floods are a worrying phenomenon, especially in case of frequency change. On the eastern mainland, the total rainfall recorded over three days increased by 20% in 2021-2050. The situation seems to changes significantly by the end of the 21th century. In regions of Western Greece and Thrace, the amount of rapid rainfall decreases by 10-20%, while in Northwest Macedonia, this parameter increases by 30% (EMEKA, 2011).

3.3 IMPACT OF CLIMATE CHANGE ON FOREST FIRE REGIME

3.3.1 Impact on forest ecosystems

3.3.1.1 Impact on forests spatial spread and distribution
Forest fires, like any other natural process of an ecosystem, are strongly affected by climate change as the behavior of fire is directly related to the moisture content of the fuel, which in turn is determined by rainfall, relative humidity, air temperature and wind speed. Thus, the projected rise in average temperature due to climate change will increase the dryness of the fuel reducing relative humidity, and this will become more pronounced in areas where rainfall is decreasing. At the same time, the increase of the incidence of extreme weather conditions is expected to have a significant
impact on the forest vulnerability to fires (EMEKA, 2011; Mouillot, 2002; Kalfagianni, 2014).

The critical factor that affects the spatial spread in the Mediterranean zone is the amount and distribution of precipitation, while in the mountainous areas the low temperatures. The expected increase in average air temperature may lead to limited changes in the composition of forests at local level. The forests species most affected will be those that grow in boundary locations of their geographical range of spread in terms of soil moisture and temperature (Royce and Barbour, 2001). It is estimated that due to climate change by the year 2100, there will be a spatial redistribution of forests resulting in the decrease of harvesting. Drought-tolerant sheltered conifers are expected to extend northern and higher to the oak zone, oak forests at higher altitudes towards beech, fir and black pine forests zone, while beech, fir and black pine forests move to the sub-alpine zone, where there is a limited space of expansion and therefore they are expected to shrink (Diaz and Cabido, 1997).

After 15 years of crown condition monitoring in Italy, the observations revealed crown transparency levels between 15% and 30% for coniferous areas. Higher values in transparency occurred in years of extreme events, 2003 and 2007. Some species such as beech, oaks and hornbeam, recovered in satisfactory level, while other showed increased transparency. Chestnuts are grown in hills and show low capacity of adapting in increased temperature and extended drought because they were planted under non-favorable conditions (mateucci).

In a 30 years climate analysis in Spain (Valencia), it was shown that the reduced precipitation and their distribution variability consisted in favorable conditions for the development of forest fires and erosive rainfalls that could lead to alteration of
ecosystem composition. In a protected area in central Italy, there was a strong relation of reduced vegetation index (NVDI) to decreased precipitation in winter (mateucci; De Louis et al, 2001; Maselli, 2004).

The expected rise in temperature combined with the reduction of precipitation will increase the risk of desertification of the coastal areas mainly in southern and island Greece, which are currently covered by the coniferous and broadleaved formations. It is estimated that about 1% of 4000 to 2% or 8000 of the total forest cover of these forests has an increased likelihood of desertification (EMEKA, 2011C).

3.3.1.2 Impact on forests phenology and productivity
It has been documented that the increase in average annual temperature by 1 °C results in an increase in the growth period of 5 days in Europe. It was found during 1968-1998, that the start of the growth season for 4 widespread deciduous tree species in Europe (Betula pubescences, Prunus avium, Sorbus aucuparia, Ribes alpinum) occurred on average 8 days earlier and its annual duration increased by about 5 days (Chmielewski and Rotzer, 2001). Similar reports are also reported in northeastern Spain (Catalonia), where, due to the rise in temperature by 1.4 °C IN 1952-2000, the phenology of both plant and animal organisms were altered (Peñuelas et al., 2002; Peñuelas and Boada, 2002). On the contrary, in the wider area of the Dalmatian Alps on the Balkan peninsula (Serbia, Bosnia and Herzegovina, Kosovo, Albania Bulgaria, FYROM and a small part of northern Greece), there was a slight decrease in the average annual temperature during spring seasoning the second half of the 20th century, which resulted in a delay in the start of the growth period (Chmielewski and Rotzer, 2001).
Phenology variations in the start and duration of the growth period attributed to the temperature increase are similar for more species (Kramer et al., 2000). The expansion of the growth period in areas where there is sufficient soil and nutrients, as in northwestern Greece, will help to the increase of production. It is estimated that the start of the growth period will occur from 1-2 weeks earlier (scenario B2) to 2-3 weeks (scenario A2) and that the overall increase in the duration of the growth period will range from 10-15 days, which will make a positive distribution to the production of forests, as there is sufficient soil moisture in winter (EMEKA 2011C).

For European forests as a whole, it is estimated that C storage will be positive for the next 50 years due to the potential increase of growing stock which will be favored by the expected increase of CO₂ concentration and temperature (Karjalainen et al., 2003). Such spatial variations have already been recorded and are larger in the Mediterranean zone than in the forests of the northern European countries (Hoff et al., 2002).

In Greece, the predicted rise in average air temperature in winter months is expected to increase the rate of photosynthesis and thus the CO₂ capture by trees. Conversely, summer temperature rise combined with limiting of precipitation is expected to cause stress on plants by reducing significantly photosynthesis rate and CO₂ capture rate. With the increase in temperature and CO₂ concentration, there will obviously be a positive balance in areas where the amount of precipitation is about to increase (Aegean islands), and there will be negative for areas where precipitation is expected to fall (central and southern mainland) (EMEKA, 2011C).

Based on the BIOME3 model for Greece, it is estimated that carbon capture rate by forests will have fallen by 25% and 30% for the B2 and A2 scenarios respectively in 2050, and by 7% and 15% more by 2100. Decrease in carbon capture rate is expected
to cause varying forest productivity changes depending on the composition of vegetation, soil quality and applied management (EMEKA, 2011C).

Drought is a strong limiting factor for forest growth (Keenan et al., 2011; Silva et al., 2012). Species usually can easily adapt to climates with water stress, however, their growth is lower than in temperate climates (Palahi et al., 2008; mateucci). In Spain, in southern areas with low altitude, the growth of beech forests is very low in comparison with higher altitudes, due to the increase of water consumption and the decrease of air moisture which is attributed to warming (Peñuelas, 2008). Similarly in Italy, climatologically analyses showed that beech forests have been grown slowly due to the limiting factor of moisture since 1970, suggesting that extended drought has led to the decrease growth of beech forests in central Apennines which agrees to other trends in Mediterranean mountains (Piovesan et al., 2008).

3.4 CLIMATE CHANGE AND FOREST FIRE RISK
The characteristics of Mediterranean climate include the few rainfalls during winter, mild winters, and hot and dry summers. Summer is the period that favors the start and rapid development of forest fires, because of the very high temperatures, the low relative humidity levels and the almost non-existent rainfalls. All above, combined with strong summer winds, create the proper conditions for easy and rapid spread of fires (Keeley et al., 1999). The combination of higher temperatures and the reduced average rainfall in summer are expected to cause increase in drought, which will have direct impact on the increased burnt forest areas (Pausas, 2004). Several studies have reported that the increase in drought and temperature are directly related to the occurrence of forest fires and depend on the amount and frequency of precipitation and the presence of ignition conditions (Ryan, 2000; Dimitrakopoulos et al., 2011).
In a warmer climate, the number of forest fires will increase, especially in central and southern Europe (Giorgi, 2006). Burnt areas will be more and the periods of high risk will be long termed. According to climate change scenarios, an increase in the intensity in fires by 25% to 50% is expected due to the increase in the volume of biomass and a change in plant composition (EEA, 2008; Dale et al., 2001).

The Canadian Fire Risk Index (FWI) is a daily indicator based on meteorological parameters created in Canada and used globally to estimate the risk of forest fire in a general fuel type. FWI index consists of six standard components and each of them calculates a different matter of fire risk. The first three components are moisture codes of forest fuels, which simulate daily changes in moisture content in three categories of forest fuel with different drying rates. The other three components relate to fire behavior of the propagation rate, the weight of the consumed forest fuel and fire intensity. FWI is the numerical estimate of fire intensity and used to calculate the fire control difficulty. The system is only dependent on weather variables, which take place at noon: temperature, relative humidity, wind speed and rainfall (EMEKA, 2011). FWI values increase with the increase of the risk of forest fire. Fire risk is low for FWI<15 and increases for FWI>15.

Studies have analyzed the extent and intensity of the climate impact on forest fire regime. Piñol et al. (2008) in their study have analyzed a series of 50-year climatic data and correlated it with two indicators of fire hazard in provinces of southern Spain. The trend of change of the two indices was increasing for this period as a consequence of the increasing average daily temperature and decreasing average daily humidity. The researchers concluded that this correlation could indicate the effect of climate change on the fire regime in the study area. Pausas et al. (2004) analyzing
data from 350 meteorological stations on the east Iberian Peninsula corresponding to the period (1950-2000) as well as fire incidents data for the same area, concluded that there is clear relationship between the increasing number of fire incidents and the extend of burning, considering that this increase is also due to the observed climate change (Pausas, 2004).

Figure 28 shows the changes in the number of days with an extremely high fire risk, a parameter that is equally important for forest, agricultural and tourist areas in Greece. Extremely increased fire risk increases by 20 days in 2021-2050 and by 40 days in 2071-2100 across Eastern Greece from Thrace to Peloponnese. Lower increases are expected in Western Greece, mainly due to the wetter climate in the region (EMEKA, 2011).

Giannakopoulos et al. (2009) support that based on a climate change scenario of temperature increase up to 2 °C, the risk in forest fire is increasing significantly. According to the study, the most vulnerable Mediterranean areas are central Spain, Turkey, Maghreb, and Balkan where the temperature is getting higher in August. The
southern France is strongly influenced in August and September, while there is not remarkable change in temperature in northeastern Mediterranean. The increase in forest fire risk is corresponding to one month or more of fire risk and this may lead to increased risk of extreme forest fires.

Giannakopoulos et al. (2009) used the FWI to assess the risk of forest fires in Mediterranean region. Giannakopoulos et al. (2009) set a limit of FWI>30 as a measure for elevated fire risk and calculated monthly variations of FWI from May to October and concluded that: “The increase is higher during the summer, with the maximum increase in August in the North Mediterranean inland”, “Balkans, Maghreb, North Adriatic, central Spain, and Turkey seem to be the most vulnerable regions”, the “South of France is as strongly affected as Spain, but only in August and September” and the “southeast Mediterranean (from Lebanon to Libya).

Two to almost six more weeks of fire risk is expected for all areas except southern Italy, northern Tunisia and Libya where one additional week is expected (Fig. 28). Southern France shows a rise in number of days of increased fire risk but not extreme fire risk. Central Iberian peninsula, parts of north Africa and Balkans are expected to have more than 6-7 weeks of increased fire risk and more specifically extreme fire risk with FWI>30 (Fig. 28 bottom). Maximum risk of forest fires is occurred in August and July, in central Balkan area, north Italy, Spain and Turkey. Some areas such as Morocco, Algeria and southeastern Turkey present increased fire risk in May and October (Giannakopoulos et al., 2009).
Figure 29. Changes in the number of weeks with fire risk (FWI>15 (top) and extreme fire risk (FWI>30) (bottom) (Giannakopoulos et al., 2009).

According to Trigo (2012), strong and massive heatwave incidents occurred in the last decade in Mediterranean areas leading to the outbreak of intense forest fires: in Greece and Italy (2007), in Portugal (2003, 2005), and in Spain (2006). Portugal has faced a large heatwave followed by increased maximum and minimum temperatures in August and low humidity which caused disastrous forest fires that burned 450,000ha of land (Trigo, 2012).

In Israel, the delay of winter rainfall will cause the increase of forest fire risk due to low moisture in vegetation in autumn. There will be an increase of intensity, extent and frequency of forest fires due to low moisture levels in soil, increased evaporation and the rise in number of heatwaves. The occurrence of forest fires may result in
problematic forest resilience and disappearance of Mediterranean ecosystems (Pe’er and Safriel, 2000).

Moriondo et al. (2006) used the 2 RCM future climate scenarios (HadRM3P-A2 and HadRM3P-B2) to assess the increase in fire risk in the Mediterranean region and found that there was a high impact on mountainous areas in Italy, Spain and generally in Balkan region. Different features of fire regimes such as the increase in number of seasons with high risk, the increase in number of fire incidents with high FWI, increase in the length of seasons with fire risk, total number of days with FWI>45 and percentage change in the number of events with FWI>45 for 7 consecutive days (Fig. 30). As Moriondo et al. (2006) support, the results are consistent with those reported by other studies claiming that rise in maximum temperature and decrease in rainfall and relative humidity can trigger forest fires easily during summer period, resulting in higher forest fire risk.

Figure 30. Percentage changes in the number of incidents of FWI>45 for at least 7 days for A2 (A) and B2 (B) scenarios (Moriondo et al., 2006).
Kalabokidis et al. (2015), in their study, analyzed FWI values for present and future time periods. The results showed that a reduction of number of days with low FWI and an increase in more frequent days with high or extreme FWI values are expected. A positive correlation between forest fire ignitions and FWI values and the increasing anthropogenic influence on fire ignition frequencies show that there will be an increase in the number of forest fires in the future. The number of days with high fire risk increases by one month for the period 2071-2100, resulting in significantly extended fire seasons for the region of Messinia. Moreover, large forest fires with increased intensity and size are about to occur in the Messinia area till the end of the 21th century leading to increasing conditional burn probabilities. Fig. 30 shows that drier conditions and higher temperatures in the eastern area of Messinia result in increased days with extreme fire risk. As Kalabokidis et al. (2015) claim, “extreme fire risk ranges between 13 days/year at the northwest part of Messinia and 70 days/year at the southeast part of Messinia” (Figure 31A). “The decrease in total precipitation in combination with an increase in mean summer temperature lead to an increase in the number of days with extreme fire risk in the entire domain for the future” (Figure 31B).
CONCLUSIONS

The climate of southern Europe and the Mediterranean region in general is projected to become warmer than the global average and precipitation will decrease, especially in the summer. Mediterranean countries are vulnerable to climate change and particularly in rise of temperature and the increased forest fire risk. Forest fires are a significant problem in most Mediterranean countries with a rather increasing tendency the last years. The increase in temperature and prolonged droughts has led to an increase in number of forest fires and the burnt area. Future fire risk projections, due to climate change, show a growing trend of risk.
In a warmer climate, the number of forest fires will increase, especially in central and southern Europe. Number of burnt areas will increase and the periods of high risk will be prolonged. According to climate change scenarios, an increase in the intensity in fires by 25% to 50% is expected due to the increase in the volume of biomass and a change in plant composition.

Studies based on the Fire Weather Index show that the increase of serious fire risk is higher during summer, with the maximum increase in August in the North Mediterranean inland. The Balkans, Maghreb, North Adriatic, central Spain and Turkey seem to be the most vulnerable regions. The South of France is as strongly affected as Spain, but only in August and September, while the southeast Mediterranean (from Lebanon to Libya) sees no particular increase or decrease. Extremely increased fire risk increases by 20 days in 2021-2050 and by 40 days in 2071-2100 across Eastern Greece from Thrace to Peloponnese. Lower increases are expected in Western Greece, mainly due to the wetter climate in the region.
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