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Tree Line Shift in the Olympus Mountain (Greece) and Climate Change

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Abstract: One of the effects of climate change is, among others, changes to forest ecosystems. Research Highlights: Temperature increases and upward tree line shifts are linked in many studies. However, the impact of climate change on tree lines has not been studied in Greece. Background and Objectives: The aim of this study is to assess the relation of tree line shifts and climate change in Olympus mountain, and especially in a protected area. Materials and Methods: In the Olympus mountain, which includes a protected area (the Olympus National Park core) since 1938, GIS data regarding forest cover were analyzed, while climate change from a previous study is presented. Results: Forest expansion and an upward tree line shift are proven in the Olympus mountain area. In the National Park core, the tree line shift is the result of climate change and attributed to the significant temperature increase in the growing season. Conclusions: There are strong indications that a temperature increase leads to an upward shift of the tree lines in the National Park core.

Keywords: climate change; National Park; tree line shift

1. Introduction

The natural environment is expected to be strongly impacted by global warming. Wide parts of Southern Europe will be affected severely by climate impacts [1]. One of the major effects of climate change on forest ecosystem is changes in forest boundaries, with upward shifts in tree lines [2–5]. According to Paulsen et al. [6], there is an abrupt shift in the growth rates of the tree line, especially in plant species such as Alpine [6]. As Motta and Nola [7] postulate, there are significant growth trends and changing aspects of the alpine plant communities and species compositions [7]. Young trees are known for responding to the environmental change and their establishment in forest gaps close to the tree line may be seen in many areas [8–10]. However, it is important to understand the drivers of these trends in the alpine ecological community [11].

Firstly, these trends could be a result of a significant shift in climate change. Due to the temperature changes, alpine trees are directly influenced; therefore, it is anticipated to lead to structural shifts of the composition of trees and in a rise of the alpine tree line [7].

A probable tree line shift of around 200 m is expected to be found in the Swiss Alps as an effect of changes in the climate that have been experienced since 1980 [12,13]. The shift can be calculated by looking at the difference in temperatures between altitudes—a linear reduction in temperature of 0.55 °C per 100 m elevation was recorded. Walther et al. [10] discovered that the vegetation in the southeastern Swiss Alps had also experienced constant change since 1985, and concluded that the change in vegetation was resulted by an increased temperature at the related sites.

This research will entail an examination to determine the connection of shift tree lines and climate change. This examination will be conducted by answering the following questions: 1. Is there a tree

line shift in Olympus mountain? 2. Is there a significant temperature or/and precipitation variability in Olympus mountain? Positive responses to the above can justify the dependence of tree line shifts on climate change in the protected area of the mountain (i.e., the National Park core), given that this area was declared a National Park in 1938 (the core of the National Park is approximately 4000 ha) and, at least since 1981 [14], no management was implemented.

2. Materials and Methods

2.1. Study Area

The study area is the central part of Olympus mountain that was bare of vegetation (meadow) in 1960. Apart from its historical value and importance in Greek mythology, which are recognized not only in Greece but also in Europe and worldwide, Olympus mountain is also noted for its ecological value, regarding its exceptional biodiversity and rich flora.

Olympus mountain is the highest mountain in Greece, with varying elevations. Its type of climate, according to the Köppen climate classification, is Cfb = temperate oceanic climate, meaning that the coldest month averages above 0 or −3 °C, and all months have average temperatures below 22 °C, and at least four months average above 10 °C. There is no significant precipitation difference between seasons. This climate description of the study area is based on meteorological data of the nearest meteorological station to the study area, Litochoro (coordinates, 40.091 N, 22.361 E; elevation 2579 m; climate data for the period 1901–2018) [15]. These data are illustrated in a climate chart (Figure 1).

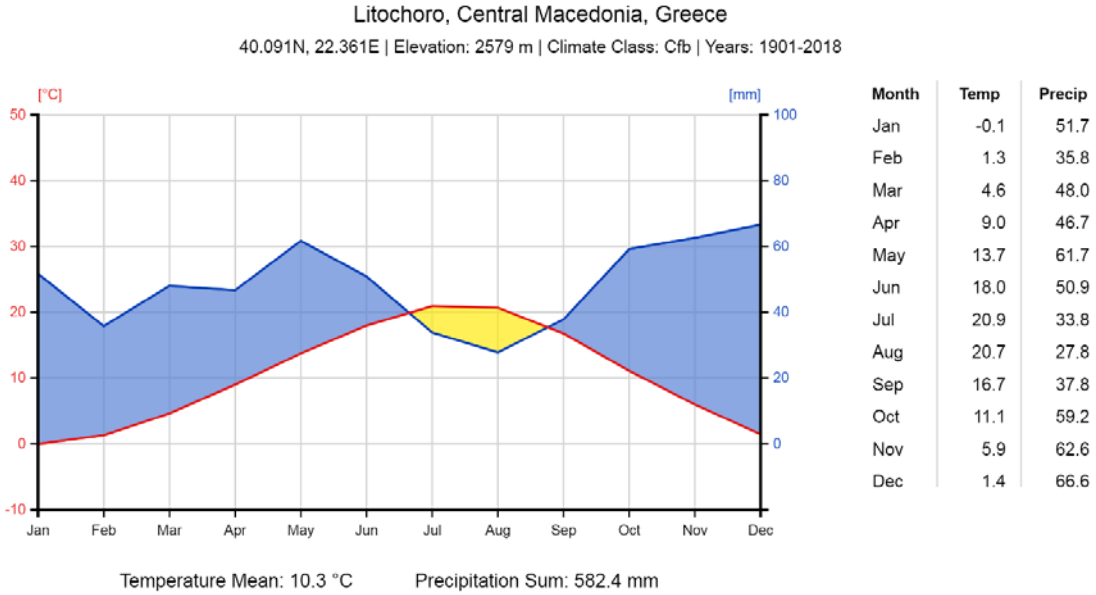

Figure 1. Ombrothermic diagram of Litochoro [15].

Today the Olympus National Park Management Agency manage a larger area than the core area of the National Park. This area has ecological importance, due to the rare and useful flora and fauna environment. The area also carries geomorphological formations and stream of waters. The area is protected through a legal arrangement that ensures that the park maintains its ecological friendly environment. Furthermore, the park became the first area to be regulated by a Royal Decree; the Decree was issued in 1938. The law was, however, enacted in 1985, when the park became fully operational. The area has been classified by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as a biosphere reserve since 1981. The area offers a natural environment for the conservation of wild birds, and is protected by the NATURA 2000 Network program, which is certified by the habitats directives for wild birds [16].

Olympus consists mainly of dolomite limestones and marbles of various dimensions and ages. Gneisses are found on the western slopes of Mount Olympus, and flysch occurs locally. The predominance of limestone significantly affects the climate and the appearance of vegetation [17].

2.2. Forest Cover and Tree Line Shift

Forest expansion in the study area was quantified using data from the Hellenic Military Geographical Service, for the year 1960 [18], and the National Cadastre and Mapping Agency S.A. company, for the year 2020 [19]. Aerial photographs of the year 1960 were purchased by the Hellenic Military Geographical Service, along with a license. For the year 2020, mosaics of orthophotographs were used, which were purchased from the National Cadastre and Mapping Agency S.A. company [19]. Geographic data from the ASTER GDEM v2 Worlwide Elevation Data (1 arc-second Resolution) were used [20]. Data were analyzed by using QGIS (free software) [21] and Global Mapper (partially licensed software) [22].

There are many terms regarding the shift of vegetation covered areas to bare areas [23]. In this study, in both measurements (for the years 1960 and 2020), the tree line was considered to be the line created by the limits of closed forest.

2.3. Climate Change

The assumption that the climate has really changed in the study area is based entirely on the work of Klesse et al. [24]. The dendrochronological investigation of black pine (*Pinus nigra* Arn.) from the Olympus mountain, extending from 850 to 1700 m in elevation, conducted by Klesse et al. [24] using the standard dendrochronological technique of Stokes and Smiley [25], showed significant long-term deviations in temperature and precipitation over time, with summers tending to be significantly warmer (late summer) and wetter (early summer) than the summers of the last century.

3. Results–Discussion

3.1. Forest Cover and Tree Line Shift

During the last 60 years, Olympus mountain lost more than one quarter of its area bare of forest vegetation. The study area that we have digitized for 1960 was calculated to have an area equal to 126.536 km^2; this was area bare of forest vegetation (including alpine mountain meadow). The area bare of forest vegetation, bounded by the tree line, in the year 2020, was calculated equal to 88.185 km^2 (Figure 2).

More analytically, in the east side there is a decrease in the area bare of forest vegetation, i.e., an increase in the forested area, by 7.088 km^2, in the west side by 16,637 km^2, in the south side by 9.688 km^2, and in the north side by 4.937 km^2. In the core of the National park, the increase in the forested area is 3.837 km^2. Besides forest expansion (increase by 38.351 km^2), in Figure 2 we observe that, at some points the new tree lines touch the old ones, while they have a general upwards trend. However, in a very few spots (mainly in north side), the forest retreated slightly in 2020 compared to 1960.

In the east side, the lowest altitude of the tree line in 1960 was 1848 m, while in 2020 in that particular area the altitude of the tree line goes up to 2082 m. On the same side, in 2020, the highest altitude of the tree line was 2496 m, while in 1960 that particular area was 2138 m. On the west side the lowest altitude of the tree line in 1960 was 1132 m, while in 2020 that particular area goes up to 1629 m. On the same side, in 2020, the highest altitude of the tree line was 2230 m, while in 1960 that particular area was 1595 m. On the north side, the lowest altitude of the tree line in 1960 was 1568 m, while in 2020 that particular area goes up to 1800 m. On the same side, in 2020, the highest altitude of the tree line was 2000 m, while in 1960 that particular area was 1750 m. On the south side, the lowest altitude of the tree line in 1960 was 1285 m, while in 2020 that particular area goes up to 1661 m. On the same side, in 2020, the highest altitude of the tree line was 2230 m, while in 1960 that particular area was

1595 m. The core of the National Park (declared in 1938) exhibits the tree line altitudes of the east side, since it is incorporated in that side and the described altitudes appear in the core.

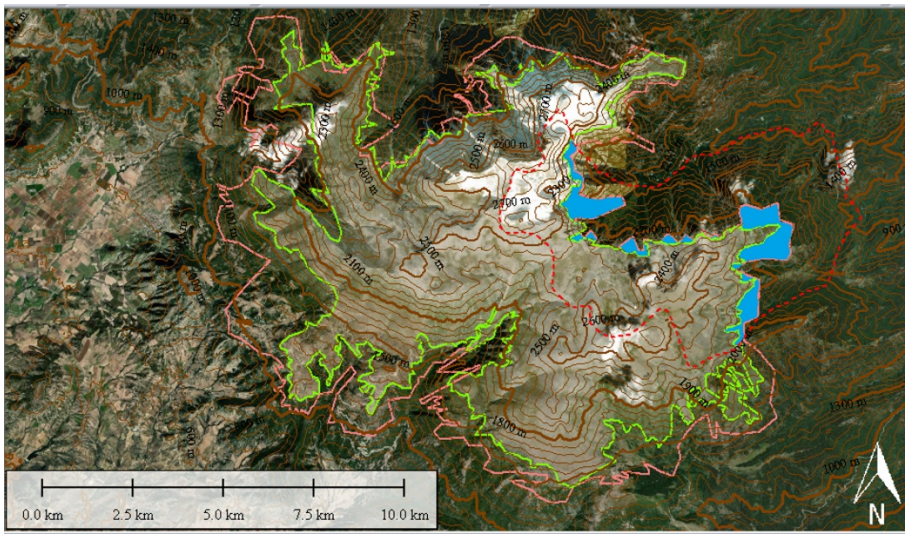

Figure 2. Area bare of vegetation in the year 1960 (vivid tangerine red line), and in the year 2020 (chartreuse green line) with contour lines per 100 m (reference: the year 2020). Area bare of vegetation (decrease) in the core of the National Park (sky-blue color).

3.2. Climate Change and Land Use Changes

According to the results of this study, the highest tree line altitude in Olympus is 2496 m. According to Theodoropoulos et al. [26] the forest in Olympus approximately reaches the altitude of 2500 m.

A tree line ascent involves changes in a number of consecutive processes (viable seed production, seed spreading, appropriate regeneration sites, germination, seedlings survival and growth); consequently, changes in temperature and precipitation alone does not unavoidably mean that there will be a tree line shift [27,28]. Even with the tree line shift, the climate change relationship is very complex, on a global scale, and one of the main factors that affects tree lines is the temperature of the growing season [29,30]. Forest expansion with an upward shift of the tree line is linked to a temperature increase [10,31–35]; however, changes in land use have a great impact on the upward shift of the tree line [12,36]. Human activities such as the grazing of domesticated animals affect tree mountain lines [37]. Moreover, Speed et al. [38] mention that, along with climate change, changes of land use have to be considered as factors affecting tree line ecotone shifts. Grazing strongly affects forests in Greece [39–41]. Near the west side of the study area there are villages where the grazing of domesticated animals was one of the main land uses [17,42]. Grazing is a significant disturbance factor in the area of the Olympus mountain [17,26]. The movement of the tree line at higher altitudes in almost the entire study area, and, especially in the west side, is strongly related to the gradual abandonment of the traditional land use. This is obvious from the altitude where the area bare from vegetation is observed in most areas in 1960 and in 2020. The abandonment of grazing and other land uses is a crucial factor in the formation of structures and in the development of patterns of forests in mountainous areas [43,44]. However, it seems that, in the National Park core, the tree line shift is, actually, the result of climate change. Given the fact that there was a significant change in climate in the area, this conclusion is based on the following facts: (a) there were no villages and consequently there were no human-induced disturbances in the vicinity of the core, (b) human activities such as grazing have been forbidden since 1981 [14]—most likely grazing had stopped many years before 1981, due to the protection status of the core—(c) the steep ground slopes of many areas of the core make the area unsuitable for gazing and (d) the elevation of the tree line changes between 1960 and 2020.

The shift in the tree line in the entire study area (not just the National Park core) is significant, and, even though the study area is not protected (except for the National Park), climate change probably accelerated the tree line shift in general. The influences of climate change and the reduction in or the elimination of grazing are difficult to study separately [37,45]. Unfortunately, there are no available livestock data for the study area in order to assess the impact of grazing on the tree line shift. The only official livestock data are those of the Greek Payment Authority of Common Agricultural Policy (CAP) Aid Schemes (url: http://aggregate.opekepe.gr), and are available only for the East Olympos, and only for the period 2011–2014 (after 2014 the neighboring municipalities were merged; consequently, livestock data were aggregated for a number of municipalities and are not comparable with those before 2014). Nevertheless, since there was no management implemented in the Olympus National Park core (absence of grazing for many decades), we can claim that the cause of the tree line shift in the National Park core is, exclusively, climate change.

4. Conclusions

An increase in forest cover by 38.351 km^2 with an upward shift of the tree line from 1960 to 2020, has been noted in Olympus mountain, while the corresponding area for the Olympus National Park core is 3.837 km^2. The movement of the tree line at higher altitudes in almost the entire study area, and especially on the west side, is related to the gradual abandonment of the traditional land use, i.e., grazing. However, in the Olympus National Park core, the tree line shift is solely the result of climate change in the area, and more specifically because of warmer summers. This conclusion is based mainly on the protection status of the core (absence of grazing for many decades), combined with other factors such as altitude changes of the tree line, and steep slopes.

The forested areas are likely to increase further, if the climate keeps getting warmer. Future research should focus on long-term and area-wide observations of regeneration and tree growth. It should also catch more factors that affect the tree line ecotone and recognize any hidden facilitators.

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Conflicts of Interest: The authors declare no conflict of interest.

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