



Modelling and mapping of current and future potential distribution areas of *Anemone coronaria* L. in Türkiye

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ABSTRACT

Background and Aims This study aim to predict the current and future potential distribution areas of *Anemone coronaria* L., an important geophyte species naturally distributed in Türkiye.

Methods The species' potential distribution modelling and mapping were conducted using the MaxEnt (Maximum Entropy) method. Current climate data were obtained from the WorldClim database, while future projections for the year 2100 were derived from the

UKESM1-0LL global climate model outputs under four Shared Socioeconomic Pathways (SSP) scenarios. Species occurrence records were sourced from the Global Biodiversity Information Facility (GBIF) database.

Results The modelling results indicated that the Area Under the Curve (AUC) values were 0.938 for the training dataset and 0.933 for the test dataset, classifying the model's performance as "excellent." The environmental variables on the species' potential distribution were Annual Precipitation (BIO12), Precipitation of the Warmest Quarter (BIO18), Temperature Annual Range (BIO7), ruggedness, and elevation. Currently, *A. coronaria* shows high habitat suitability concentrated along the coastal zones of the Aegean, Mediterranean, and southern Marmara regions. Future projections suggest varying degrees of habitat contraction depending on the severity of climate change.

Conclusions *A. coronaria* is highly sensitive to climate change and that future habitat contraction could adversely affect its ecological, aesthetic, and cultural values. This study contributes to the sustainable management of *A. coronaria* and provides a model framework for the conservation of other climate-sensitive Mediterranean flora.

Key Words: Climate change, geophyte, MaxEnt, Mediterranean ecosystems, species distribution modeling, SSP scenarios

Türkiye'de *Anemone coronaria* L.'nin günümüz ve gelecekteki potansiyel dağılım alanlarının modellenmesi ve haritalanması

ÖZ

Giriş ve Hedefler Bu çalışmada, Türkiye'de doğal yayılış gösteren önemli bir geofit türü olan *Anemone coronaria* L.'nin, mevcut ve gelecekteki potansiyel dağılım alanlarının tahmin edilmesi amaçlanmaktadır.

Yöntemler Türün potansiyel dağılım modellenmesi ve haritalanması, MaxEnt (Maximum Entropy) yöntemi kullanılarak değerlendirilmiştir. Analizlerde güncel iklim verileri WorldClim veri tabanından, geleceğe yönelik projeksiyonlar ise 2100 yılına ait dört farklı SSP (Sosyo-Ekonomik Yollar) senaryosuna göre UKESM1 0LL küresel iklim modeli çıktılarında elde edilmiştir. Türün var verileri, Küresel Biyoçeşitlilik Bilgi Tesisi (GBIF) veri tabanından temin edilmiştir.

Bulgular Modelleme sonuçlarına göre, modelin eğitim veri seti AUC değeri 0.938, test veri seti AUC değeri ise 0.933 olarak belirlenmiş ve model "mükemmel" kategorisinde yer almıştır. Türün potansiyel dağılımını etkileyen çevresel değişkenler, yıllık Yağış (BIO12), en sıcak çeyreğin yağışı (BIO18), yıllık sıcaklık aralığı (BIO7), engebe ve yükselti olmuştur. Günümüzde *A. coronaria*'nın Ege, Akdeniz ve Güney Marmara kıyı kuşağında yüksek uygunluk gösteren alanlarda yoğunlaştığı ortaya koyulmuştur. Geleceğe yönelik projeksiyonlarda ise, iklim değişikliğinin şiddetine bağlı olarak potansiyel dağılım alanlarında farklı oranlarda daralmalar öngörülmüştür.

Sonuçlar *A. coronaria*'nın iklim değişikliğine yüksek duyarlılık gösterdiğini ve gelecekte potansiyel dağılım alanlarının olası daralmasını türün ekolojik, estetik ve kültürel değerlerini olumsuz yönde etkileyebileceğini göstermektedir. Çalışma, hem *A. coronaria*'nın sürdürülebilir yönetimine katkı sağlamak hem de Akdeniz florasına özgü hassas türlerin korunmasına yönelik model niteliğinde bir yaklaşım sunmaktadır.

Anahtar Kelimeler: İklim değişikliği, geofit, MaxEnt, Akdeniz ekosistemleri, tür dağılım modellenmesi, SSP senaryoları

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1. Introduction

Global climate change is recognized as one of the most significant environmental challenges currently affecting the biosphere (Karl and Trenberth, 2003; Adedeji et al., 2014). Rising temperatures, altered precipitation regimes, drought, extreme weather events, and seasonal shifts directly influence the habitats, distribution ranges, and ecological functions of all organism groups, particularly plants. Changes in plant species distributions accelerate biodiversity loss in sensitive ecosystems and threaten ecosystem functioning (Lloret et al., 2012; Grimm et al., 2013).

Climate change not only alters species' distributions but also undermines interspecific interaction networks, which are fundamental to ecosystem functioning (Tylianakis et al., 2008; Traill et al., 2010). The disruption of ecological processes such as plant-pollinator relationships, seed dispersal, symbiotic interactions, and food web dynamics jeopardizes the continuity of ecosystem services. This loss contributes to declines in biodiversity and weakens ecosystem resilience (Vanbergen and Insect Pollinators Initiative, 2013; Kumar et al., 2024). Altitudinal range shifts, local extinctions, and contractions in species distributions pose threats to endemic, range-restricted, or environmentally sensitive plant species (Vitt et al., 2010; Yan and Tang, 2019). Consequently, predicting the impacts of climate change on species has become critical for the conservation and sustainable use of ecologically and economically important taxa (Hannah et al., 2002; Summers et al., 2012; Foden et al., 2019).

The Mediterranean Basin, one of the region's most strongly affected by climate change, is classified as a global biodiversity hotspot (Medail and Quezel, 1997; 1999). Mediterranean ecosystems, characterized by high endemism rates and a distinctive flora, are highly sensitive to climate change (Valavanidis and Vlachogianni, 2011; Solomou, 2025). Türkiye, as a key component of the Mediterranean Basin, harbors more than 12,000 plant taxa. Among this diversity, bulbous (geophyte) plants hold ecological and economic importance (Mathe and Turgut, 2023). Due to their early flowering, these species contribute to pollinator cycles and are valued in landscape aesthetics (Seyidoğlu et al., 2009; Thomson, 2010; Babarabie et al., 2023). Additionally, their bulbs are harvested as medicinal and aromatic plants, generating economic returns both for domestic markets and export channels. However, this economic potential also increases the risk of overharvesting, exerting pressure on natural populations. For these reasons, bulbous plants are among the plant groups prioritized for conservation in the face of threats such as habitat loss, excessive collection, and climate change (Seyidoğlu and Yayım, 2007).

In this context, *Anemone coronaria* L. stands out as an ecologically and culturally significant geophyte species naturally distributed in the flora of Türkiye (Perevolotsky et al., 2011). Commonly known as "mountain anemone" or "anemone", the species is widespread in the Mediterranean, Aegean, and southern Marmara regions (Güner et al., 2012; Uzunoğlu et al., 2025). *A. coronaria* occurs across a broad altitudinal range from sea level to approximately 900 m. Its natural habitats include *Quercus* shrublands, rocky slopes, and grasslands, with a preference for slightly alkaline soils rich in phosphorus and potassium (Çelik et al., 2004). Flowering in

winter and early spring, *A. coronaria* serves as an early-season food source for a variety of pollinators, including bees, beetles, and flies. This ecological role makes the species a critical component in pollination cycles, supporting the continuity of biodiversity. Moreover, its pronounced floral color polymorphism (red, white, pink, purple-blue tones) attracts diverse pollinator groups, thereby promoting genetic diversity and enhancing adaptive capacity to environmental variability (Dafni et al., 1990; Perevolotsky et al., 2011).

Beyond its ecological functions, *A. coronaria* is notable for its aesthetic and economic value. Its vivid floral colors and elegant morphology make it a desirable ornamental plant, marketed for cut flowers and horticulture (Laura et al., 2025; Uzunoğlu et al., 2025). It is also harvested as a medicinal and aromatic species (Seyidoğlu and Yayım, 2007), with bulb trade contributing to domestic and international markets (Read, 1989; Kamenetsky, 2004). For local communities, this provides an additional income source, while also serving as an attractive feature for ecotourism, botanical tourism, and nature-based tourism (Çakmakçı et al., 2017). However, it is predicted that increasing temperatures, drought and changing precipitation regimes with climate change will lead to narrowing and spatial shifts in the suitable potential distribution areas of plant species (Miranda et al., 2023; Tekeş et al., 2025; Düdükçü Tekeş and Acarer, 2025). Additionally, unsustainable bulb harvesting, rapid population growth, urbanization, grazing, and tourism activities are among the major anthropogenic pressures threatening its natural populations (Turan and Mammadov, 2020). Such multifaceted pressures pose significant risks not only for the sustainability of *A. coronaria* but also for the conservation of other plant species in the region. Accordingly, it is necessary to determine the current and future potential distribution of *A. coronaria* under climate change scenarios using species distribution models.

A review of the literature reveals that research on *A. coronaria* has addressed its ecological traits, pollinator relationships, floral color polymorphism, phenotype, and genotype (Nissim et al., 2004; Dafni et al., 2020; Koçak et al., 2022; Saabna et al., 2025). However, no comprehensive spatial analysis has yet been conducted to assess the species' current and future potential distribution under climate change scenarios. This gap hinders the development of species-specific conservation strategies, particularly in the climate-sensitive Mediterranean Basin. Therefore, in this study, the potential distribution of *A. coronaria* under present conditions and future climate projections for the year 2100 (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) was modelled using the Maximum Entropy (MaxEnt) approach. MaxEnt is widely used in species distribution modelling because it operates with presence-only data, produces high-accuracy results with limited occurrence records, and is open-source (Elith et al., 2006; Phillips et al., 2017; Acarer, 2024). In this study, high-resolution, up-to-date bioclimatic variables were employed to represent the environmental factors influencing the potential distribution of *A. coronaria*. These climate data were obtained from the WorldClim database (<https://www.worldclim.org/>). Based on the results, potential spatial changes in the distribution of *A. coronaria* under current and future conditions were evaluated, and projections regarding its future range dynamics were developed. In this way, the study aims to provide significant

insights into the ecological future of the species, as well as to establish a strategic foundation for science-based planning in its conservation, sustainable use, and assessment of future habitat risks.

2. Materials and Methods

2.1 Study area and species data

The study area, T rkiye, is located between 26°–45° E longitude and 36°–42° N latitude. Situated at the intersection of three distinct phytogeographical regions (Mediterranean, Euro-Siberian, and Irano-Turanian) T rkiye is recognized as one of the world's major centers of plant diversity (Atalay, 2008; G l and D larslan, 2021). This unique position makes T rkiye an important gene center for plant diversity at both regional and global scales (Erg ner et al., 2019).

In this study, the objective was to determine the current and future potential distribution areas of *A. coronaria*, a species naturally occurring across various ecosystems in T rkiye. Presence records for the species were obtained from the Global Biodiversity Information Facility (GBIF) database (GBIF, 2025). The initial dataset contained 22,076 occurrence records compiled at a global scale. These data were spatially filtered to match the boundaries of the study area, resulting in a subset of 786 valid presence records within T rkiye (Figure 1).

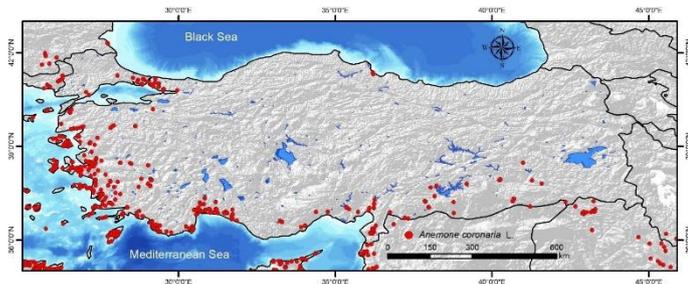


Figure 1. Location map of the study area (T rkiye) and occurrence data of *A. coronaria*

2.2 Methods

2.2.1 Preparation of digital base maps

To generate the digital base maps used in this study, a Digital Elevation Model (DEM) of the study area was first obtained from the United States Geological Survey (USGS) data portal (www.usgs.gov/). The DEM data were processed in ArcMap to match the boundaries of the study area and prepared for analysis.

Using the DEM, various topographic variable maps were generated, including slope, aspect, shading index, topographic position index (TPI), land surface classification, solar illumination index, ruggedness index, roughness index, and solar radiation index. After generating these base maps, additional indices were computed using different equations from the literature. These included the Radiation Index (RI) (Moisen and Frescino, 2002; Aertsen et al., 2010), the Aspect Suitability Index (ASI) (McCune and Keon, 2002), and the Temperature Index (TI) (Parker, 1988).

Climatic data for the study area were obtained from the WorldClim database. The 19 bioclimatic variables developed by Fick and Hijmans (2017) were used to represent both present-day conditions and future (2100) climate projections. For future scenarios, the UKESM1-0-LL (United Kingdom Earth System Model), reported to better represent Mediterranean climate characteristics, was selected (Sellar et al., 2019; Hertig et al., 2023). Climate projections for four Shared Socioeconomic Pathways (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) were downloaded at a resolution of approximately 1 km (30 arc-seconds). All climate data were clipped to the study area and subjected to geometric corrections to ensure compatibility with the modelling process. Finally, all environmental variables and climate projections were saved in ASCII format, creating a dataset suitable for statistical analysis (Table 1).

Table 1. Codes and descriptions of the bioclimatic variables

Code	Description of Climatic Variables
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range
BIO3	Isothermality
BIO4	Temperature Seasonality
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

2.2.2 Statistical analyses and modelling process

In the modelling stage, including highly intercorrelated independent variables simultaneously in the model can lead to multicollinearity issues (Feng et al., 2019). To prevent this, a correlation analysis was first conducted on the variables, followed by factor analysis to identify representative variables. The 19 bioclimatic variables known to exhibit high correlation in the literature (Acarer, 2025; G l, 2025) were subjected to factor analysis, and those with the highest explanatory power among the environmental variables were selected. Pairwise relationships between the selected climatic and topographic variables were re-evaluated using Pearson's correlation coefficient. As a result of this process, only variables that did not show a correlation of $p \geq 0.80$ were included in the modelling process.

2.2.3 Model accuracy

Within the MaxEnt framework, model performance was evaluated using the Area Under the Curve (AUC) metric, which is automatically calculated by the software (Phillips and Dud k,

2008). Accordingly, the AUC value was employed to assess model accuracy. Based on the classification proposed by Swets (1988), AUC values ≥ 0.90 are considered “excellent,” 0.81–0.90 “very good,” 0.71–0.80 “good,” 0.61–0.70 “low,” and values below 0.60 “failures” (Özdemir, 2022). To determine the optimal model performance, the model with the smallest difference between training and test AUC values, while also exhibiting the highest overall AUC score, was selected (Baldwin, 2009). Once the best-performing model was identified, UKESM1-0-LL climate projection data were used to estimate the potential distribution of *A. coronaria* for the year 2100 under different emission scenarios.

3. Results

3.1 Variable selection

According to the factor analysis results, the four extracted components explained 93.95% of the total variance (Table 2). A variance value greater than 1 and a variance percentage exceeding 10% indicate that these axes adequately represent the main variability in the dataset (Kaiser, 1960; Gorsuch, 1974). Therefore, it was decided that the bioclimatic variables to be used in the modeling process would be selected based on these four axes (Table 3).

Table 2. Variance explanation values of axes based on factor analysis

	Total	% of Variance	Cumulative Variance %
1	6.80	35.81	35.81
2	5.72	30.13	65.94
3	3.46	18.23	84.17
4	1.86	9.77	93.95

Table 3. Factor analysis results

	Component			
	1	2	3	4
BIO1	0.833	0.223	-0.239	0.405
BIO2	-0.107	0.917	0.147	0.185
BIO3	0.181	0.459	0.193	0.464
BIO4	-0.292	0.904	0.094	-0.156
BIO5	0.250	0.947	-0.032	0.170
BIO6	0.704	-0.609	-0.252	0.241
BIO7	-0.234	0.963	0.122	-0.025
BIO8	0.652	-0.447	-0.280	0.491
BIO9	0.560	0.737	-0.157	0.196
BIO10	0.515	0.761	-0.150	0.241
BIO11	0.800	-0.385	-0.250	0.378
BIO12	0.248	-0.138	0.931	0.061
BIO13	0.540	-0.121	0.825	-0.023
BIO14	-0.804	-0.156	0.244	0.489
BIO15	0.913	0.090	0.008	-0.318
BIO16	0.556	-0.109	0.819	-0.038
BIO17	-0.790	-0.184	0.280	0.497
BIO18	-0.787	-0.174	0.277	0.506
BIO19	0.582	-0.041	0.799	-0.049

Based on the factor analysis results, the variables with the highest explanatory loadings on each axis were identified as BIO7, BIO12, BIO15, and BIO18, and these were selected as representative variables. Subsequently, the relationships between these variables and the topographic variables were

evaluated using Pearson’s correlation analysis. Variables exhibiting high correlations at $p \geq 0.80$ were excluded to prevent multicollinearity issues. As a result, a total of 14 environmental variables comprising 3 bioclimatic and 11 topographic variables were retained for the modelling process (Table 4).

Table 4. Code and description of environmental variables entering the model

Code	Description
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO12	Annual Precipitation
BIO18	Precipitation of Warmest Quarter
ELEV	Elevation
LANDFORM	Landform Classification Index
ASPECT	Aspect
SLOPE	Slope
RUGGED	Ruggedness Index
HILLSHADE	Hillshade
RI	Radiation Index
HEAT	Heat Index
SOLARRAD	Solar Radiation Index
SOII	Solar Illumination Index
TPI	Topographic Position Index

3.2 Modelling and mapping the current potential distribution of *A. coronaria*

During the modelling process, a 10-fold cross-validation procedure was applied, and the number of iterations was set to 5,000 (Phillips et al., 2006). To identify the variables contributing most to the model, a variable selection approach based on contribution rates was employed, and the model explaining the best relationship between dependent and independent variables was selected. Applying the model across the entire study area yielded a potential distribution map for *A. coronaria* under current climatic conditions. Performance evaluation indicated that the selected model had an omission curve (Figure 2a), a training AUC value of 0.938, and a test AUC value of 0.933 (Figure 2b). According to the classification of Swets (1988), the model falls within the “excellent” category.

Examination of the Jackknife test results revealed that the variables contributing most to the model were, in order, elevation (ELEV), Temperature Annual Range (BIO7), Precipitation of the Warmest Quarter (BIO18), ruggedness (RUGGED), and Annual Precipitation (BIO12). In the graph, the light blue bars represent the change in model performance when each variable is omitted, the dark blue bars indicate the independent contribution of each variable to the model, and the red bars show the combined effect of all variables. For model consistency, the dark blue bars are expected not to exceed the light blue bars. In this study, the Jackknife test results indicated that all variables included in the model were compatible (Figure 3).

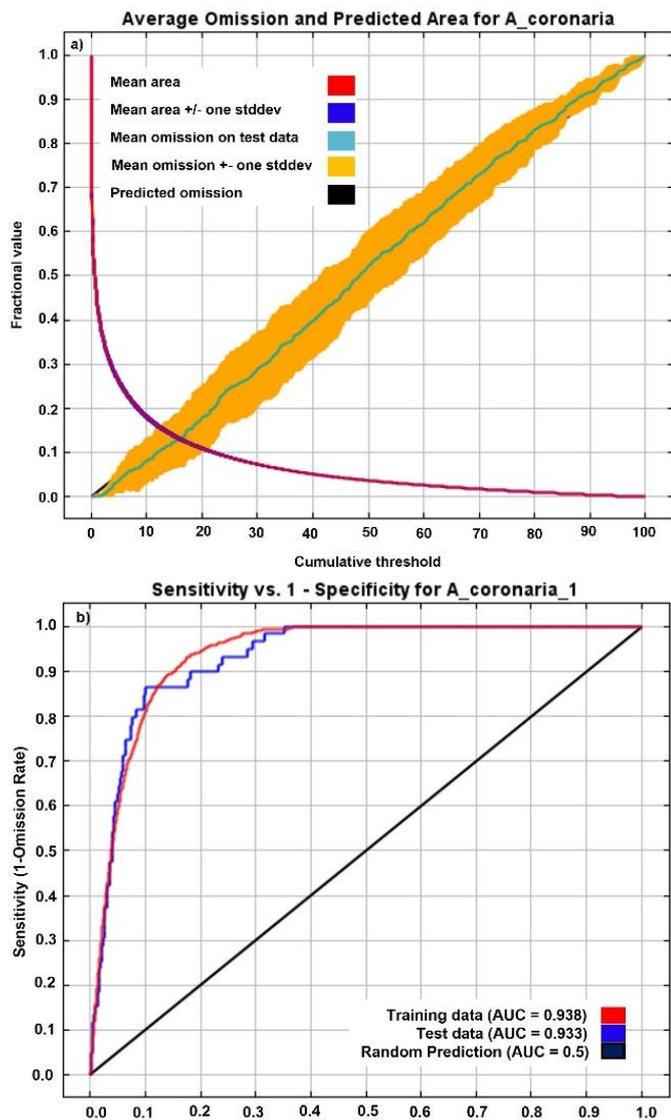


Figure 2: (a) Mean omission rate and estimated distribution area of *A. coronaria* (b) ROC curve and AUC value of *A. coronaria*



Figure 3. Jackknife chart of current distribution model of *A. coronaria*

The marginal response curves for each variable are presented below. According to the model results, elevation was the most influential factor in the distribution of *A. coronaria*. The probability of occurrence was highest in low-altitude areas, peaking between 0–200 m, declining sharply above 1,000 m, and disappearing entirely at elevations of 2,500 m and higher (Figure 4a). This finding indicates that *A. coronaria* typically occurs in coastal and lowland areas influenced by maritime conditions, whereas at higher elevations, its ecological limits begin to be exceeded.

For the second most important variable, Temperature Annual Range (BIO7), the highest probability of occurrence was observed within the 15–20°C range, while habitat suitability gradually decreased as the temperature range increased. At temperature ranges of 35°C and above, the probability of occurrence dropped markedly (Figure 4b). This pattern demonstrates that *A. coronaria* is well adapted to Mediterranean climatic conditions and has a limited distribution in continental climates.

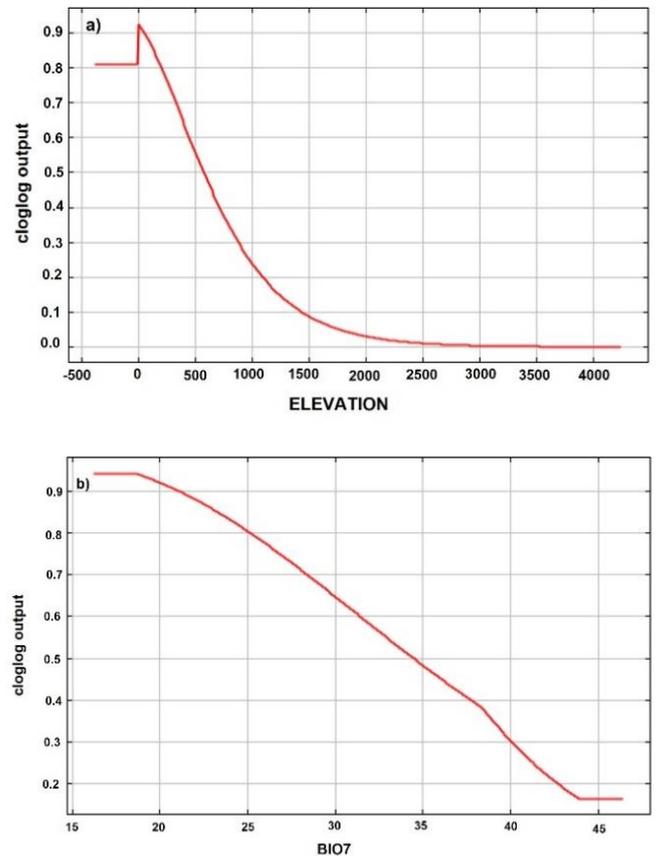


Figure 4. *A. coronaria* contributing to current potential model: a) elevation graph and b) Temperature Annual Range (BIO7)

The third variable, Precipitation of the Warmest Quarter (BIO18), indicated that *A. coronaria* has a higher probability of occurrence under low-precipitation conditions during the summer or the warmest three-month period. The probability of occurrence peaked particularly when summer precipitation was below 50 mm but declined at values above 100 mm (Figure 5a). This finding suggests that *A. coronaria* has developed a life strategy adapted to the summer drought typical of Mediterranean climates.

The fourth variable, ruggedness index (RUGGED), showed that the species prefers moderately rugged areas. The highest probability of occurrence was observed within the range of 0.682–0.684. In contrast, both very low ruggedness values (flat terrains) and extremely rugged, steep slopes were associated with reduced occurrence probabilities (Figure 5b). This pattern indicates that *A. coronaria* predominantly inhabits stony grasslands, gently sloping hillsides, and microhabitats where agricultural pressure is relatively low.

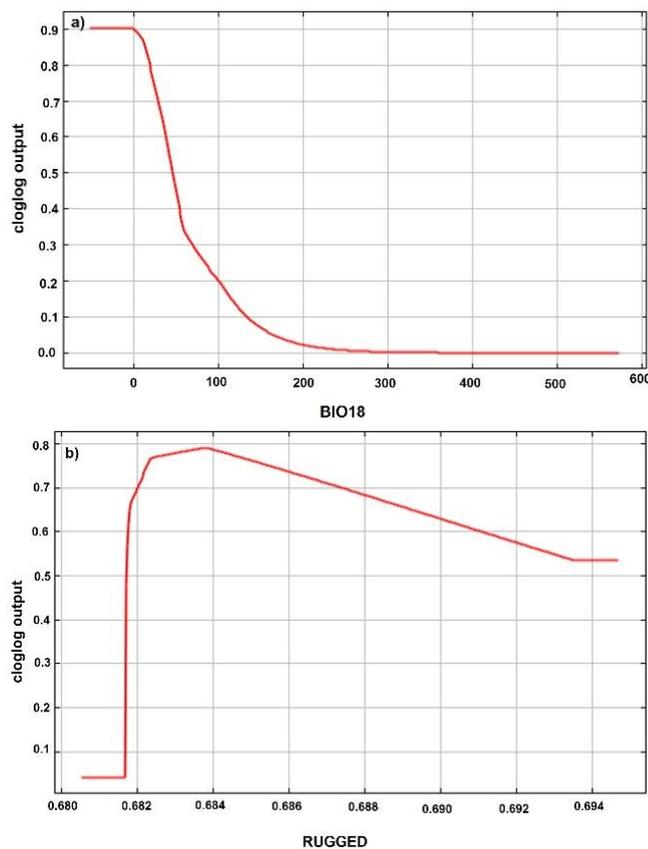


Figure 5. *A. coronaria* contributing to current potential model: a) Precipitation of Warmest Quarter (BIO18) graph and b) RUGGED (ruggedness index) graph

For the final variable, Annual Precipitation (BIO12), the probability of occurrence of *A. coronaria* was found to be low at precipitation values up to approximately 300 mm, increased between 300 mm and 1,100 mm, and then gradually declined between 1,100 mm and 1,500 mm. When precipitation exceeded 1,700 mm, the probability of occurrence dropped to zero (Figure 6). This pattern indicates that the species possesses an ecological tolerance adapted to the semi-arid to humid conditions characteristic of the Mediterranean climate.

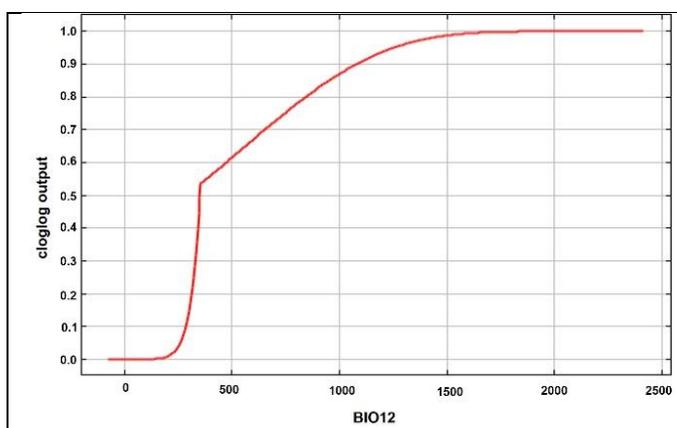


Figure 6. *A. coronaria* contributing to current potential model: a) Annual Precipitation (BIO12)

According to the modeling results, the current potential distribution map indicates that *A. coronaria* in Türkiye is predominantly concentrated along the coastal zones of the Aegean, Mediterranean, and southern Marmara regions. This coastal concentration pattern reflects the climatic characteristics typical of the Mediterranean climate. In particular, the species' high habitat suitability in these regions is primarily attributed to its adaptation to summer drought, mild winter conditions, and narrow annual temperature ranges. In contrast, the probability of occurrence is considerably lower in Central Anatolia, Eastern Anatolia, and along the Black Sea coast. This suggests that high elevations, wide temperature fluctuations, or excessively humid climatic conditions act as limiting factors for *A. coronaria* (Figure 7).

3.3 Future potential distribution maps of *A. coronaria*

Using the occurrence data for *A. coronaria* and the model developed for current conditions, potential distribution maps for the period 2081–2100 were generated under four different climate scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) based on the UKESM1-0-LL projection.

3.3.1 Future mapping 1 (SSP1-2.6 scenario)

Under the SSP1-2.6 (optimistic) scenario, the potential distribution of *A. coronaria* largely mirrors its current pattern, with suitable habitats concentrated along the Aegean coast, southern Marmara, and the Mediterranean region. This indicates that climatic conditions consistent with the species' ecological niche are expected to persist to a great extent. However, a limited contraction in potential distribution areas is observed, particularly in certain coastal parts of southwestern Anatolia and the eastern Mediterranean. This reduction suggests that moderate increases in temperature and changes in precipitation regimes could partially decrease habitat suitability in areas approaching the species' ecological tolerance limits. Overall, the SSP1-2.6 scenario projects that most of *A. coronaria*'s potential distribution will be maintained, offering an encouraging outlook for the species' long-term persistence (Figure 8).

3.3.2 Future mapping 2 (SSP2-4.5 scenario)

Under the SSP2-4.5 (intermediate) scenario, the potential distribution of *A. coronaria* shows a tendency toward contraction compared to the current distribution map. Notably, along the Aegean coast and in both the eastern and western Mediterranean regions, some areas that currently exhibit high occurrence probability have shifted to moderate suitability classes; areas with suitability values of 0.8–1.0 have been replaced by values of 0.4–0.6. These results indicate that, under the SSP2-4.5 scenario, rising temperatures and changes in summer precipitation patterns are pushing the species toward the limits of its ecological tolerance. In particular, the combined effects of increased summer precipitation and a wider annual temperature range appear to constrain the potential distribution of *A. coronaria* to narrower coastal zones (Figure 9)

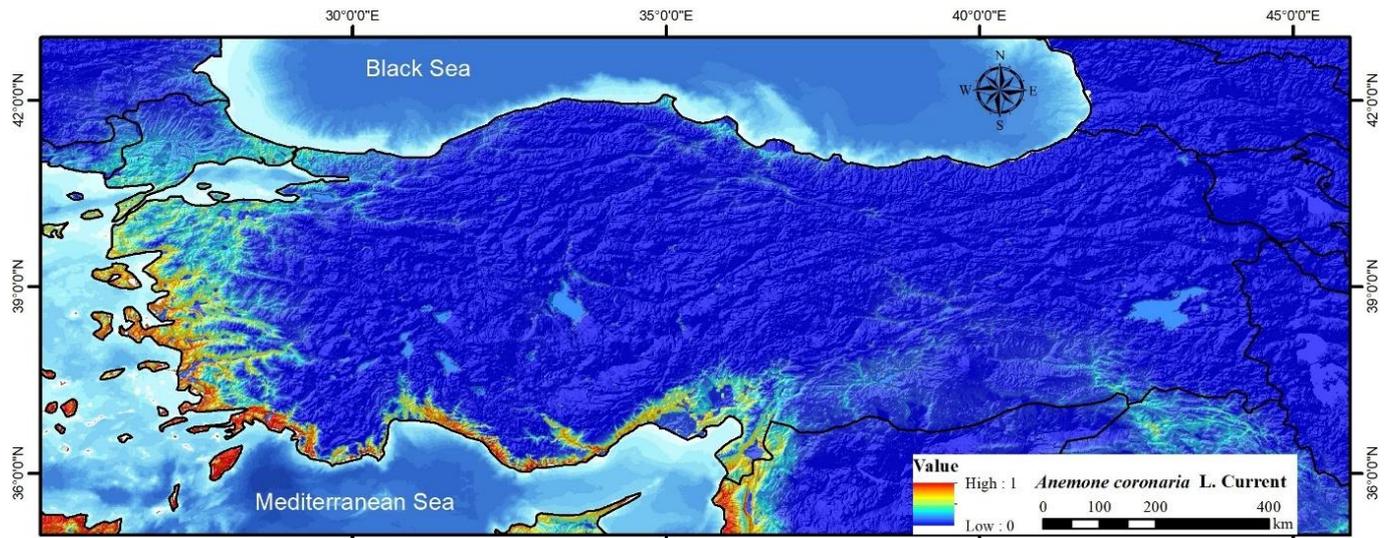


Figure 7. Potential distribution map of *A. coronaria* according to current climatic conditions

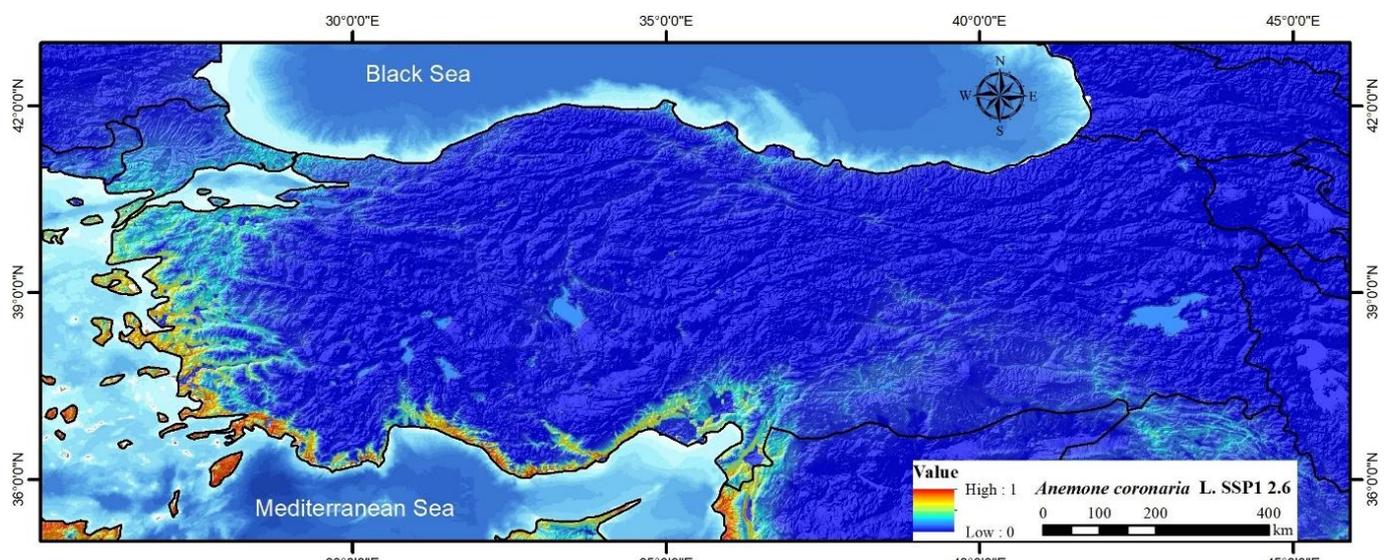


Figure 8. Potential distribution map of *A. coronaria* for the year 2100 under the SSP1-2.6 scenario

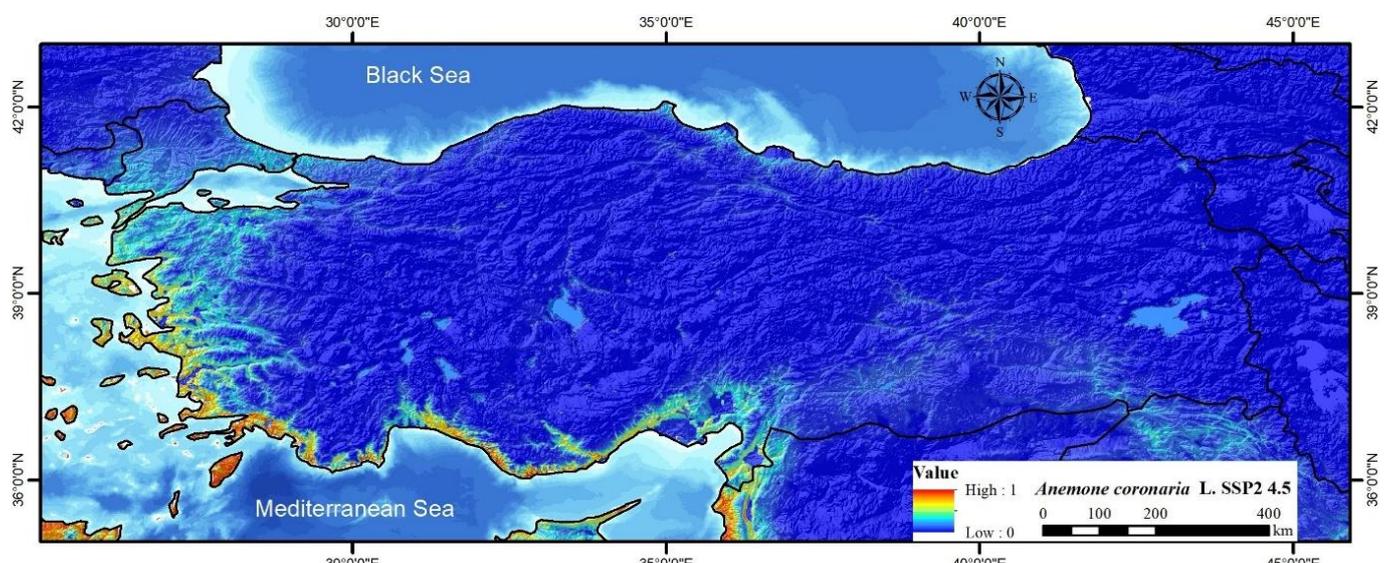


Figure 9. Potential distribution map of *A. coronaria* for the year 2100 under the SSP2-4.5 scenario

3.3.3 Future mapping 3 (SSP3-7.0 scenario)

Under the SSP3-7.0 (moderately pessimistic) scenario, the potential distribution of *A. coronaria* shows a pronounced contraction compared to the current distribution map. In this scenario, much of the potential habitat along the Aegean, Mediterranean, and southern Marmara coasts areas that presently exhibit high occurrence probabilities has diminished substantially, with many regions shifting from suitability values of 0.8–1.0 down to 0.4–0.6. The most pronounced losses are observed along the coastal areas of western Anatolia and in the eastern Mediterranean. This contraction is associated with rising temperatures, alterations in summer precipitation, and an expansion of the annual temperature range. The species appears to be retreating from areas expected to experience greater continental climatic influence, where suitability values remain low. The model results suggest that under this scenario, the ecological niche of *A. coronaria* would contract significantly, leading to substantial losses in its potential distribution range (Figure 10).

3.3.4 Future mapping 4 (SSP5-8.5 scenario)

Under the SSP5-8.5 (most pessimistic) scenario, the potential distribution of *A. coronaria* is projected to undergo a severe ecological contraction. In this scenario, much of the habitat along the Aegean and Mediterranean coastal zones areas that currently exhibit high occurrence probabilities disappears, with suitability values in the 0.8–1.0 range declining substantially to 0.2–0.4. Significant losses in habitat suitability are observed in western Anatolia, the eastern Mediterranean, and the southern Marmara regions, with potential distribution areas shrinking considerably within coastal ecosystems. These results indicate that, under the SSP5-8.5 scenario, extreme temperature increases, disruptions in drought cycles, and increased summer precipitation are likely to cause a substantial reduction in the species' ecological niche. Model projections suggest that in the future, *A. coronaria* may persist only within a few highly localized, microclimatically suitable areas along the coastal belt (Figure 11).

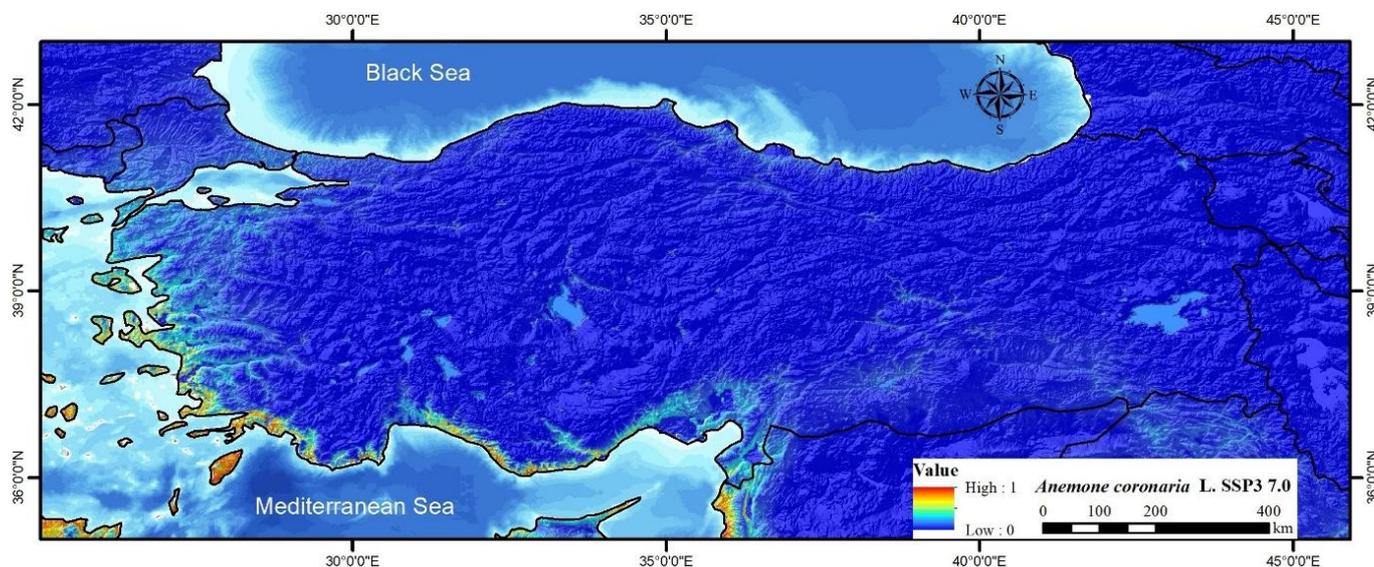


Figure 10. Potential distribution map of *A. coronaria* for the year 2100 under the SSP3-7.0 scenario

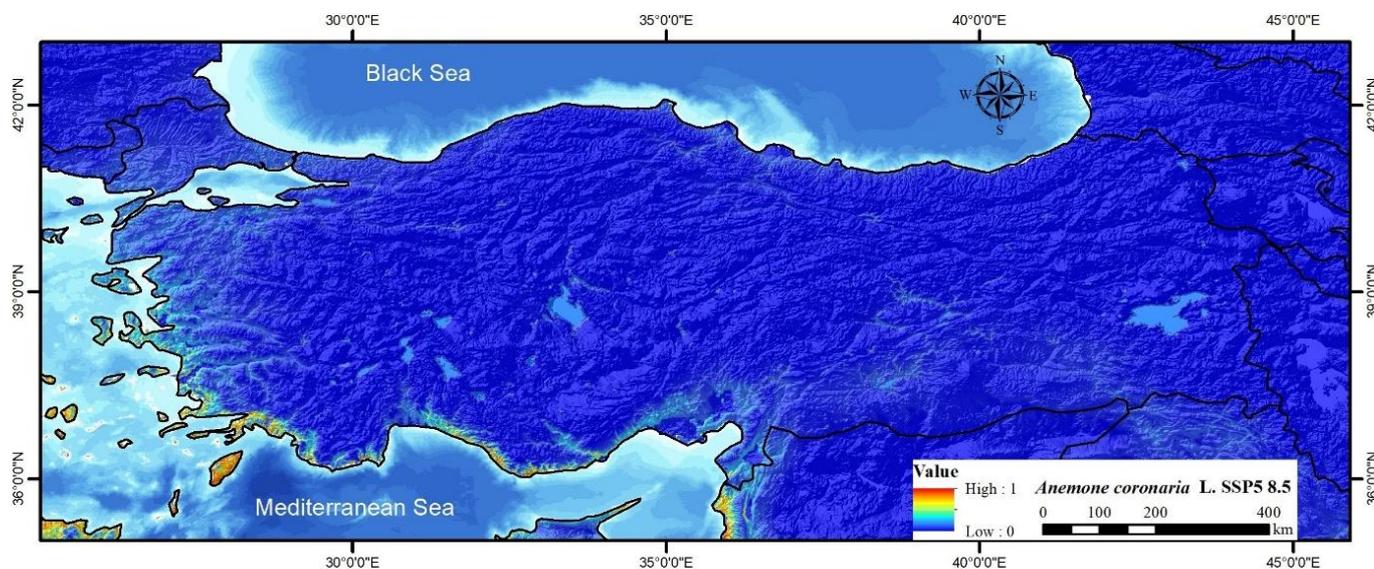


Figure 11. Potential distribution map of *A. coronaria* for the year 2100 under the SSP5-8.5 scenario

4. Discussion

In this study, the potential distribution of *A. coronaria* in Türkiye under current climatic conditions and four future climate change scenarios for the year 2100 (SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5) was analyzed using the MaxEnt approach. The findings reveal that, at present, the species is concentrated along the coastal zones of the Aegean, Mediterranean, and southern Marmara regions, a distribution consistent with ecological traits such as low elevation preference, tolerance to summer drought, and a narrow annual temperature range. Future projections indicate substantial changes in the species' potential distribution depending on the climate change scenario. Under the optimistic SSP1-2.6 scenario, most potential habitats are expected to be maintained, with only minor contractions in coastal ecosystems. Under the intermediate SSP2-4.5 scenario, high-suitability areas, particularly along the Aegean coast and in the western Mediterranean, are projected to shift to moderate suitability classes. The more pessimistic scenarios, SSP3-7.0 and SSP5-8.5, project severe range contractions. In the SSP3-7.0 scenario, even coastal ecosystems are reduced to only microclimatically favorable zones, while in the SSP5-8.5 scenario, extreme temperature increases and changes in precipitation regimes are expected to cause the species to retreat almost entirely from the coastline, persisting only in a few highly localized refugial areas.

These findings align with previous research demonstrating the high sensitivity of Mediterranean plant species to temperature increases and changes in precipitation regimes (Peñuelas et al., 2002). For instance, a study on *Anemone moorei* a range-restricted and endangered species predicted that climate change could render its current potential distribution entirely unsuitable by 2055 (Alarcón et al., 2023), supporting the likelihood that *A. coronaria* faces a similar ecological contraction risk. Likewise, species distribution modelling studies focusing on endemic and range-restricted plants with high climate sensitivity have projected losses of 26–100% in their optimal habitats (Alves-de-Lima et al., 2025).

Previous research on the biology of *A. coronaria* also helps explain the potential ecological impacts of climate change. For example, Dafni et al. (1990) reported that the species' early flowering is closely linked to its pollination strategy, while Dafni et al. (2020) found that it can maintain genetic diversity even under varying environmental conditions. Nevertheless, climate change poses potential risks to this genetic diversity. Rising temperatures and altered seasonal patterns may negatively impact the species' ecological cycle, particularly by increasing the risk of water stress or bulb rot during dormancy (Ben-Hod et al., 1988; Umiel et al., 1992). Similar threats have also been reported for other geophyte species in the Mediterranean flora (Mondoni et al., 2009).

Beyond its ecological functions, *A. coronaria* holds notable economic and cultural value. It plays an important role in landscape aesthetics, nature-based tourism, non-wood forest product (NWFP) trade, and ecotourism, particularly contributing to rural development through the export of wild-harvested bulbs. However, population declines due to habitat loss and climate change threaten the sustainability of this economic value. The continuation of uncontrolled bulb harvesting in parallel with the impacts of climate change poses

a serious threat to the species' future viability (Turan and Mammadov, 2020).

In this context, the study's findings highlight the necessity of designing conservation strategies with a focus on climate change adaptation. Such strategies should include the establishment of conservation zones in coastal and lowland natural areas, habitat restoration, seed and bulb banking, monitoring of genetic diversity, and the implementation of sustainable NWFP management practices. Furthermore, promoting the sustainable use of the species in local ecotourism activities and landscape applications would yield both ecological and socio-economic benefits.

In conclusion, this study demonstrates that *A. coronaria* exhibits high sensitivity to climate change in Türkiye, with its potential distribution projected to contract substantially, particularly under high-emission scenarios. Ensuring the species' long-term sustainability will require integrated approaches that combine climate adaptation policies, habitat protection measures, and local development strategies. Moreover, the case of *A. coronaria* serves as a strong indicator of the urgent need for proactive climate change mitigation measures for other climate-sensitive plant species characteristic of the Mediterranean flora.

5. Conclusion

This study represents an important step toward understanding the impacts of climate change on *A. coronaria*. Analyses conducted under different climate scenarios reveal projected changes in the species' future potential distribution, providing critical insights into possible ecological transformations that may influence the structure and functioning of ecosystems. Such information holds strategic significance for biodiversity conservation, the sustainability of ecosystem services, and the long-term persistence of the species. In light of the findings, comprehensive and practical strategies should be developed for the conservation of *A. coronaria*. As a priority, identifying and protecting microclimatic refugia is considered critical for the species' survival during periods of climatic stress. Additionally, integrating in situ and ex situ conservation approaches is essential to safeguard both natural habitats and genetic material. It is equally important to control adverse factors that may disrupt the species' ecological cycle particularly grazing pressure during its early growth stages. Furthermore, the initiation of long-term ecological monitoring programs will enable systematic documentation of population dynamics, flowering phenology, and pollinator interactions, facilitating early detection of potential risks. Active participation of local communities will increase the likelihood of successful conservation outcomes. In this regard, awareness-raising activities, ecotourism initiatives, and sustainable use practices should be planned to generate both ecological and socio-economic benefits. Finally, all proposed conservation and management measures should be integrated with national biodiversity strategies and climate policies to ensure the species' long-term sustainability.

This research is one of the first comprehensive studies to assess *A. coronaria* using current climate scenarios, considering its study area, methods, and evaluated parameters. As such, it fills a gap in the literature and serves as an important reference

for both conservation practitioners and policymakers. Moreover, the results can guide future research on similar species in other regions, contributing to the advancement of scientific and applied conservation efforts for climate-sensitive plant species characteristic of the Mediterranean flora.

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