BIBLIOGRAPHIC INFORMATION SYSTEM

Journal Full Title: **Journal of Biomedical Research & Environmental Sciences**

Journal NLM Abbreviation: J Biomed Res Environ Sci

Journal Website Link: https://www.jelsciences.com

Journal ISSN: **2766-2276**

Category: Multidisciplinary

Subject Areas: Medicine Group, Biology Group, General, Environmental Sciences

Topics Summation: 133

Issue Regularity: Monthly

Review Process: Double Blind

Time to Publication: 21 Days

Indexing catalog: IndexCopernicus ICV 2022: 88.03 | GoogleScholar | View more

Publication fee catalog: Visit here

DOI: 10.37871 (CrossRef)

Plagiarism detection software: iThenticate

Managing entity: USA

Language: English

Research work collecting capability: Worldwide

Organized by: SciRes Literature LLC

Manuscript should be submitted in Word Document (.doc or .docx) through

Online Submission

form or can be mailed to support@jelsciences.com

IndexCopernicus ICV 2022: 83.03

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JOURNAL OF BIOMEDICAL RESEARCH & ENVIRONMENTAL SCIENCES
issn: 2766-2276
SUBJECT AREA(S): CLIMATE CHANGE BIOLOGY | ECOSYSTEM SCIENCE | ECOHYDROLOGY
DOI: 10.37871

RESEARCH ARTICLE

Climate Change in Southwestern Anatolia (Turkey) and Its Possible Impacts on Plant Biodiversity

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Abstract

Biodiversity is of great importance for ecosystems such as protecting soils against erosion, increasing soil fertility, providing clean water to streams/rivers, contributing to the healthy continuation of nutrient cycling, pollinating plants, and acting as a buffer against diseases. These characteristics of biodiversity are called "ecosystem functions" or "ecosystem services". However, many factors threaten biodiversity, such as changes in land cover and land use, pollution, invasion of exotic species and climate change. Among these, it would not be wrong to say that the anthropogenic climate change experienced today is one of the most important threats to biodiversity. As is known, the Mediterranean basin is one of the most sensitive areas in terms of global climate change. This study aimed to reveal the possible effects of climate change on plant biodiversity in south-western Anatolia. For this purpose, daily, maximum and minimum temperature data and daily total precipitation data of 10 meteorological stations located in the research area were evaluated. The non-parametric Mann-Kendall test was used to test the changing trends in temperature and precipitation. Then, the possible effects of changes and trends in temperature and precipitation on plant biodiversity in the study area are explained.

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DOI: 10.37871/jbres2102

Submitted: 05 May 2025

Accepted: 15 May 2025

Published: 16 May 2025

Introduction

The United Nations Convention on Biological Diversity (1992) defines biological diversity as "the variety of living organisms of any origin, including terrestrial and marine ecosystems, other aquatic systems and the ecological complexes of which they are a part, addressing diversity within and between species as well as between ecosystems". Biodiversity is of great importance for ecosystems such as protecting soils against erosion, increasing soil fertility, providing clean water to streams/rivers, contributing to the healthy continuation of nutrient cycling, pollinating plants, and acting as a buffer against diseases. These characteristics of biodiversity are called "ecosystem functions" or "ecosystem services". Healthy ecosystems, supported by high biodiversity, provide numerous ecosystem services that are essential for human well-being. These services are often taken for granted, but they are indispensable to our survival [1,2]. However, many factors threaten biodiversity, such as changes in land cover and land use, pollution, invasion of exotic species and climate change. Among these, it would not be wrong to say that the

ENVIRONMENTAL SCIENCES GROUP
CLIMATE CHANGE BIOLOGY | ECOHYDROLOGY | ECOSYSTEM SCIENCE
VOLUME: 6 ISSUE: 5 - MAY, 2025

How to cite this article: Sütgibi S. Climate Change in Southwestern Anatolia (Turkey) and Its Possible Impacts on Plant Biodiversity. J Biomed Res Environ Sci. 2025 May 16; 6(5): 444-456. doi: 10.37871/jbres2102, Article ID: JBRES2102, Available at: https://www.jelsciences.com/articles/jbres2102.pdf

anthropogenic climate change experienced today is one of the most important threats to biodiversity. Indeed, both the reports of the Intergovernmental Panel on Climate Change (IPCC) and many studies clearly reveal the impacts of current and future climate change on biodiversity [3-7]. For example, according to the IPCC report, "climate change has caused increasing and irreversible losses and significant damage to terrestrial, freshwater, cryospheric, coastal and open ocean ecosystems". However, building biodiversity resilience to climate change and supporting ecosystem integrity can contribute to disaster risk reduction, climate change adaptation and mitigation, as well as benefits to people, including livelihoods, human health and well-being, and the provision of food, fibre and water [8]. Therefore, the conservation and sustainability of biodiversity is becoming more and more important today.

Plant species, which are the cornerstone of terrestrial ecosystems, can reproduce and grow successfully only under certain climatic conditions. When these conditions change, these species will either adapt or be forced to migrate. However, migration is often difficult for some species, especially those living at high altitudes and in northern regions. When plant species cannot adapt to changing conditions or cannot relocate, they will face the danger of extinction. A reduction in the richness of plant species can limit overall biodiversity and lead to reduced ecosystem stability. It may become a threat to some ecosystem products and services such as raw materials, pollination, gas regulation, especially medicine and food. In addition, changes in plant species distribution and vegetation composition may have some consequences on the climate system [9]. As a result, plant species diversity is of great importance for the healthy continuation of ecosystem functions or ecosystem services. However, studies show that plant species composition has changed or species have disappeared in many regions of the world with the human induced climate changes experienced today, especially anthropogenic effects. For example, Bakkenes M, et al. [10] reported that species are becoming extinct at a rate 100-1000 times greater than what is considered normal, while Parmesan and Yohe [11] found that a large number of plant species in Europe have moved northwards in the last few decades and that this is closely related to temperature increases. Studies also show that plants and vegetation, especially in high mountainous areas such as the Alps, are more sensitive to climate change [12-15].

According to IPCC reports, Turkey, like other Mediterranean countries, is one of the countries that will be most affected by climate change. As a matter of fact, many studies on climate change in Turkey also support this. For example, studies show that the number of tropical and summer days in Turkey has a statistically significant increasing trend, night temperatures have been rising rapidly since the mid-1980s, and the minimum temperature regime or statistical distribution has changed remarkably [16-19]. Our research is based on the assumption that the impacts of climate change on plant biodiversity and thus ecosystem services in Southwest Anatolia will be severe; in fact, these impacts, such as increasing temperatures, extreme pressure on water resources, increased frequency of severe weather conditions and floods, increased coastal erosion and more forest fires, etc., have started to be seen in our research area as in many parts of the world.

Study Area

The study area is located in southwestern Turkey within the Mediterranean phytogeographic region and within squares C1 and C2 according to the Flora of Turkey quadratic system determined by Davis [20] (Figure 1). Squares C1 and C2 geographically cover the Aydın Mountains, the Menteşe region and part of the western Taurus Mountains. In this respect, it is observed that the area is highly rugged and the elevation, slope and aspect conditions change frequently in very short distances (Figure 2). These topographical features have enabled the formation of local climatic zones in the research area, which is generally located in the Mediterranean macro-climatic zone, leading to an increase in biodiversity and the number of endemic species. The topographic features of the area and the associated local climatic zones provided a refuge for migratory plants during the last glacial period (Würm) [21]. As a matter of fact, approximately 3444 plant species have been identified in the area, of which approximately 772 are endemic and the rate of endemism is over 25% [22]. In addition to the diversity created by topographic conditions, the geological structure of the research area is also an effective factor in the high rate of endemism. In this area, serpentines in the ophiolite series among the ultramafic rocks occupy a large area and the areas where these types of rocks are found and the areas with high endemism rates mostly overlap.

ISSN: 2766-2276

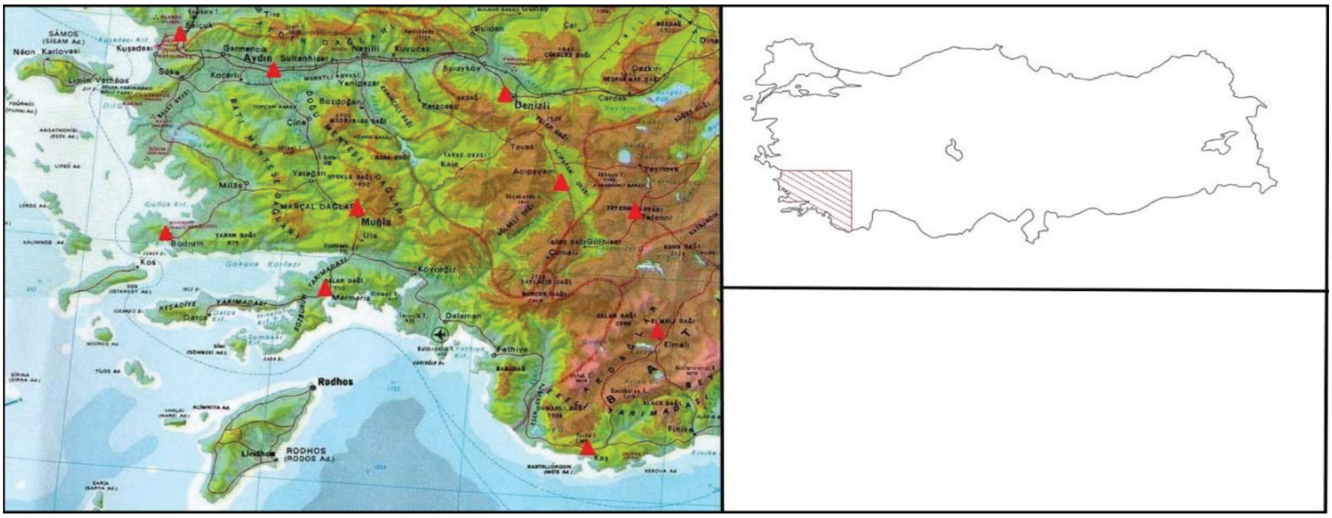

Figure 1 Map showing the location of the study area and the meteorological stations (red triangles) used in the study.

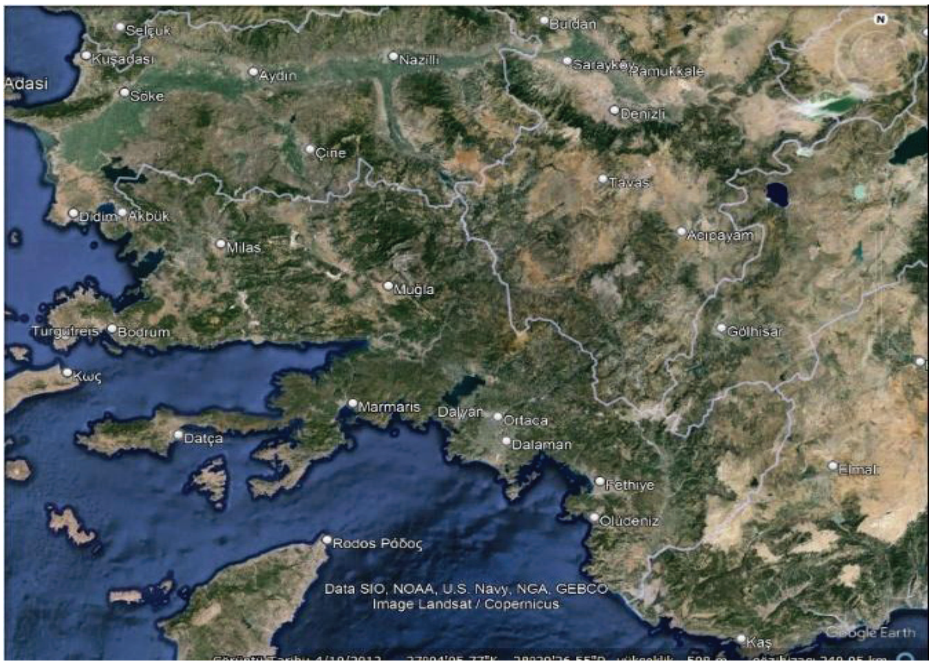

Figure 2 Frequent changes in elevation, slope and aspect conditions cause the formation of local climate areas in the area, which in turn causes plant diversity.

This situation is explained by geological isolation and Mason [23] uses the name "edaphic endemic" for these species which are found on ultramafic rocks and have a narrow distribution (Photo 1).

The research area is located in the "Mediterranean Basin biological hotspot area" with its plant biodiversity. As is known, hotspots are defined as areas with at least 1500 plant species that are found nowhere else and have lost more than 70 per cent of their original habitat [24]. The Mediterranean Basin is the third richest hotspot in the world in terms of plant biodiversity and one of the most important areas in the world for endemic plants. In addition, there are 15 important plant areas in our research area (Table 1). Important Plant Areas (IPAs) are defined as "natural or semi-natural areas that hosting very rich populations of rare, endangered and/or endemic plant species and/or contain botanically exceptionally rich and/or highly valuable vegetation" [25].

Material and Methods

In order to reveal the changes and trends in

Photo 1 *Eryngium thorifolium* is one of the serpentine endemics found in the research area.

Table 1: Important plant areas in the research area and the number of endangered taxa and species in these areas.

Important Plant Area	Endangered Taxa	Endangered Species in Europe	Globally Endangered Species
Dilek Peninsula and Menderes Delta	20 (6 endemic)	5	2
Western Menteşe Mountains	22 (7 endemic)	6	2
Gölköy (Bodrum-Muğla)	No Data	1	-
Bozburun and Datça Peninsula	159 (35 endemic)	18	9
Köyceğiz Lake and Dalyan	105 (50 endemic)	34	11
Dalaman Plain	5 (2 endemic)	-	2
Baba Mountain	47 (42 endemic)	34	6
Patara Sand Dunes and Gelemiş Plain	40 (21 endemic)	16	4
Sandras Mountain	68 (65 endemic)	61	4
Göleli Mountains	30 (29 endemic)	26	3
Honaz Mountain	50 (41 endemic)	37	4
East Boncuk Mountains	38 (36 endemic)	35	1
Dokuzgöl Mountains	39 (37 endemic)	33	4
Salda Lake	22 (20 endemic)	19	1
Acıgöl	8 (8 endemic)	2	6

temperature and precipitation in the research area, daily average, daily maximum and daily minimum temperatures and daily total precipitation data of 10 selected meteorological stations were obtained from the General Directorate of Meteorology (Figure 1).

MAKESENS (Mann-Kendall test for trend and Sen's slope estimates) was used to determine the long-term changes and trends in temperature and precipitation and to test their statistical significance. MAKESENS performs two types of statistical analyses. First the presence of a monotonic increasing or decreasing trend is tested with the nonparametric Mann-Kendall test and secondly the slope of a linear trend is estimated with the nonparametric Sen's method. These methods are here used in their basic forms; the Mann-Kendall test is suitable for cases where the trend may be assumed to be monotonic and thus no seasonal or other cycle is present in the data. The Sen's method uses a linear model to estimate the slope of the trend and the variance of the residuals should be constant in time. These methods offer many advantages that have made them useful in analyzing atmospheric chemistry data. Missing values are allowed and the data need not conform to any particular distribution. Besides, the Sen's method is not greatly affected by single data errors or outliers [26].

Field studies were carried out in the research area on different dates between 2018 and 2024 and the plant biodiversity of the area and the geographical environmental factors that are effective in this and the current threats on plant biodiversity were observed.

Results and Conclusion

Changes and trends in temperature and precipitation

When the time series plots of the mean, maximum and minimum temperatures of the 10 meteorological stations examined in the research area are analyzed, it is seen that the temperatures are in an increasing trend in all stations (Figures 3-5). According to Mann-Kendall test, this increasing trend is significant at all stations with a probability of 99.9% ($\alpha = 0.001$) (Table 2). When we look at the change of annual average

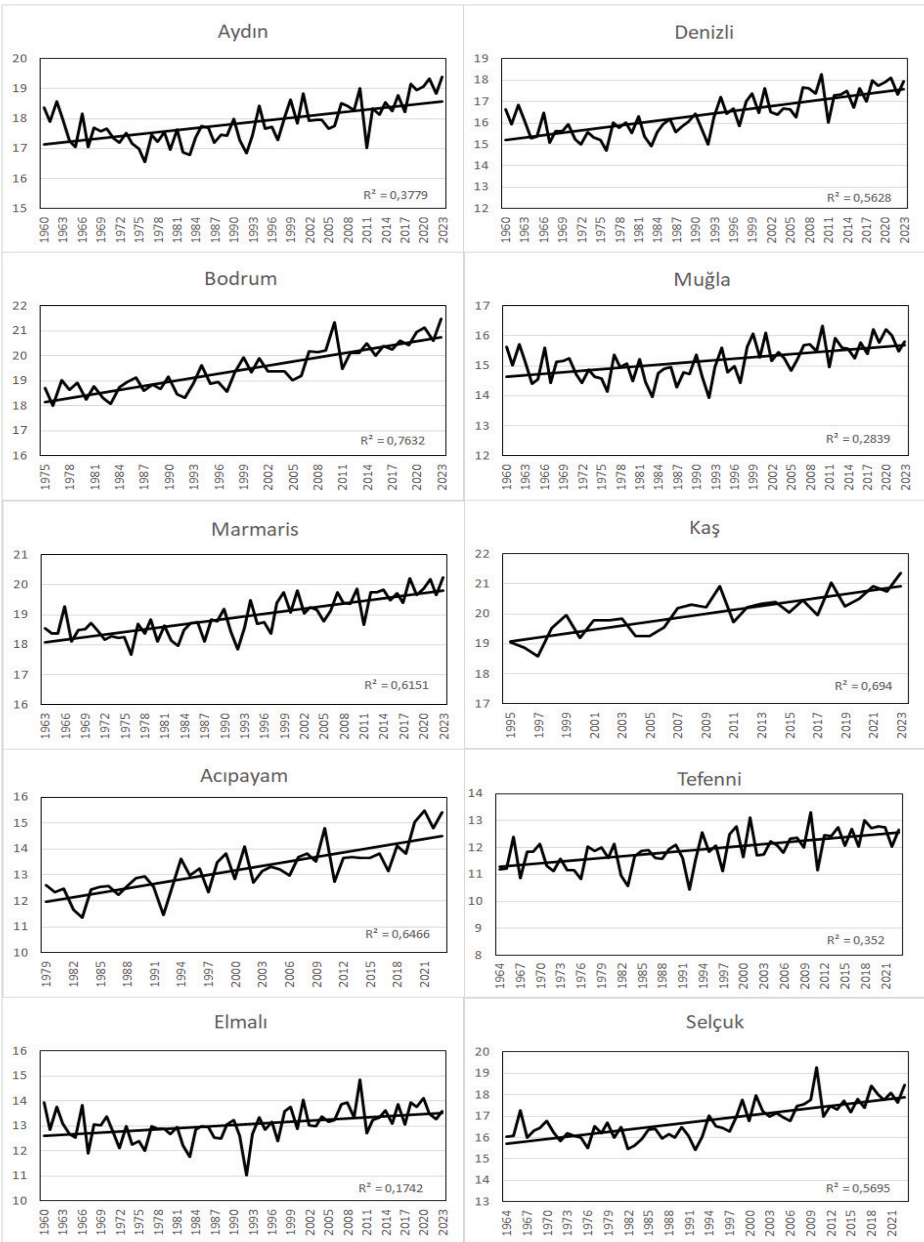

Figure 3 Long-term changes and linear trends in annual mean temperatures of 10 stations in the research area.

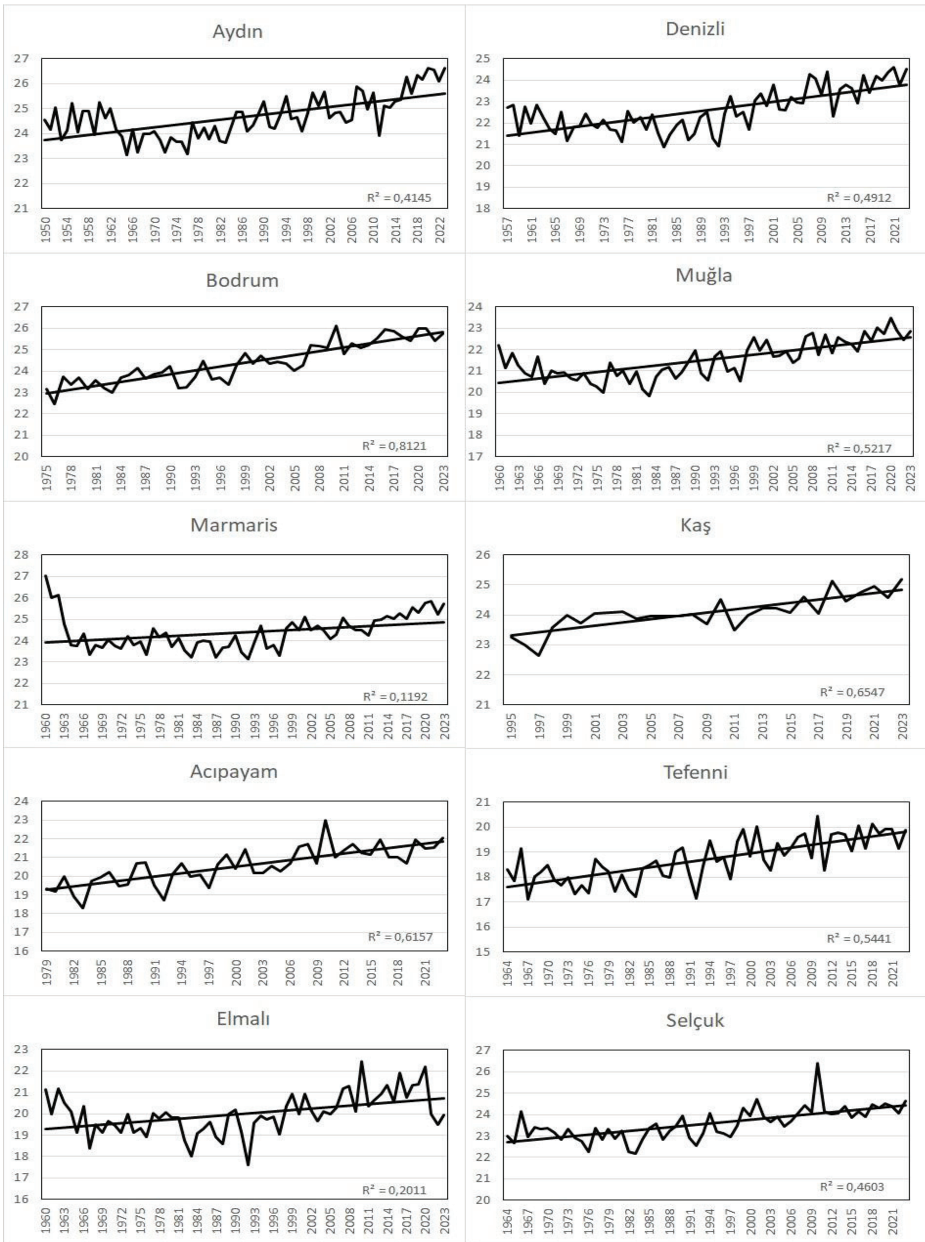

Figure 4 Long-term changes and linear trends in the mean maximum temperatures of 10 stations in the research area.

temperatures according to seasons, it is seen that there is a statistically significant increasing trend in all seasons. Especially the increase in autumn and spring temperatures has an important place for plant development because it causes a result such as prolongation of the vegetation period. For example, an extended vegetation period may benefit farmers adapting to new conditions, but may be harmful to natural vegetation or flora, as discussed in more detail below [4]. In addition, it was observed that the average temperatures of the last twenty years in the research area were 0.7 °C higher than the long-term average temperatures.

It is observed that there is a decreasing trend in total annual precipitation at all stations, but this trend is not statistically significant. Seasonal precipitation was analyzed in order to reveal the change in the distribution of precipitation during the year and the tendency of this change. Accordingly, it is observed that there is a decrease in winter precipitation in all stations analyzed except Kaş. This decreasing trend is statistically significant with a probability of 90% ($p < 0.1$) in Muğla and 95% ($p < 0.05$) in Tefenni, while the decreasing trend is not statistically significant in other stations. On the other hand, there is an increasing trend in summer precipitation in the study

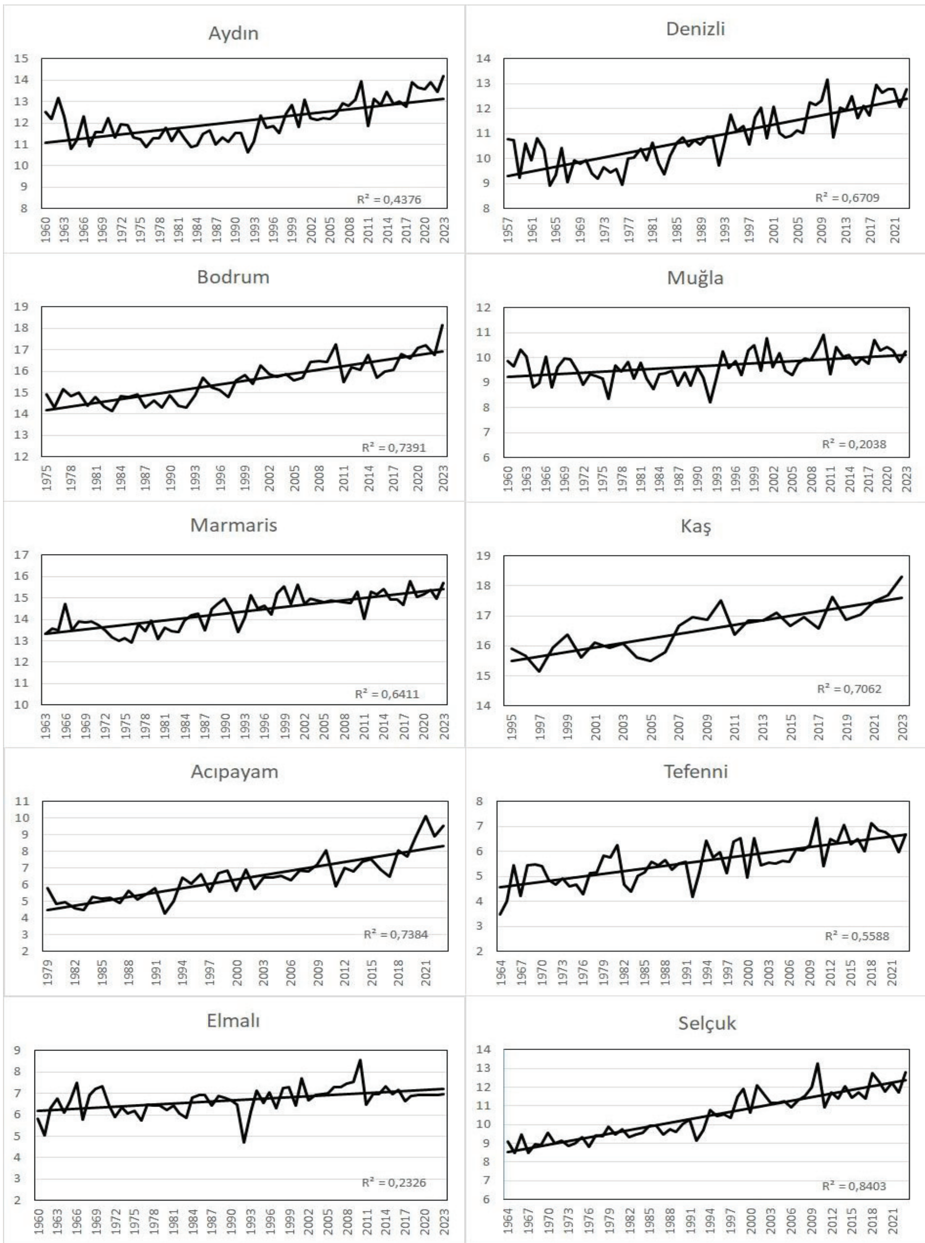

Figure 5 Long-term changes and linear trends in the mean minimum temperatures of 10 stations in the research area.

area except for one station (Bodrum). This increasing trend is statistically significant with a probability of 90% ($p < 0.1$) in Kaş, 95% ($p < 0.05$) in Acıpayam and Muğla, 99% ($p < 0.01$) in Tefenni, while the increasing trend in other stations is not statistically significant (Table 3, figure 6).

Possible impacts of climate change on biodiversity

Phenological changes: Phenology is a science that measures the timing of life cycle events for plants, animals and microorganisms and determines how the environment influences the timing of these events. When flowering plants are observed, these life cycle events or "phenological stages" include, among other steps, "bud bursting", "first flower bloom", "last flower bloom", "first fruit maturity" or "leaf drop" [27]. As is well known, some phenological responses are mainly triggered by temperature, while others are more sensitive to day length. Such changes are linked to the growing season and affect ecosystem functioning and productivity [28]. Common changes in the timing of spring activities in relation to plants include earlier shoot and leaf appearance and flowering. Changes in flowering have effects on the timing and intensity of the pollen season,

Table 2: Trend statistics of annual mean temperature and seasonal mean temperature in the study area.

	Winter		Spring		Summer		Autumn		Annual	
Meteorological Stations	**Test Z**	**Signific.**	**Test Z**	**Signific.**	**Test Z**	**Signific.**	**Test Z**	**Signific.**	**Test Z**	**Signific.**
Acıpayam	3.2	**	3.9	***	4.82	***	4.53	***	6.15	***
Aydın	1.4		3.23	**	6.15	***	3.68	***	4.99	***
Bodrum	4.46	***	4.27	***	6.8	***	6.2	***	7.06	***
Denizli	2.79	**	4.14	***	6.81	***	5.1	***	6.45	***
Elmalı	2.42	*	1.84	+	2.03	*	3.15	**	3.81	***
Kaş	2.72	**	3.88	***	2.19	*	4.71	***	5.08	***
Marmaris	1.85	+	3.84	***	6.24	***	6.05	***	6.47	***
Muğla	0.43		2.58	**	4.99	***	2.51	*	4.39	***
Selçuk	1.97	*	4.5	***	7.12	***	5.11	***	6.31	***
Tefenni	2.11	*	2.29	*	3.86	***	3.88	***	4.74	***

(Significance levels in trends: ***$p < 0.001$. **$p < 0.01$. *$p < 0.05$. +$p < 0.1$).

Table 3: Trend statistics of annual total rainfall and seasonal rainfall in the study area.

Meteorological	Winter		Spring		Summer		Autumn		Annual	
Stations	**Test Z**	**Signific.**	**Test Z**	**Signific.**	**Test Z**	**Signific.**	**Test Z**	**Signific.**	**Test Z**	**Signific.**
Acıpayam	-1.63		0.37		2.18	*	-0.89		-0.69	
Aydın	-1.64		1.18		0.83		0.54		-0.06	
Bodrum	-1.3		-0.67		-1.34		0.54		-1.03	
Denizli	-1.47		-0.03		0.89		1.05		-0.23	
Elmalı	-1.57		-0.56		1.38		1.15		-1.29	
Kaş	0.36		-0.92		1.86	+	-0.28		-0.24	
Marmaris	-0.56		0.84		0.01		-0.24		-0.5	
Muğla	-1.81	+	0.08		2.34	*	1.26		-0.86	
Selçuk	-0.98		-0.64		0.4		-0.59		-1.45	
Tefenni	-2.11	*	0.02		2.86	**	-0.26		-0.61	

(Significance levels in trends: ***$p < 0.001$. **$p < 0.01$. *$p < 0.05$. +$p < 0.1$).

which shows a progressive trend with many species starting to flower earlier [4]. Although there is no direct study showing phenological changes related to the research area, in recent years, there are studies aiming to reveal the relationships between various agricultural plants, their phenological periods and climate changes in Turkey. For example, the study, which included our research area and examined the effects of climate change on the phenological periods of fruit trees and field crops in Turkey, showed that with increasing temperatures, there was a negative relationship between the phenological periods of apple, cherry and wheat and the average temperatures of February-May, when plant growth is high. This means that plants shift their phenological period earlier in response to increasing temperatures. The trend calculated for the harvest dates of apple, cherry and wheat in the study is -25, -22, -40 days/100 years, respectively [29]. In the study examining the changes in the duration of the vegetation period and the start and end dates of the vegetation period in the Aegean region, it was found that the relationship between the average temperatures of February-March-April and the changes in vegetation duration and vegetation period starts was very high (.000) at 0.001 level. According to the results of the same study, it is seen that the vegetation period in the Aegean region in the last thirty years (1990-2019) has been extended by 5 days according to the threshold value of 5 °C and 4 days according to the threshold value of 8 °C compared to the long-term averages [30].

Change of distribution areas: In response to changing climatic conditions, plants react mainly by expanding or contracting their range, among many other responses. Indeed, evidence from glacial and interglacial periods suggests that the dominant adaptive response of climate-limited plant species is

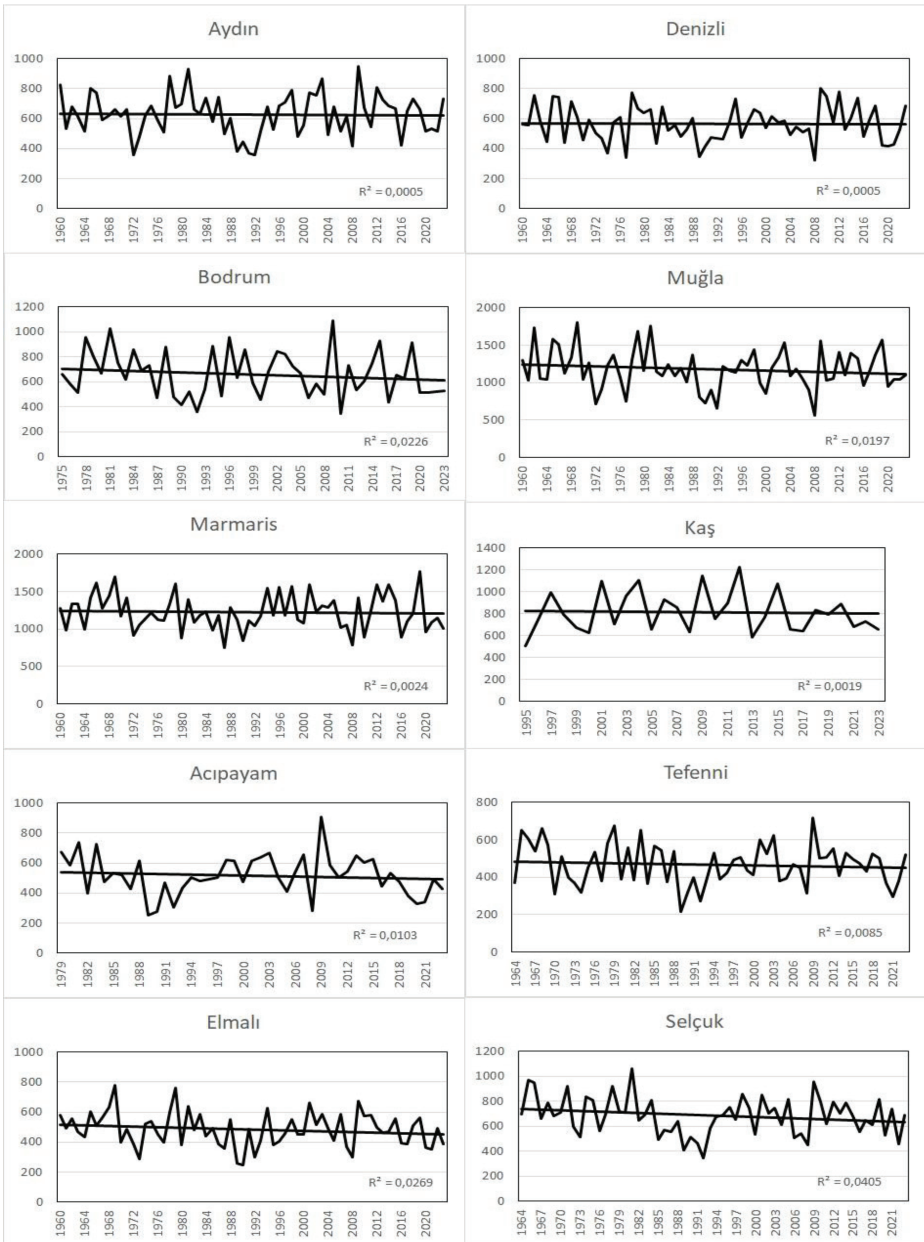

Figure 6 Long-term changes in precipitation and linear trends of 10 stations in the study area.

to shift their distributions, resulting in movements towards altitude and the poles [31]. For example, the sweetgum (*Liquidambar orientalis*) communities, which grow on the valley floors and slopes in our research area, is a Tertiary relic endemic, and while it was distributed in wider areas in Turkey in the Tertiary, it is now only found in an area limited to our research area due to changing climatic conditions (Photo 2). Again, as we have mentioned before, the topographical features of the study area and the resulting local climatic zones have made it a refuge for plants migrating during the last glacial period (Würm) and there are many species belonging to the Euro-Siberian phytogeographical region such as *Salix alba*, *Populus alba* and *Carex outrage* in the area. Studies show that plants respond to current climate changes in a similar way to those of the past. For example, holly (*Ilex aquifolium*), a climate-limited species, has been found to have expanded its range in southern Scandinavia over the last 30 years, consistent with increasing winter temperatures [31]. Similarly, in Sweden (Scandes), the tree limit of Scots pine (*Pinus sylvestris*) has increased by 150-200 meters with increasing winter temperatures [32-34]. Again, Kullman L. [33] states in his study that alpine and subalpine plant species have shifted an average of

Photo 2 Sweetgum trees (*Liquidambar orientalis*), which are known to have spread over wider areas in Turkey during the Tertiary period, now form communities in the study area, especially around Köyceğiz Lake.

200 m upslope, narrowing in the alpine zone (higher tree limit) and changing the landscape of alpine vegetation.

Extinction of species: Although there is no record of any extinct plant species in the research area due to climate change today, the records of climate changes in the Pleistocene show that species that cannot keep up with the change are in danger of extinction. In particular, rapid change in ecological conditions can overwhelm the adaptive capacity of many species and lead to ecosystem reorganization and increasing numbers of extinctions. For example, studies show that plant species in mountainous areas and endemic and rare plants are more sensitive to changes in climate [35,36]. In this respect, it would not be wrong to say that the research area is among the sensitive areas against changing climatic conditions with its rich mountainous ecosystem and plant species diversity, especially endemic plant species. As a matter of fact, as mentioned before, there are 15 important plant areas (IPA) in the research area, which are defined as areas with rich populations of rare, endangered or endemic plant species (Table 1). When the table is analyzed, it is seen that more than 600 taxa, about 60% of which are endemic, are endangered in the area. We do not have enough data to say that this threat is related to climate change. These threats seem to be mostly related to land use, grazing, forest fires or over-collection of plants from nature. But as we also know, climate change could exacerbate existing threats to biodiversity. For example, changes in rainfall and temperature can alter the distribution of pests and weeds and create new opportunities for some species to become established [37]. In addition, there are many studies showing the effects of anthropogenic climate change on the increase in the number and impact area of forest fires, which are a significant threat to biodiversity today [38-40]. In the study of Türkeş and Altan [38], which covers a large part of our research area, the relationship between droughts and forest fires is revealed and it is stated that this area, which is one of the most important areas of the Mediterranean climate zone with the most important climatic change in Turkey, may face more severe natural disasters in the future with climate change.

Another threat affecting plant biodiversity is the mismatch between the plant and its pollinators (e.g. insects) due to global warming. Mismatches in plant-pollinator interactions can occur temporally or spatially, with less coexistence of interacting partners in a shared habitat. Again, these mismatches may be due to a change in the flowering period of the plant and/or the phenology of the pollinator [41]. Recent studies also support the mismatches between phenological changes and plant/pollinator conflicts due to climate change and increasing temperatures [42- 44]. Plants in our research area are under similar threats linked

Photo 3 *Arum balansanum* (endemic, left) and *Pancratium maritimum* (right) are threatened species due to human activities in the research area and global climate change will make this threat even more serious.

to increasing temperatures. This may also affect the reproductive potential of species, leading to a gradual decline in their populations (Photo 3).

Conclusion

As a result, the research area has an important place in Turkey's biodiversity with its rich plant species and diversity. Today, however, this diversity is threatened by human activities such as urbanization, land use, forest fires and deforestation, and mining activities. Muğla, for example, has the highest number of forest fires among the regional directorates of forestry in Turkey. In particular, the wide distribution of red pine forests in the area increases the risk of fire due to the high fire potential of red pines. Muğla has the highest number of endemic species in our research area. Therefore, high fire risk also poses a risk for endemic plant species in the area. In fact, Özhatay N, et al. [25] stated in their study that the communities of Datça Date Palm (*Phoenix theophrasti*), which is the only palm species distributed in Turkey and located within the borders of Muğla (Datça and Bodrum) province in our research area, have faced the danger of extinction due to the fires in the environment in recent years. Again, the research area is one of the places in Turkey where tourism, especially coastal tourism, activities are intense. Therefore, intensive constructions and uses for tourism purposes on the coasts cause damage to these areas. However, the slightly salty coastal lakes and lagoons and coastal dunes on these coasts are among the most important plant areas in Turkey and harbor many endemic species. For example, in our research area, the only Pancratium species known to grow naturally and recorded in Turkey, and also rarely found in nature, the sand lilies (*Pancratium maritimum*), are under serious threat due to tourism activities [45]. As can be seen from these examples, plant biodiversity in the research area is under threat from human activities, and global climate change will make this threat even more serious. As a matter of fact, as a result of our study, it has been observed that there is a statistically significant increase in temperatures in the research area and a decreasing trend in annual total precipitation, although not statistically significant. It has also been determined that there are changes in the seasonal distribution of precipitation, for example, there is a general tendency to decrease precipitation in the winter season and increase precipitation in the summer season. Therefore, these changes, especially changes in temperatures, will affect plant biodiversity by prolonging the vegetation period and changing plant phenology.

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