

## Article

# The Other Side of Fire in a Changing Environment: Evidence from a Mediterranean Country

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**Abstract:** In forested ecosystems all over the world, usually, fire is the main disturbance, and due to global climate change, its effects are worsening in many areas. Although fire impacts have been studied for many years, integrative analyses of their effects on various ecosystem services (ES) at different scales are uncommon. This study tries to assess the ecological role of fire in a changing environment, focusing on a Mediterranean country. Data were collected by the use of an online questionnaire in Greece, where the summer fires in the last decades have had significant impacts on the environment and the economy and, in many cases, there were many human and animal victims from them. The sample size of the survey was 384 workers in the primary production sector from all over the country. The study showed that fire has several effects on animal husbandry, the quality of soil nutrients and fertility, the overall vegetation cover, and on general biodiversity. It seems that the degree to which fire has an effect on ecosystem components depends on the intensity, frequency, and length of the fires. Additionally, the frequency, intensity, and length of fire affect the impacts of fire on herbaceous plant, woody vegetation, soil physical qualities, and on the different animals' habitats.

**Keywords:** fire; ecosystems; sustainability of ecological systems; biodiversity; atmosphere; climate change



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## 1. Introduction

A significant portion of the terrestrial ecosystems in the globe are affected by fire, a major ecological disturbance that affects a variety of geographic areas and biomes. Fire may significantly disrupt critical ecological processes, burn enormous quantities of biomass, change the characteristics of the soil, and affect the hydrological and biochemical cycles. From a biogeographical standpoint, fire has also been crucial to the development of plants, for example by encouraging certain useful features such as re-sprouting [1]. As a result, it is also commonly recognized that fire has an impact on worldwide patterns of biodiversity and plant distribution. The precise consequences of a particular fire rely on both ecosystem traits (such as whether an ecosystem is fire adapted or fire sensitive) and fire characteristics (such as severity, magnitude, or frequency). Impacts from a single fire may vary both geographically and across many ecosystem elements (soil, vegetation, etc.). Notably, the forces driving global change are changing the present fire regimes [2–4].

Purnomo et al. [5] noted that ecosystem services relate to different conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. Fire is commonly recognized as a major factor impacting many ecosystem services due to its considerable environmental consequences [6–8]. As a matter of fact, wildfires are often cited as one of the primary disturbances that negatively impact

ES in a range of terrestrial ecosystems, including forests and woodlands [9,10]. According to Hardesty et al. [11], fire-based effects may have an influence on soil erosion, runoff, water quality, and soil fertility. Due to the important functions that natural disturbances play in ecological processes, fire may also improve various ecological systems, such as food availability or biological management of disturbances [12,13]. A fuller knowledge of fire impacts on ES is necessary to ensure successful and desired fire and land management outcomes, including the consequences of both wildfires and planned burns [14,15].

In recent years, the study of ecosystem services has changed the way the concept of nature protection is viewed in general, changing not only the rationale for managing ecosystems (e.g., forests, lakes, etc.), but additionally the broader regulations on eco-systems in nature [16,17]. While environmental protection was previously regarded as a factor contributing to human well-being, conservation of natural ecosystems is now regarded as one of among the most significant variables [16–20], as is the repair of disturbed natural ecological systems [21].

Human habitation and activities produce complex socio-ecological factors that interact with one another and influence ecosystem services. Because of regional comparative advantages and drawbacks, this interaction varies between civilizations [17]. In order to achieve long-term sustainable land management, regional policy must combine economic and environmental components that represent the local conditions [17,22–24].

The effects of fire have been investigated in some particular ecosystem types and how they function, but the effects of fire on ecological systems (ES) have not yet been investigated at the global scale [9,25–27]. Integrative studies that cover a broad temporal scale quantify the effects of fire on a variety of ES, with a broad geographical scope (including the most important ecoregions and ecosystem types worldwide), and that account for specific characteristics of these events, are still needed, even though such work is crucial to gaining a fundamental understanding of the environmental effects of this global phenomenon and strengthening our capacity [25,28,29]. In this framework, we tried to explore the ecological impacts of fire disturbances on ES in the forested ecosystems of a Mediterranean country. As a result, we were able to pinpoint important areas for future study as well as the key patterns and knowledge gaps from past studies on the fire–ES interaction. We expected that the effect of fire varies among various ES and that impacts are in part influenced by the kind of disturbance (for example, higher impacts after wildfires than following managed burns) or by the temporal framework following disturbance (stronger effects in the near term). It was therefore very important to conduct this study in order to fill the different gaps relating to how fire has influenced the growth or development of different ecological systems in this area.

### *1.1. Objectives of the Study*

The major purpose of this study was to assess the ecological role of fire in a changing environment by using evidence from a Mediterranean country. The study was equally based on specific objectives:

1. To the exploration of the negative effect between fire and atmosphere and therefore climate change.
2. To the examination of the negative effect of fire on animal husbandry.
3. To the determination of the negative effect of fire on soil nutrients and fertility.

### *1.2. Research Hypothesis*

**Hypothesis 1. (H1).** *Fire has a significant relationship with the atmosphere and on climate change.*

**Hypothesis 2. (H2).** *Fire has a significant relationship to general animal husbandry.*

**Hypothesis 3. (H3).** *There is a significant relationship between fire and the quality of soil nutrients and soil fertility.*

### 1.3. Significance of the Study

The study will help in generating knowledge in regard to the relationship between fire and conservation and the sustainability of different ecosystems, especially in the Mediterranean, or practically confirm the opinions and knowledge that prevail in Europe. Therefore, the study findings can form a basis for references for future researchers conducting a study in the related fields of fire and ecosystems.

## 2. Literature Review

### 2.1. Overview and Features of Fire

According to Noss et al. [30], fire severity refers to the physical impacts of a particular kind of fire on ecosystems, business, infrastructure, and other types of establishments. Fire affects ecosystem components that include the soil surface and those within the soil and even below it. However, the impacts are often seen above the soil surface. In contrast to wooded and bush-infested ecosystems, grassland ecosystems often have shorter fire durations because there is less fuel and biomass to burn, which causes the fire to extinguish more rapidly. Because there are so many compressed fuels present in bushland and forest areas, fires smolder for a longer period of time there [31–33].

Fire severity was categorized into three categories by IUFRO [14]: mild burn, moderate burn, and deep burn. Although it can happen in forests and woodlands as well, light burn is typically recognized in grasslands. The plant's above-ground bulk has been mildly scorched, but it is still recognizably there. Not burned are plant bases. Soil made of minerals is unaffected. Short-lived flames often produce a faint burn [9,13]. Even though moderate burn is typically associated with forests, it can also occur in woodlands and grasslands (Figure 1). Herbaceous vegetation is burnt when it happens in grasslands, and the plant roots are damaged and unrecognizable. In woods, fire damage penetrates the mineral soil three centimeters below the surface [34–36]. Forests tend to have deep burns, whereas grasslands often do not because grasses need extremely high fuel loads to survive. When it does happen in grasslands, the flora is entirely scorched and is covered in white ash. Fire penetrates the earth deeply, burning even the roots. There is a little alteration in the soil's structure [29,37].

Pheko (2021) divided fire into six classes based on its intensity as measured in energy (kilo joules; KJ) per unit time (seconds; s) per unit length (meters; m). The six categories are as follows: very hot fire is more than 3000 KJ/s/m, very coolfire is less than 500 KJ/s/m, cool fire is between 501 KJ/s/m and 1000 KJ/s/m, moderately hot fire is between 1001 KJ/s/m and 2000 KJ/s/m, and hot fire is between 2001 KJ/s/m and 2000 KJ/s/m [38].

According to Ganteaume et al. [9], the frequency of burns has an impact on the vegetation depending on how many times the treatment has been performed as well as the management intervention used in the interim. IUFRO [14] point out that the treatments used in the time between burns may alter the outcomes anticipated after the rest period, confusing the study of the outcomes. Gill [39] found that yearly burning enhanced the quantity of grasses but reduced the number of forbs when grazing was abolished in the Eastern Cape of South Africa. In contrast, burning every four years caused a considerable rise in forbs and a fall in grasses. The presence of grasses decreased after a five-year period of rest, whereas the presence of forbs increased [14,40,41]. Therefore, once every four years of burning could be mistaken for the effects of rest; the decline in grass could be caused by lack of defoliation rather than by burning every four years [5,42,43]. Burning in tree and shrub plantations originally had highly negative effects on trees and shrubs. Later burns that totally eliminated the plant debris had less of an adverse effect on the trees and bushes [25,44,45].



**Figure 1.** Intensive fires affecting the middle height forest ecosystem.

## 2.2. Fire Is a Global Conservation Issue

Natural processes such as fire have greatly shaped our ecosystem and preserved biodiversity all around the planet. A large portion of the world's terrestrial environments rely on fire for ecological survival, and it has several positive effects. Habitat distribution, carbon and nitrogen flows, and the ability of soils to retain water are all often influenced by fire [12,31,46]. Fire exclusion often leads to decreased biodiversity and increased plant density in environments used to fire and reliant on it for overall ecological health, increasing the chances of catastrophic fire over time [29,47].

Additionally, fire has been and continues to be a crucial tool for shaping the landscape and creating cultural landscapes that have an influence on ecological systems [15]. However, human introduction of fire can change habitats that are not used to it, such as a large portion of the world's wet tropical forests, in ways that result in social, economic, extinction of species, and environmental losses [48–50]. When humans start too many, too few, or the wrong kinds of fires, they put our environment in danger by releasing too many greenhouse gases into the atmosphere, opening up pathways for invasive species, changing

the hydrology of the landscape, deteriorating local and the overall regional air quality, and posing a direct and frequently increased risk to human habitation [5,51,52].

Fire must be considered in biodiversity conservation because of the many advantages and threats it poses to the environment, society, and the economy. According to a recent worldwide assessment, eight out of the 13 primary terrestrial habitat categories fail to reach the target of 10% needed for successful conservation [13,53]. Effective biodiversity protection necessitates, among other things, that fire be allowed to perform its biological function, while not presenting a harm to biodiversity or human well-being [11,54]. This is in addition to preserving ecosystems in protected places such as National Parks and other natural regions [9,55]. This implies that land preservation or management strategies must provide for proper fire management, whether it be controlled burning for the sake of biodiversity, ecosystem conservation, or fire prevention to save ecosystems that are vulnerable to fire [13,56]. Since fire seldom occurs by itself, it is a challenging conservation issue. It interacts with a variety of other worldwide threats to biodiversity including overgrazing, fire exclusion, invasive species, climate change, urban and exurban development, land use change, energy development, logging, water developments, and transportation infrastructure. By creating too much, too little, or the incorrect sort of fire compared to ecological baselines, these same dangers affect the ecological function of fire globally [57]. Ignoring fire as a worldwide conservation problem may have undesirable and far-reaching implications, regardless of whether fire is seen as a danger to biodiversity and human livelihoods or a fundamental natural activity [4,12,58].

### 2.3. Fire in Ecosystems and Society

In addition to explaining what a fire regime is and how it may be changed in each of these three distinct ecosystem types, this part presents the ideas of fire-dependent, fire-sensitive, and fire-independent ecosystems [4,59]. To successfully preserve biodiversity, it is necessary to understand the effects of changing fire regimes on ecosystems and people. Ecosystems that are responsive to fire are ones in which the majority of the species have not significantly changed due to fire [43,60]. While the introduction of ecologically inappropriate fire can have a significant detrimental effect on biodiversity, it might only have an insignificant effect on preserving natural ecosystem structure and function in systems that are vulnerable to fire. In fire-sensitive forests, excessive fire may quickly destroy the most complete forest ecosystems and trigger a negative feedback loop that renders these forests more susceptible to fire in the future [29,37,61].

Opige et al. [26] noted that any ecosystem's species composition, structural makeup, and fire characteristics can all be affected by altered fire regimes. We must comprehend not just how fire operates naturally in ecosystems, but also how humans utilize or modify native fire regimes for ecological and social gain if we are to successfully preserve biodiversity [27,34,35]. Whether an ecosystem is fire dependent, fire sensitive, or fire independent, certain human land uses may affect how well fire behaves [25]. For instance, suppression of all fire occurrences, both naturally occurring and provoked by humans, is often a component of rural development in ecosystems that rely on fires to safeguard human populations [35]. Rural development may have various effects on ecosystems that are vulnerable to fire. Human-caused fires must be prevented or put out for the purpose of biodiversity preservation after housing and infrastructure development. Conservation groups and their partners must comprehend environmental and human links to fire in order to develop successful solutions [30,62].

### 2.4. Fire and Climate Change

Experts on fire have identified climate change as a possible factor in 12 of the 14 main habitat categories and 4% of all ecoregions globally that are threatened by fire-related hazards to biodiversity [62]. The relative relevance of climate change in relation to other elements, however, was shown to vary greatly at regional expert workshops; it is possible that the real significance of climate change in altering fire regimes may be larger than the expert

rating [37,42,43,63]. Climate change is already increasing the frequency and magnitude of wildfires by altering the key fire-controlling factors such as temperature, precipitation, humidity, wind, ignition, biomass, dead organic matter, plant species composition and structure, and soil moisture [9,12,15]. The health of the ecosystem and the availability of ecosystem services are under jeopardy due to these changes [4,12,64].

Warmer temperatures, less precipitation on land, an increase in convective activity, an increase in standing biomass due to CO<sub>2</sub> fertilization, an increase in fuels from dying vegetation, and large-scale vegetation shifts are the most significant mechanisms by which global warming increases fire at the global scale [57]. In the mid-altitude, federally managed conifer forests of the western United States, fire frequency increased by 400% and burned area increased by 650% between 1970 and 2003. This was due to an increase in the summer and spring temperatures of 1 °C since 1970, earlier snowmelt, and longer summers [11,25]. However, given the low levels of human activity or fire suppression in those forests, it is possible that climate change may have different effects there than it would elsewhere. In all biogeographic domains, according to analyses of potential future conditions, fire frequencies will increase due to climate change, although this may not be the case everywhere [29]. Through significant emissions of greenhouse gases, wildfires may have a positive feedback effect on global warming [25,54]. The precise projection of local implications of climate change on fire regimes remains challenging due to the difficulty in differentiating it from other variables that affect fire regimes [65].

While significant amounts of carbon are released during combustion, greenhouse gas fluxes also play a significant role in carbon budgets [25]. Regardless of the changes made to the soil's structure, how long it takes plants to recover might have an impact on how quickly lost carbon is recovered [13]. In addition, [57] noted that fires only marginally boost methane absorption while having little impact on methane loss. However, depending on how quickly the transition from moist to dry soils occurs, permafrost melting brought on by heat may turn upland soils into transient methane sources. After a fire, the level of nitrous oxide in the soil very slightly decreases [4,29].

### 2.5. Fire Effects on Vegetation

According to Dimopoulos et al. [33], fire has the ability to affect changes in herbaceous vegetation, but whether it suppresses or promotes a particular plant species depends largely on the time of the fire in relation to the phenology of the particular species. Phenology is the study of the timing of life events in plants. Numerous studies demonstrate that the growth stage plays a significant role in predicting plant-fire damage [35,50]. Fire may have different impacts on dormant and developing plants, according to [12]. As an example, if the region is set on fire, plant species that are actively developing may be more negatively impacted than plant species that are dormant because of their sensitivity to harm and death. Estrella and Saalismaa [37] note that each plant's level of fire damage depends on its physiological state and the temperatures reached in its living tissue. According to Lang and Moeini-Meybodi [60], the plant's size, growth form, and stage of development all affect how vulnerable living tissue is to heat injury. According to Dowdy et al. [1], meristematic tissue seems to be damaged at temperatures over 60 °C, yet many seeds have a significantly greater heat tolerance and can endure temperatures of above 100 °C.

Harvey and Enright [59] revealed that plant damage from fire is also determined by the intensity of the fire, which is affected by the rangeland's topography, the general quantity, as well as the distribution and dryness of the fuel, the weather, and soil moisture. According to Turbé et al. [29], the needed intensity of the fire is less than 1000 KJ/s/m if the goal of burning the rangeland is to remove moribund material. The kind of biome, previous exposure to fire, season of the year, quantity of vegetation, velocity and direction of wind, and air temperature are only a few of the biotic and abiotic elements that determine how vegetation reacts to fire [9,35]. A healthy rangeland ecology requires periodic, mild defoliation of the plants. Withholding fire from rangelands can have negative effects on vegetation production in the same way that burning rangelands can be harmful to

ecosystem processes. This is because too much litter buildup due to a lack of light can stunt the growth of new vegetation shoots and reduce vegetation yield [14]. It should be noted that some plants are typically improved by fire because it starts the natural selection process, which allows plants to modify their genetic makeup to adapt to environmental changes [9,25].

Mooney and Zavaleta [55] found that the ability of vegetation to recover from exposure to high intensity fires depends on favorable temperatures, the capacity to resprout, and the involvement of mycorrhizae. According to IUFRO [14], frequent fires also cause changes in plant composition. Plant species that have developed systems to withstand fire thrive and take control of the environment. According to Coughlan and Petty [53], the way that plants develop has an impact on how fire affects them. Some annual grasses and forbs that bear seeds immediately following the winter season disperse them in the late spring. The ecosystem's functioning suffers if a fire destroys the plants before they spread seeds (WWF, 2020). Burning sometimes is used to manage annual plants, however Norgaard [13] claims that biennial species need a different strategy than annual plants do. To manage biennial species, multiple-year fires should be used; otherwise, different control strategies will need to be used [36,66].

According to Estrella and Saalismaa [37], a plant species' sensitivity to fire may depend on where its perennation organs are located on the plant. More fire damage may be sustained by plant species with these organs on the exposed plant body than by species with perennation organs in the soil. Plants' perennation organs that are exposed to fire die at the high temperatures caused by intense fires. Prescribed burning may help the sedges and grasses in wetland areas look better. In contrast, all hydrophytes would be harmed by a slow-moving fire that may burn into marsh peat [11,40]. According to Huntley [15], mosses typically reproduce by spores, but upon fire, they acquire vegetative regeneration. According to Mapiye et al. [35], although lichens are often killed by fire, certain moss species regrow easily after a fire. After a fire occurrence in an area, lichens eventually re-establish.

## 2.6. Fire and Soil Nutrients and Fertility

After burning rangeland, plant waste or ashes on the ground include potassium, calcium, magnesium, and phosphorus [29]. The amount of nutrients lost via burning rangelands is small unless and until such nutrients are released through water and wind when they are attached to other organic molecules [50,67,68]. Nitrogen and sulfur are lost by volatilization after the fire has reached a temperature that may create white ash. Black ash denotes low-intensity burning, which results in less systemic mineral loss. According to Hardesty et al. [11], phosphorus levels in the soil increase while fire temperatures stay below 200 °C. When minerals are released quickly and pH is raised slowly or very little, this has a significant impact on soil nutrients. According to Turbé et al. [29], while nitrogen is lost from the environment via smoke, publications do not often include nitrogen loss from burning in grassland ecosystems. The cause may be related to the pioneer plants' quick restoration of that lost nitrogen via nitrogen fixation, which is often accomplished by annual legumes.

According to Harvey and Enright [59], burning organic matter results in the production of carbonates and oxidants, which results in an alkaline reaction. Due to the high levels of acidity in the soil, thick humus layers hold enormous quantities of nutrients yet are unreachable [9]. Fire speeds up the humus' sluggish breakdown, making the nutrients more readily accessible for ingestion [69]. By demonstrating how changes in the physical characteristics of the soil caused by warming and cooling have an impact on the minerals in the soil, Norgaard [13] confirmed that heat may cause the volatilization of certain nutrients or elements. However, leguminous plants, which naturally predominate at sites almost immediately after fire, quickly replace this nitrogen through fixation [12,36].

Although fire may not raise soil temperatures, it undoubtedly affects both above- and below-ground organic materials [70]. According to Hood et al. [43], fire typically increases soil organic matter by killing plants, which reduces the amount of organic matter that is

available for decomposition. The removal of plant cover decreases the quantity of organic matter and the activity of microorganisms in the soil because the components that build up and degrade organic matter are removed from the system [71]. This has an impact on the soil's stability and infiltration properties as well [14,26]. According to Turbé et al. [29], when high-intensity flames consume the whole top soil, they may result in a drop in the amount of organic matter present in organic soil. Conversely, areas of the soil profile that certain organic components have transformed to black carbon are burned by weaker flames [27]. The sources of the increase in organic matter include high soil temperatures that encourage development, a brief overabundance of annual pioneering plants, and the reduction of roots from fire-killed plants [5,35].

Hirschberger [72] noted that the impacts of fire may affect plant metabolism and development in addition to the physical characteristics of the soil. If the soil structure is modified and moisture retention and porosity are decreased, the plant's ability to absorb nutrients and water may be affected. Legakis et al. [12] noted that major fires result in damage to the soil structure, the removal of organic matter, and changes to soil porosity. Nutrients from the soil are lost in large quantities. Severe fires have a detrimental impact on the majority of elements that contribute to the stability and structure of soil. The local terrain, vegetation, and prevailing meteorological conditions will all affect how well the land recovers from the fire [9,25,73].

### 2.7. Fire Effects on Animal Husbandry

Fire has minimal effect on highly mobile animals since they can escape the burning or burned area, but it may be lethal to less mobile and flightless animals and organisms since they find it difficult to escape the damaged area [9,40]. According to Ganteaume et al. [9], a fire may cause an area's insect population to increase or decrease. Despite the fact that many people are killed by flames, others manage to escape and return thereafter. In various stages of succession after a fire, specific plants that are abundant provide food for returning species. In connection to the quantity of cover, which is impacted by fire, other insect species are numerous [5,29].

According to Estrella and Saalismaa [37], ground-nesting birds are susceptible to the loss of their nests, habitat, and food. Bird populations react to burning because it often impacts both food and cover. For instance, in the Southeast United States, controlled burning with hot flames increases herbaceous legumes and quail, but no burning or mild burning reduces legumes and bobwhite quail [73,74]. According to Purnomo et al. [5], animals may be impacted both favorably and unfavorably by changes in plant composition brought on by fire. Some animals make use of areas that have been cleared of vegetation and settle there to lower their risk of being attacked by predators as visibility is increased [13,43,75]. On the other hand, some animals would rather hide from predators under shrubs and thick grasses. However, Turbé et al. [29] found that larger animals are relatively unaffected by grassland fires, and the majority of these creatures manage to flee from forest fires. By burning the tops of shrubs that have grown too tall for deer to access, sprouts and seedlings will thrive. When there is a fire, large animal species flee, but as soon as it is put out, they return to the fresh food. Animals react to an altered environment more so than they do to the fire itself [76].

According to McLauchlan et al.'s [6] research on burnt lands, several species of beetles' population did not decrease right away after a fire, which may indicate that they survived. However, the population started to decline a few months later. According to Legakis et al. [12], the depletion of food supplies brought on by fire was the reason of the population decline. There were no dead termites in the higher layer of the soil that had some warmth, thus McLauchlan et al. [6] reasoned that they must have fled to the lower layers of the soil since termites are highly mobile. According to Mooney and Zavaleta [55], the biggest impact that a fire may have on an ecosystem is the death and extinction of uncommon species, since this might lead the ecosystem to become permanently unstable and lose its usefulness.

### 3. Materials and Methods

#### 3.1. Research Design

The study used a quantitative research methodology based on the cross-sectional survey design. The cross-sectional survey design is basically an extensive inquiry in which quantitative data are collected and consequently evaluated to characterize a particular phenomenon in terms of current trends, current occurrences, and current connections between various variables. The cross-sectional survey design enabled the researcher to effectively generalize the different findings of this study to a larger population of the world in regard to the ecological role of fire.

#### 3.2. Target Population

The study targeted over 1,000,000 people across Greece as this target population would help in obtaining an optimal sample for this study. Emphasis was put on the Greek population living near forest areas or cultivated lands since these are where most effects of fires are usually felt. The survey focused mainly on workers in the primary production sector (820,000 owners and family members in agricultural holdings) and less on seasonal workers (120,000 out of a total of 850,000 in Greece) [77].

#### 3.3. Sample Size and Sampling Technique

Using the table from Krejcie and Morgan [78–80], the optimal sample size from the population will be calculated. Krejcie and Morgan developed a table for calculating sample size for a certain population. Based on the target population of 1,000,000 participants, a corresponding sample size of 384 participants as per Krejcie and Morgan [78] was used for this study.

Equation (1) shows the equation of Krejcie and Morgan.

$$n = \frac{\chi^2 NP(1 - P)}{d^2(N - 1) + \chi^2 P(1 - P)} \quad (1)$$

where:

$n$  = Sample size.

$N$  = Population size (1,000,000).

$\chi^2$  = Chi square for specified confidence level at 1 degree of freedom (3.841).

$d$  = Desired Margin of Error (expressed as a portion = 0.05).

$P$  = Population portion (0.05 in the table of Krejcie and Morgan).

Another approach for identifying the sample exists, which yields a smaller sample; however, this method was not employed in this study since the offer from the respondents was significant [64,75].

#### 3.4. Data Collection

A questionnaire with survey questions was utilized to collect data from the selected study participants. The questionnaire measured how fire affects ecological systems across Europe, but particularly in Greece. The study variables were measured among a five-point Likert scale of strongly agree, agree, disagree and strongly disagree. The questionnaire was divided into five sections.

Section A included questions about the demographic characteristics or personal information of the study participants. Section B focused on assessing the effect of fire on the atmosphere and therefore on climate change across Europe based on a Likert scale of 1–5 (strongly agree to strongly disagree). Section C focused on assessing the effect of fire on animal husbandry across Europe based on a Likert scale of 1–5 (strongly agree to strongly disagree) and D focused on the effect of fire of soil nutrients and fertility across Europe based on a Likert scale of 1–5 (strongly agree to strongly disagree), while section E focused on the dependent variable which was growth and sustainability of ecosystems and was measured using the nominal scale.

### 3.5. Data Analysis

The quantitative data collected from the selected participants in the different areas of Greece were coded and then transferred to SPSS to be analyzed. Tables were used to display the findings, and frequencies and percentages were used in interpretation. Regression analysis was also undertaken in order to determine the ecological role of fire on the global scale and consequently establish the level to which the different effects of fire predict the growth and sustainability of different ecosystems. In this case, a multiple regression model (Equation (2)) to establish the different predictive values [75,79,81].

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \varepsilon \dots\dots\dots 1 \quad (2)$$

where:

Y = sustainability of ecological systems;

$\beta_0$  = constant (coefficient of intercept);

$X_1$  = fire's effect on the atmosphere and therefore on climate change;

$X_2$  = fire's effect on animal husbandry;  $X_3$  = fire's effect on soil nutrients and fertility;

$\varepsilon$  = represents the error term in the multiple regression model.

$X_1$ : Fire's Effect on the Atmosphere and on Climate Change: This variable represents the impact of fire on atmospheric conditions and its contribution to climate change. It encompasses factors such as the release of greenhouse gases, particulate matter, and other pollutants into the atmosphere during wildfires. Measurement of  $X_1$  involves assessing the quantitative and qualitative aspects of these emissions, considering factors such as carbon dioxide levels, air quality, and the overall influence on climate patterns.

$X_2$ : Fire's Effect on Animal Husbandry: This captures the repercussions of fire on animal husbandry, focusing on how wildfires affect the well-being and sustainability of animal populations. This variable includes considerations such as the loss of habitats for wildlife, the direct impact of fires on animal health, and the disruption of ecosystems that support animal species.

$X_3$ : Fire's Effect on Soil Nutrients and Fertility: This represents the influence of fire on soil conditions, specifically its impact on nutrients and fertility. This variable encompasses the changes in soil composition, nutrient levels, and the overall fertility of the land resulting from a fire. Measurement of  $X_3$  involves analyzing soil samples for variations in nutrient content, assessing the impact on plant life, and understanding the long-term consequences of fires on the sustainability of ecosystems.

Equation (2), which is the multiple regression model, combines these three variables to predict the sustainability of ecological systems (Y). The coefficients ( $\beta_0, \beta_1, \beta_2, \beta_3$ ) represent the relationship and strength of influence of each variable on the dependent variable (Y), and  $\varepsilon$  is the error term accounting for unobserved factors not included in the model. In essence, this regression model aims to quantify and analyze how the effects of fire on the atmosphere, on animal husbandry, and on soil nutrients collectively, contribute to the sustainability of ecological systems in the context of a Mediterranean country such as Greece. Each variable plays a distinct role in understanding different facets of the ecological impact of fires in the region.

The hypothesis of the study was tested at a 0.05 level of significance or at 95% confidence interval and the acceptance or rejection of the stated hypothesis in this study was based on whether the *p*-value is less or greater than 0.05.

### 3.6. Ethical Consideration

The researcher ensured that there is informed consent whereby respondents were informed about the details of the study and, consequently, the researcher assessed their willingness to participate. This was in addition to observing a high level of confidentiality and privacy when handling the data collected from respondents.

The participants were given two weeks to respond to the online questionnaire, and this time period was deemed sufficient for the respondents to respond. A high level

of confidentiality and privacy was maintained when collecting data from the selected professionals. Data collection started only when participants gave informed consent and it was confirmed that they were willing to participate in the study.

## 4. Results

### 4.1. Demographic Characteristics of Respondents

Results about the demographic characteristics of the selected respondents that participated in the study are presented in Table 1:

**Table 1.** Showing participants' demographic information.

Characteristic	Frequency	Percentage (%)
Gender		
Male	293	76.3
Female	91	23.7
Age bracket		
Below 30 years	22	5.7
31–40 years	93	24.2
41–50 years	183	47.7
Above 50 years	86	22.4
Area of specialty		
Agriculture	198	51.6
Forest	52	13.5
Farming	78	20.3
Environment management experts (academic, government agencies, NGOs)	35	9.1
Others	21	5.5
Total	384	100

Source: Survey (2023).

The majority of the selected study participants (76.3%) were male, and only 23.7% were female. The majority of the study participants (47.7%) were 41–50 years old, and only 5.7% were below 30 years, which shows that data were collected from relatively older persons that could be having great knowledge on how fire affects ecological systems. Most participants (51.6%) had a specialty in the area of agriculture, followed by 20.3% that had a specialty in the area of farming, and followed by 13.5% that had a specialty in the area of forests.

### 4.2. Descriptive Results

The study assessed whether the participants agreed with the notion that fire negatively affects the atmosphere and therefore climate change across the globe, and the results are presented in Table 2.

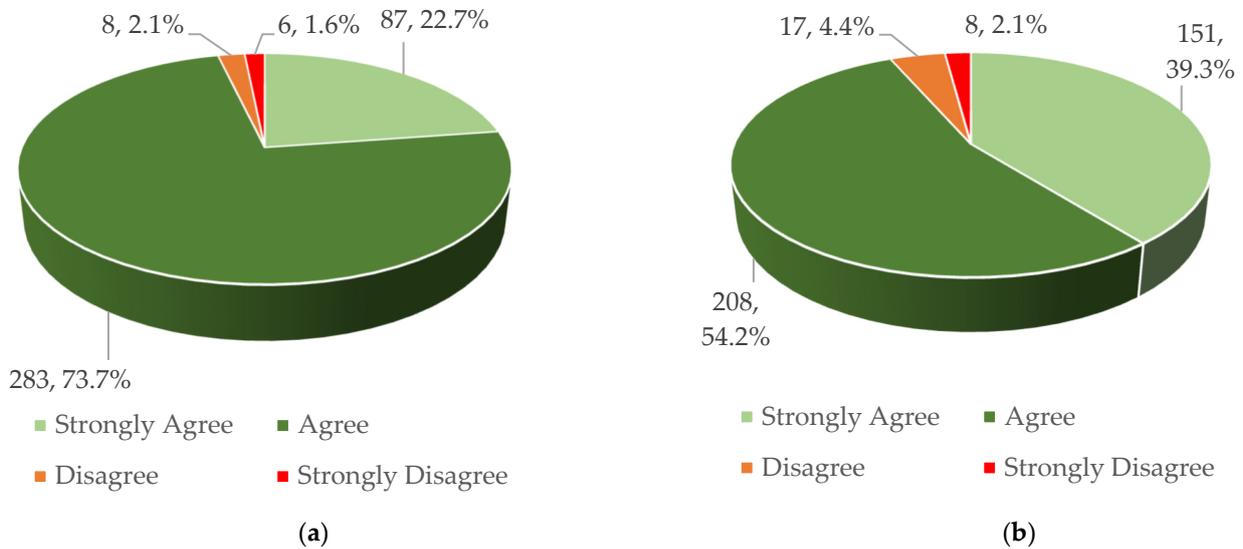
**Table 2.** Effect of fire on the atmosphere and therefore on climate change across Europe.

Likert Scale	Frequency	Percentage (%)
Strongly Agree	87	22.7
Agree	283	73.7
Disagree	8	2.1
Strongly Disagree	6	1.5
Total	384	100

Source: Survey (2023).

According to the results in Table 2, the majority of the participants (73.7%) agreed that fire influences the atmosphere and therefore climate change across the globe, 22.7% also strongly agreed with this notion, and only 2.1% and 1.5% strongly disagreed and disagreed, respectively.

Results on the opinions of respondents concerning the negative effect of fire on animal husbandry are presented in Figure 2a (both frequency and percentage are presented).



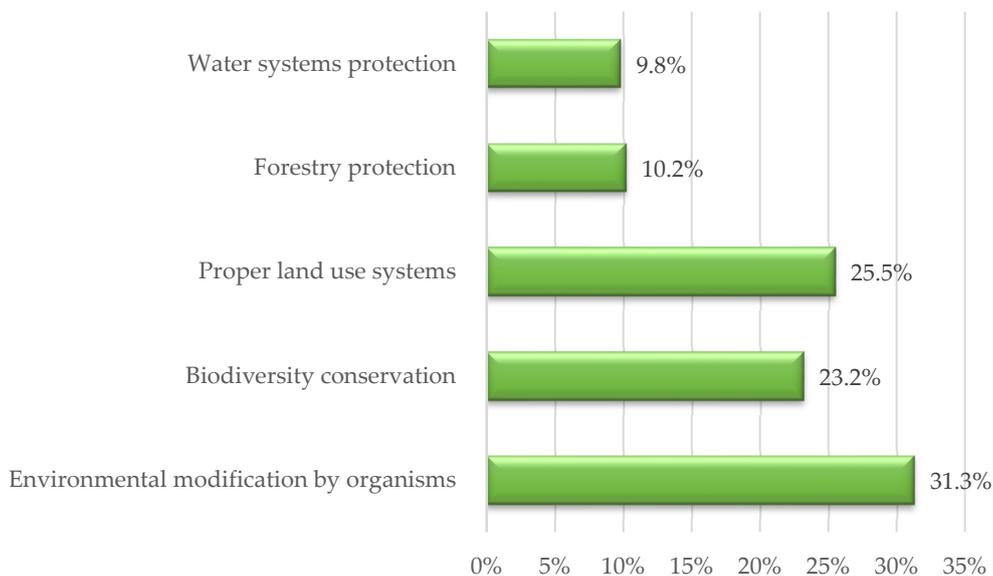
**Figure 2.** Effect fire on animal husbandry (a) and effect of fire on soil nutrients and fertility (b). Source: Survey (2023).

In regard to animal husbandry (immediate killing, destruction of facilities, reduction of available areas for grazing, etc.), the majority of the participants (80.5%) strongly agreed that fire affects animal husbandry and only 2.4% strongly disagreed.

The results on the effect of fire on soil nutrients and fertility are presented in Figure 2b (both frequency and percentage are presented).

In regard to whether fire has an effect on soil fertility, the majority of the participants (54.2%) agreed and only 2.1% strongly disagreed. The results are a clear indication that fire has a major impact on fertility levels of soils. In this case, soils are bound to either lose or gain fertility depending on how they are exposed to fire. Similarly, soil nutrients can easily be lost in soils once uncontrolled fires attack the soil cover.

The results on the different aspects of the sustainability of ecological systems are presented in Figure 3:



**Figure 3.** Aspects of sustainability of ecological systems.

Most of participants (31.3%) showed that the sustainability of ecological systems is much related to environmental modification by organisms, followed by proper land use systems (25.5%), then biodiversity conservation (23.3%), and the remaining participants revealed that ecosystem development is related to forestry protection (10.2%) and water system protection (9.8%), respectively.

#### 4.3. Regression Analysis

The one-way ANOVA was performed to determine the goodness of fit of the linear regression model or whether the three independent variables were excellent predictors of the dependent variable. Since  $F(3, 381) = 95.214$ ,  $p < 0.05$ , the model has been deemed a satisfactory match for the data (Table 3).

**Table 3.** ANOVA analysis.

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	51.240	3	16.082	95.214	0.002
Residual	8.108	381	0.036		
Total	59.348	384			

Dependent Variable: Growth and sustainability of ecosystems. Predictors: (Constant), Fire's negative effect on the atmosphere and therefore on climate change, on animal husbandry, and on soil nutrients and fertility.

Regression analysis further helped to understand how independent variables (fire's effect on the atmosphere and therefore on climate change, fire's effect on animal husbandry, fire's effect on soil nutrients and fertility) predict the growth and sustainability of ecosystems across the globe. The results are presented in Table 4.

**Table 4.** Multiple regression analysis.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	2.441	0.354		6.889	0.017
Fire's effect on the atmosphere and therefore on climate change	0.453	0.034	0.352	4.221	0.000
Fire's effect on animal husbandry	0.251	0.035	0.161	2.596	0.010
Fire's effect on soil nutrients and fertility	0.103	0.073	0.239	1.184	0.007

Dependent Variable: growth and sustainability of ecosystems.

The results in Table 4 show that, among the different predictors of sustainability of ecological systems, fire's effect on the atmosphere and therefore on climate change (Beta = 0.453,  $p < 0.05$ ) predicts the sustainability of ecological systems better than fire's effect on animal husbandry (Beta = 0.251,  $p < 0.05$ ) and fire's effect on soil nutrients and fertility (Beta = 0.103,  $p < 0.05$ ) (see Table 3). The results indicate that, despite fire having an influence on the growth and sustainability of ecological systems, there are other factors that could influence the ecological nature of the world.

Since all the  $p$ -values are significant at  $p < 0.05$ , all the hypotheses, H1, H2, and H3 were accepted. This indicates that fire has a significant negative effect on the atmosphere and therefore on climate change across the globe (H1), on the general animal husbandry (H2), and the quality of soil nutrients and soil fertility (H3).

From Table 5, the different independent variables can predict a 64.2% change in service quality in Greek government institutions. The F-statistic of 17.106 at prob. (Sig.) = 0.003 conducted at 5% level of significance means that there is a significant linear relationship that exists between the independent variables (fire's effect on the atmosphere and therefore on climate change, on animal husbandry, and on soil nutrients and fertility) and the dependent variable (growth and sustainability of ecosystems) as a whole.

**Table 5.** Model summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
	0.712 <sup>a</sup>	0.635	0.642	0.363

<sup>a</sup> Predictors: (constant): fire's negative effect on the atmosphere and therefore on climate change, on animal husbandry, and on soil nutrients and fertility.

## 5. Discussion

This study assessed the ecological role of fire in the modern society based on the global perspective. The results revealed that fire and its effects have a significant impact on the growth and sustainability of ecological systems in modern society. Specifically, it was established that fire has a significant effect on climate change, animal husbandry, and the quality of soil nutrients and soil fertility. The results show that it is important to keep in mind that managers and researchers have been studying the damaging effects of fire on the environment for many years, and that society generally views fire as a serious socioeconomic and environmental risk. Therefore, it is conceivable that, rather than emphasizing the positive roles that fire plays, such as in the functioning of the environment [38,60]. Studies carried out to date have concentrated on identifying and highlighting the negative effects of fire [6,11]. Studies with large effects may also be published more often than those with modest or negligible effects [4,9,33].

This study showed that fire has different effects on biodiversity as well as soil and its fertility levels. Prior research has identified a number of potential advantages of fire, including those on water yield, on food production, and on the different pollinator populations [4,56,62]. However, these advantages do not include those on water quality. Indicators that negatively affect one ecological system may also have positive secondary effects on other ES. For instance, soil erosion, which is typically viewed as having a negative impact, can also be seen as a natural process that aids in the redistribution of soil, nutrients, and other materials [5,7]. Furthermore, erosion can cooperate with other ecological processes at the landscape scale and have a positive effect on other ES, such as the burial of soil carbon, which is a beneficial ecological system from the perspective of regulating the climate. As a result, the type and accessibility of studies conducted to date may in part conceal the positive effects of fire on ES and the identification of ES directly resulting from fire occurrence [5,25]. Because of the aforementioned potential bias and data scarcity related to particular ES, specific types of fire occurrences, and specific pyromes/biomes, the generally negative effect of fire on ES stated here should be viewed with caution [43,82]. In long-term studies, fire has a considerable (unfavorable) influence on climate regulation, which may be partly explained by the fall in post-fire ecosystem carbon buildup rates [6,47].

According to the study, fires in areas with low fire frequency had less of an adverse effect on regulating the climate than fires in areas with high fire frequency. Some past studies found no evidence of lower levels of impact in places with high-intensity fire regimes than in areas with low-intensity regimes [5,83–85]. Comparing various biomes also showed that there are not many notable variations, such as those related to water availability. It should be highlighted that just a small portion of the extensively studied impacts of fire were taken into account in our investigation [29,83,86]. A number of combinations of component levels were either underrepresented in our database or had relatively tiny sample sizes, which prevented us from investigating interactions among explanatory variables, which may also be important [9,60].

Along with the immediate dangers to preserving and reestablishing fire's ecological function, dangers frequently compound one another to amplify the negative effects of changed fire regimes on the environment, society, and the economy [15,32,53]. For instance, raising cattle for farming and ranching often aids in the spread of invasive species, which in turn modifies fire regimes by varying the continuity and kinds of fuel [72,74]. In addition, climate change may make nearby ecosystems more flammable and susceptible to escaping fire, which can accelerate the spread of environmentally harmful agricultural and livestock fires [12,32,40]. Similar to how commercial plantings and logging may increase a forest's

susceptibility to the impacts of fire, slash and burn techniques are more troublesome when practiced next to these damaged woods [4,14]. Tropical wildfires pose a hazard to the region's coastal marine ecosystems as well. According to Shlisky et al. [54], wildfires in countries such as Indonesia provided enough iron fertilization to cause an exceptional red tide that caused reefs to suffocate to death. The massive volumes of smoke created by these fires also significantly hampered area economic activity and hindered visibility [30]. In conclusion, fires across the world have both negative and positive influences on the different ecological systems such as soil, water, vegetation and animal husbandry, as well as influencing climate change [7,15,26].

## 6. Conclusions

This study confirmed that fire has an impact on ecological systems in the modern world. The results revealed that fire and its effects have a significant impact on the growth and sustainability of ecological systems such as animal husbandry, environment or vegetation, soil and soil nutrients, among others. The world's forest and woodland ecosystems depend heavily on fire, which has an impact on important elements of how they operate ecologically. This study shows that the focus of research has primarily been on regulating-type services, particularly those related to the soil component such as soil fertility, erosion mitigation. This is in addition to the water and carbon cycles, alongside a strong geographic bias toward some countries, and biomes such as temperate forests. High intensity, frequent, and long-lasting fires often cause damage to ecosystem components and slow down the ecosystem's ability to operate. These flames often start spontaneously or without warning. The employment of fire as a tool to manipulate ecological balance is crucial. Fire is often seen by society as a natural danger with mostly negative impacts. The study shows that burning rangelands may affect ecosystem processes; not burning rangelands can have detrimental impacts on the growth of plants. This is owing to the fact that excessive litter accumulation brought on by a lack of light may hinder the establishment of new plant shoots and lower vegetation production. Because fire initiates the natural selection process, which enables plants to change their genetic makeup to adapt to environmental changes, it should be noted that some plants are typically improved by fire.

### 6.1. Recommendations

Integrated multi-ES techniques should be implemented by different countries as support for creating land management and wildfire mitigation plans at various spatial scales (from local to supranational). Before defining policies, it is important for countries to consider the ecological systems that are not frequently evaluated (such as cultural ecological systems).

Given the reduced negative consequences of controlled burns compared to wildfires for ES, including erosion reduction and water-quality regulation, this worldwide study recommends their usage as a management technique.

When extrapolating results from some places to understudied areas, care should be used since it has been noted that there is a dearth of research about the impacts of fire on ES for certain specific pyromes and biomes (i.e., tropical and subtropical).

### 6.2. Areas for Future Research

In regard to future research, there is need for a thorough examination of the function of fire as a supplier of ES and its incorporation into management tactics to optimize certain services. There is also need for more research clearly assessing the effects of potential fire regimes, especially those that exceed the normal or historical range of variability for various biogeographical and ecological locations.

Perhaps the ecological role of fire should be highlighted through regeneration, which naturally accelerates after fire ends. Nature is trying to survive and calls everyone to help in this direction (Figure 4).



**Figure 4.** After fire, the life rebeginning.

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