scientific reports

OPEN

Effect of climate change on current and future potential distribution of Strawberry tree (*Arbutus unedo* L.) in Türkiye

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The demand for nontimber forest products (NTFPs) has increased significantly in recent years. Hundreds of plant species that grow naturally in Türkiye have medicinal and aromatic value. Medicinal and aromatic plants are primarily used as a sources of tea, spices, condiments and essential oils. Species belonging to the genus *Arbutus* L. are used for decorative purposes and as fuel wood in many wood-based industries, they also have a wide range of uses in packaging, chairs making and furniture production. Additionally, the fruits of these trees are widely consumed by humans and animals because they are rich in sugar and vitamin C. It is predicted that changes in climatic conditions will significantly change the distribution, composition and function of forests threatening biodiversity. The purpose of this study was to model current and future potential geographical distributions of *Arbutus unedo* L., which is among the species that naturally grow in Türkiye and is of substantial value in terms of its ecological contribution to forest ecosystems, based on species presence data and environmental variables (bioclimatic variables and altitude). The current and future distribution area models for *Arbutus unedo* L. indicate that the potential distribution areas of the species in the coming years will gradually decrease, and in the SSP5 8.5 model, which represents the highest level of world resource usage this gradual decrease will reach its highest level and there will be no suitable distribution area left for the species. Therefore, it is predicted that the species will become endangered. In-situ and ex-situ conservation measures need to be taken to ensure the sustainability of the species in forestry and landscape areas.

Climate change has caused forest communities to expand, contract or shift over the long term, they northwards as the climate warms and toward the south as it cools[1,2]. Global scientific studies and observations indicate that, due to climate change, plants will migrate to high altitudes and this will continue to occur over the next 100 years[3–5]. Climate change increases the risk of extinction of plant species by negatively affecting biodiversity and the geographical distribution of species[6,7]. The biological responses of species to climate change can result in three different situations[6,8]. First, the target species may migrate to another region by following ecological niches[4,9]; second, the species could adapt to the new climatic conditions of their current location and third, local extinction could occur[10–12]. To elucidate the specific impacts of climate change on species and reduce the negative effects of climate change on ecosystems and biodiversity, conservation strategies need to be integrated with species distribution modelling to identify suitable habitats for various species[13–16]. Species distribution models (SDMs) provide insights into future biogeographical attributes[17,18]. MaxEnt, based on the maximum entropy algorithm, is a tool used to model the suitable distribution areas of species and is based on a species distribution model[19,20]. The working principle of the MaxEnt algorithm is based on estimating potential distribution areas using data (sample points representing the natural distribution areas of the species) and bioclimatic variables (environmental variables)[21,22].

Members of the *Arbutus* genus, which belongs to the Ericaeae family, are woody plants that do not shed their leaves in winter and are bushes and shrubs. *A. unedo* L. and *A. andrachne* L. grow naturally in Türkiye[23]. These two species are undoubtedly of great importance for forestry. This importance stems from the fact that the wood of the tree species belonging to this genus is used for decorative purposes and as fuel wood in many wood-based

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industries, with or without alterations to its structure; it also has a wide range of uses in packaging, chair-making and furniture-making. In addition to these areas of use, the fruits of these trees are widely consumed by humans and animals because they are rich in sugar and vitamin C[24,25].

In this study, the current geographical distribution areas of *Arbutus unedo* in Türkiye and its potential geographical distribution areas in ~ 2050 and ~ 2090 according to the MIROC-ES2L model SSP2 and SSP5 scenarios were determined by using MaxEnt 3.4.1 software and other geographic information system (GIS) programs and tools. We aimed to predict and determine how the spatial distribution of the identified species will change. The MIROC-ES2L, Earth System Model (ESM) is the Model for Interdisciplinary Research on Climate (MIROC), which is known as Earth System version 2 and is used for long-term simulations[26]. The SSPs created for the models are based on five narratives that describe broad socioeconomic trends that may shape future societies, predicting how socioeconomic conditions will affect the implementation of climate policy. However, SSP2, which is used in the study, represents a moderate level of mitigation and adaptation, and SSP5 represents a high level of use of fuel and world resources.

Materials and methods
Study region and occurrence data
The occurrence data for Strawberry tree (*Arbutus unedo*) were obtained from the Flora of Türkiye, GBIF (global biodiversity advisory facility), TUBIVES (Turkish plant data service) and from literature reviews[27–34]. The data obtained from the Flora of Turkey[30], TUBIVES[33] and literature reviews were based on local field observations. The data obtained from GBIF[25] were filtered with base maps, and points that were located in areas where the species would not show a natural distribution (agricultural land, settlements, dunes, etc.) were eliminated and not included in the study. A total of 43 points were selected as the sample area were processed in QGIS 3.24, and were converted to csv format to be input into the MaxEnt algorithm[35]. The sample points and the study area are shown in (Fig. 1), and the attributes of the sample points are shown in (Table 1).

The algorithm takes the projection of the sample points on climatic variables, yields the attribute information of the species in those areas and determines points suitable for the species based on the determined attributes by randomly assigning points in the background. Areas that have similar attributes in the obtained and future projection data are considered suitable distribution areas for the species. In this study, 10000 background points were used according to the area size.

Climate data
In this study, the model was first generated using all variables (Table 2). Then the impact levels of the bioclimatic variables were determined by using the jackknife (pull-out) test, and according to the results, the model was reconstructed using 9 high-impact variables[36–38]. The variables used in the newly created model were BIO 2, BIO 4, BIO 6, BIO 8, BIO 12, BIO 13, BIO 14, BIO 15 and BIO 18. Two different models were constructed for two shared socioeconomic pathways (SSP2-4.5 and SSP5-8.5) under greenhouse warming scenarios. All variable rasters were at a 30 arc-second resolution.
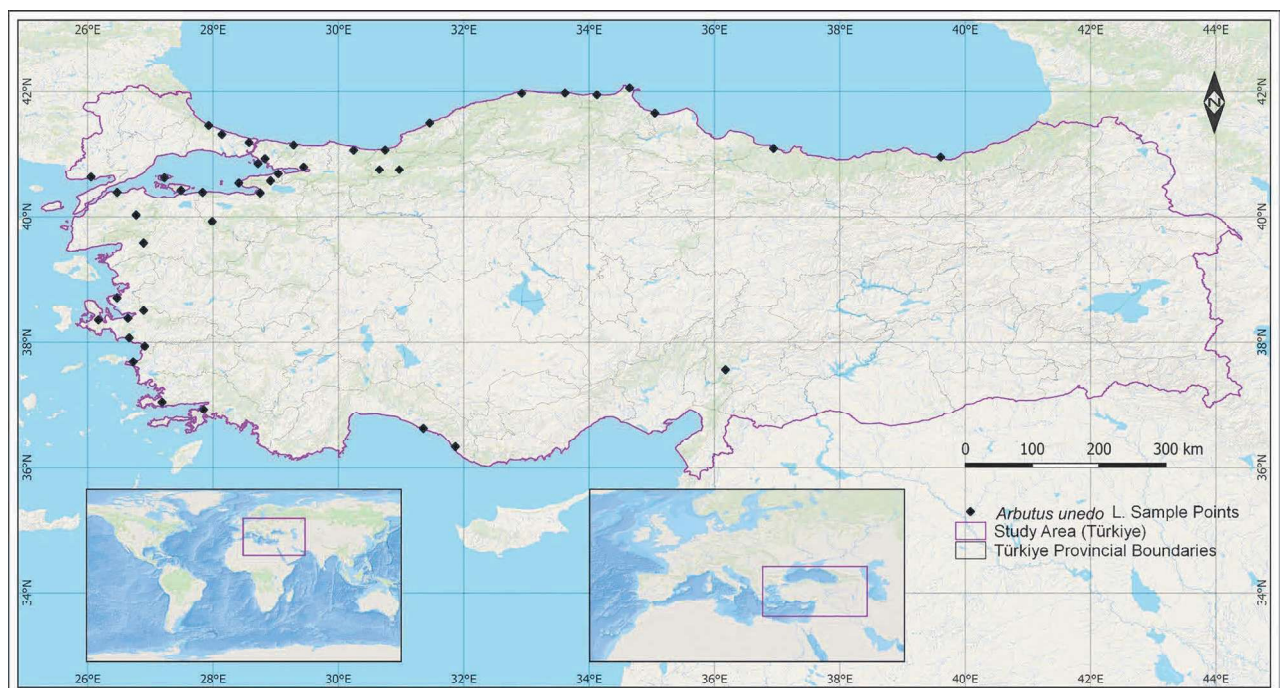

Figure 1. Input data for the maximum entropy area of *Arbutus unedo* at the study boundary—created using QGIS v3.24[35].

	X (Latitude)	Y (Longitude)	Region	Province	Altitude (m)	Avr. Temperature (°C)	Precipitation (mm)
1	28.3309	41.45786	İstanbul	Çatalca	60.0	13.4	54.0
2	28.54114	41.31712	İstanbul	Çatalca	41.0	13.6	56.6
3	28.97641	41.18794	İstanbul	Sarıyer	121.0	13.3	62.4
4	29.11764	40.85213	İstanbul	Adalar	52.0	13.7	57.4
5	29.22997	40.93091	İstanbul	Kartal	286.0	13.4	61.3
6	29.68655	41.14682	İstanbul	Şile	56.0	13.5	70.8
7	26.5725	38.35556	İzmir	Urla	282.0	16.0	52.6
8	26.87057	38.71405	İzmir	Foça	83.0	16.0	56.1
9	27.04387	38.38178	İzmir	Balçova	92.0	16.2	57.9
10	27.06298	38.06904	İzmir	Menderes	350.0	15.9	58.2
11	27.29505	38.50646	İzmir	Bornova	372.0	15.3	60.3
12	27.31167	37.93611	İzmir	Selçuk	31.0	17.0	56.8
13	26.87023	40.39119	Çanakkale	Lapseki	107.0	14.3	55.4
14	27.1739	40.02976	Çanakkale	Çan	532.0	12.7	61.0
15	31.75599	36.62793	Antalya	Alanya	110.0	18.8	86.0
16	32.26675	36.33537	Antalya	Alanya	166.0	17.7	70.8
17	27.12774	37.68887	Aydın	Kuşadası	597.0	16.8	58.3
18	27.29357	39.5864	Balıkesir	Havran	390.0	13.3	60.1
19	27.62416	40.61863	Balıkesir	Marmara	425.0	12.5	58.1
20	27.88967	40.42239	Balıkesir	Erdek	335.0	13.1	58.8
21	28.23438	40.39042	Bursa	Karacabey	392.0	12.8	58.7
22	28.38797	39.92693	Bursa	Mustafakemalpaşa	248.0	13.5	53.5
23	29.15241	40.38075	Bursa	Gemlik	266.0	13.8	50.4
24	31.05444	40.75	Düzce	Gölyaka	162.0	12.6	66.6
25	31.14545	41.06621	Düzce	Akçakoca	72.0	12.8	79.4
26	31.37232	40.75032	Düzce	Kaynaşlı	683.0	10.7	51.3
27	26.45569	40.63197	Edirne	Keşan	62.0	14.3	52.3
28	36.57478	37.56701	Kahramanmaraş	Onikişubat	1484.0	11.1	55.8
29	33.32601	41.9706	Kastamonu	Cide	242.0	12.2	63.6
30	34.01623	41.97514	Kastamonu	Abana	241.0	13.0	85.8
31	29.84549	40.79554	Kocaeli	Derince	168.0	12.7	61.6
32	27.58787	37.05126	Muğla	Bodrum	198.0	18.2	64.5
33	28.25028	36.9299	Muğla	Marmaris	350.0	17.3	82.9
34	37.34234	41.09298	Ordu	Ünye	112.0	11.6	69.8
35	30.64384	41.06386	Sakarya	Karasu	103.0	13.4	74.6
36	35.44983	41.65569	Samsun	Yakakent	154.0	13.3	55.4
37	34.52447	41.94673	Sinop	Ayancık	130.0	12.7	67.9
38	35.04644	42.05634	Sinop	Sinop merkez	1.0	13.9	58.4
39	40.00892	40.95549	Trabzon	Araklı	203.0	13.9	93.8
40	28.81269	40.53683	Yalova	Armutlu	254.0	13.2	53.3
41	29.3174	40.57022	Yalova	Yalova merkez	432.0	12.6	54.8
42	29.44056	40.68205	Yalova	Altınova	79.0	14.2	57.4
43	31.85672	41.49677	Zonguldak	Kilimli	97.0	13.3	95.0

Table 1. Information on the attributes of *Arbutus unedo* L.

Statistical model

MaxEnt modelling was carried out using the 'auto features' feature. The success of the model was measured by obtaining the AUC (area under the ROC curve) value extracted from ROC (receiver operating characteristic) analysis[39,40]. The AUC value is interpreted as the estimated probability of the existence of a randomly determined grid cell, and if the AUC value is > 0.5, the model performs better than a random guess[41].

As the AUC approaches 1, the sensitivity of the model increases and more accurate predictions are made[42–45]. Five classifications were made for maps of potential distribution areas (0 is not suitable, 0–0.25 is slightly suitable, 0.25–0.50 is slightly suitable, 0.50–0.75 is suitable and 0.75–1.0 is very suitable). After the classifications were made, the maps obtained as raster were converted into vector format, and the areal coverage is presented in tables.

Variable	Description
BIO 1	Annual mean temperature
BIO 2	**Mean diurnal range (mean of monthly (max temp − min temp))**
BIO 3	Isothermality (WC2/WC7) (× 100)
BIO 4	**Temperature seasonality (standard deviation × 100)**
BIO 5	Max temperature of warmest month
BIO 6	**Min temperature of coldest month**
BIO 7	Temperature annual range (WC5–WC6)
BIO 8	**Mean temperature of wettest quarter**
BIO 9	Mean temperature of driest quarter
BIO 10	Mean temperature of warmest quarter
BIO 11	Mean temperature of coldest quarter
BIO 12	**Annual precipitation**
BIO 13	**Precipitation of wettest month**
BIO 14	**Precipitation of driest month**
BIO 15	**Precipitation seasonality (coefficient of variation)**
BIO 16	Precipitation of wettest quarter
BIO 17	Precipitation of driest quarter
BIO 18	**Precipitation of warmest quarter**
BIO 19	Precipitation of coldest quarter

Table 2. Environmental variables; those used in the study are indicated in bold [22].

Results

In the model generated in this study, the AUC training data value was calculated to be 0.966 and the test data value was calculated to be 0.965 (Fig. 2). According to the jackknife (pull-out) test, the environmental variables with the five greatest gains are "Temperature Seasonality (BIO 4)", "Mean diurnal range (BIO 2)", "Annual precipitation (BIO 12)", "Maximum temperature of the coldest month" temperature (BIO 6)" and "Precipitation of Wettest Month (BIO 13)" (Fig. 3).

The predicted potential distributions of the species displayed a significant degree of similarity with the sample points representing its current distribution. The area of highly suitable habitat was calculated to be 8205,5 km^2 and the highly suitable habitat area was calculated to be 29560.1 km^2 (Table 3). The map for the current potential distribution area of *Arbutus unedo* L. is shown in (Fig. 4), and the distribution areas for future periods generated according to the MIROC_ES2L climate change model are in Figs. 5, 6, 7, 8.
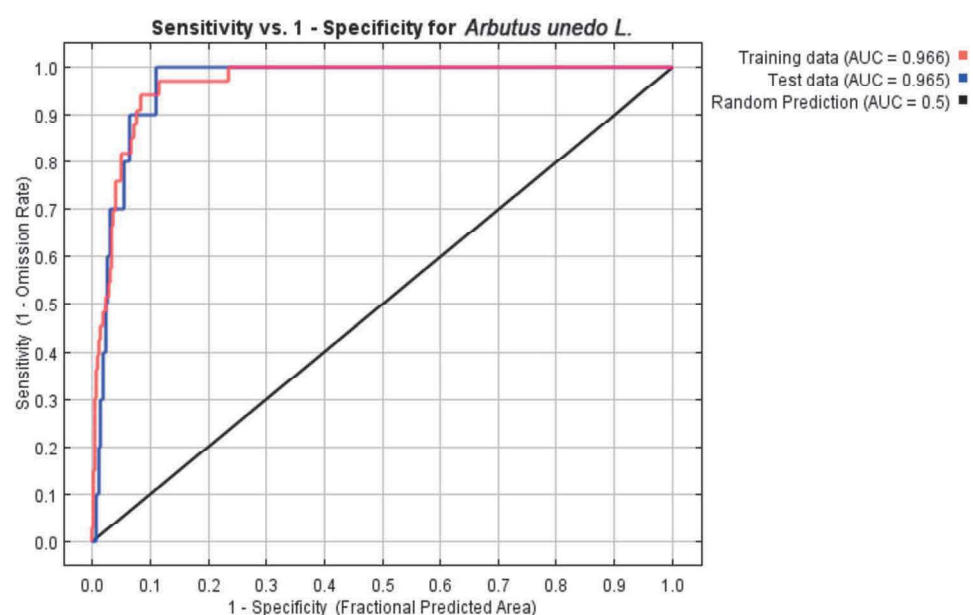

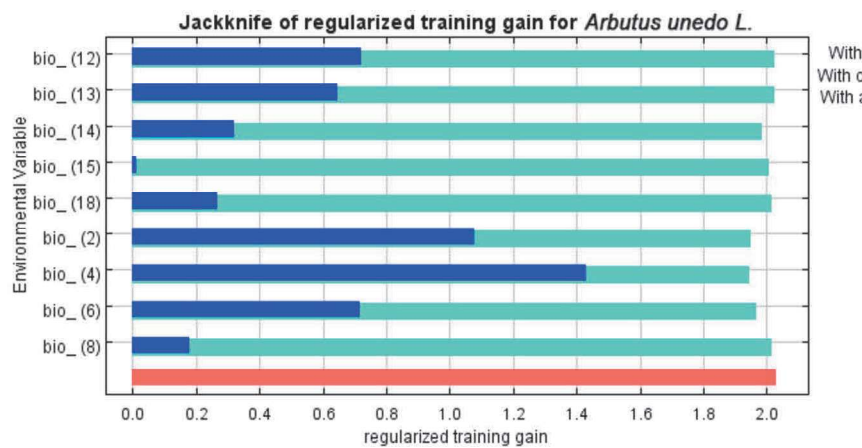**Figure 2.** ROC curve and AUC of the model.

Figure 3. Predictive accuracy of the model variables the Jackknife test.

Suitability	*Arbutus unedo* L.	SSP2-4.5		SSP5-8.5	
	Current	2041–2060	2081–2100	2041–2060	2081–2100
0	638185.5	669230.6	711673.6	720151.7	774302.4
1	66029.6	65128.12	49638.84	46923.5	5645.218
2	37964.92	29067.49	14367.77	9666.84	0
3	29560.12	13972.42	4119.748	2913.848	0
4	8205.546	2546.788	145.404	290.623	0

Table 3. Spatial distribution of the potential geographical distribution of *Arbutus unedo* L. in the present day and in the future according to the SSP2 4.5 and SSP5 8.5 climate scenarios (km^2).
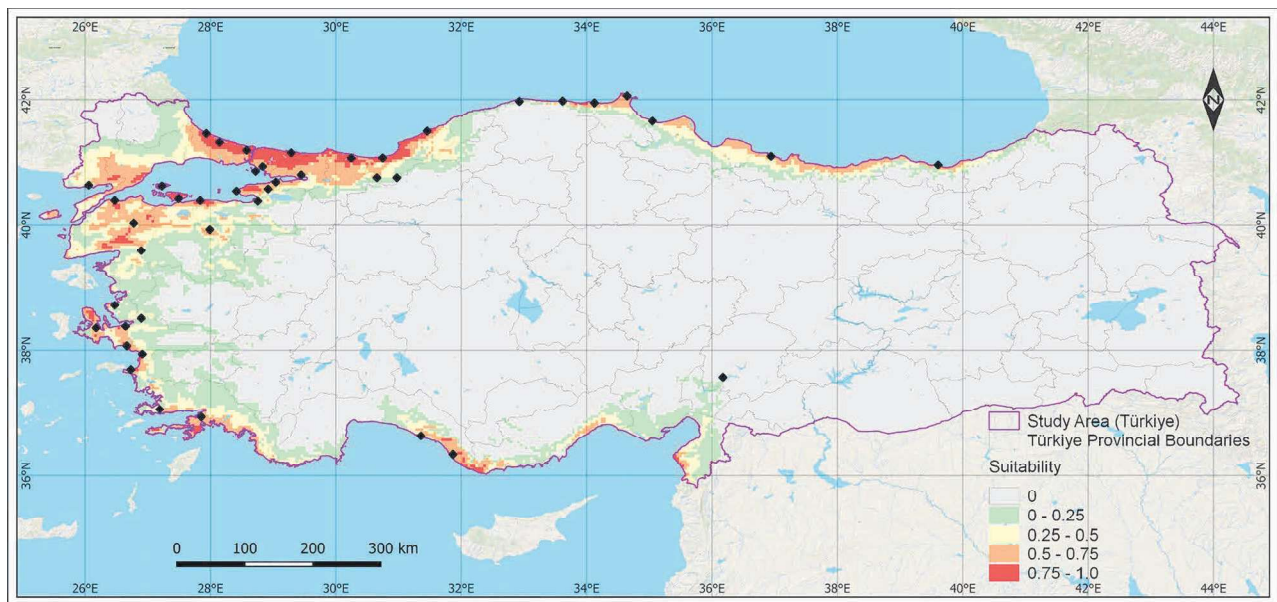
Figure 4. Potential distribution of *Arbutus unedo*—created using QGIS v3.24[35].

The existing data and the model created for the current study were consistent. The distribution area of *Arbutus unedo* is on the coast of the country, and its current distribution is far northwards on the northern coast of Marmara sea.

According to SSP2 4.5, in the models created for the distribution areas for the years 2041–2060 and 2081–2100, *A. unedo* will start to withdraw from the Mediterranean and Aegean regions, where it already has a limited distribution, and its distribution will shift to the northern parts of the Marmara region, where it is seen
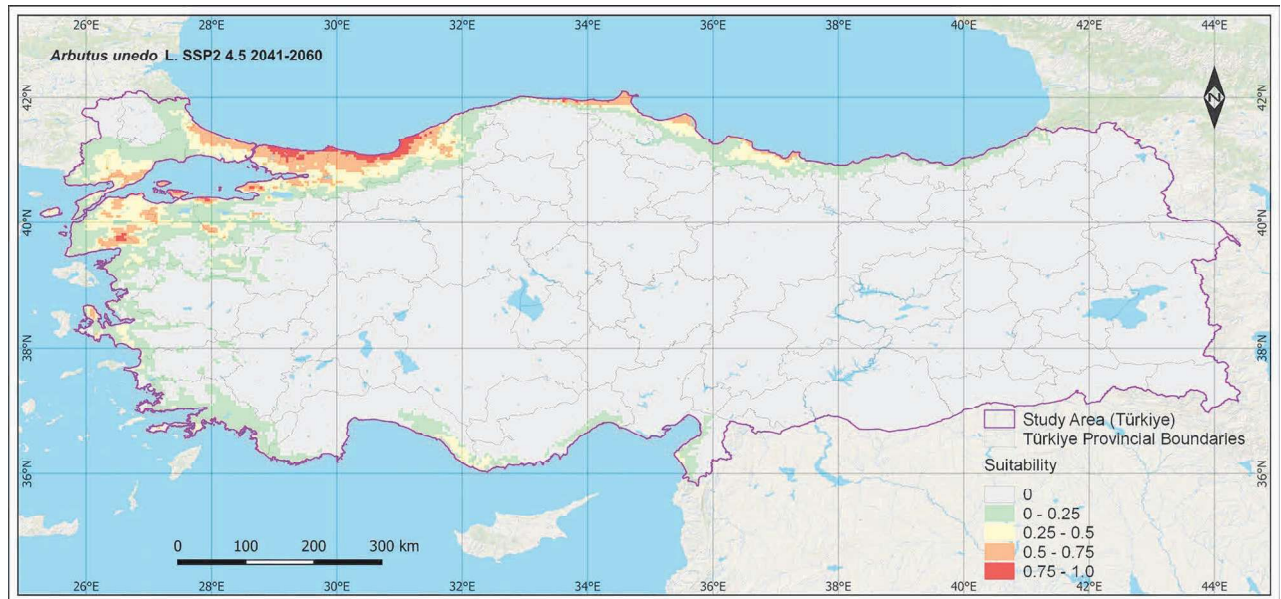
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Figure 5. Estimated distribution areas of *Arbutus unedo* according to the SSP2 4.5 scenario for the 2041–2060 period—created using QGIS v3.24[35].

Figure 6. Estimated distribution areas of *Arbutus unedo* according to the SSP2 4.5 scenario for the 2081–2100 period—created using QGIS v3.24[35].

densely distributed. In the 2081–2100 scenario, the presence of very suitable distribution areas for the species in the northern areas will be severely restricted.

According to the distribution area model of *Arbutus unedo* in the 2041–2060 (~2050) and 2081–2100 (~2090) according to SSP5 8.5, the distribution of the species in year ~2050 will be almost the same as that in the year ~2090 under SSP2 4.5, except for local areas in Southern Marmara and around the Bafra district of Samsun Province near the Black Sea. Considering the conditions of the ~2090 period, it is unfortunately estimated that no suitable habitats for *Arbutus unedo* will exist. To reveal these differences, the results of the change analysis (loss and gain), in which the current distribution areas are compared with the predicted distribution areas from the model are shown in (Table 4), and corresponding maps are shown in Figs. 9, 10, 11, 12.

Figure 7. Estimated distribution areas of *Arbutus unedo* according to the SSP5 8.5 scenario for the 2041–2060 period—created using QGIS v3.24[35].

Figure 8. Estimated distribution areas of *Arbutus unedo* L. according to the SSP5 8.5 scenario for the 2081–2100 period—created using QGIS v3.24[35].

Change	SS2 4.5		SSP5 8.5	
	Current to ~ 2050	Current to ~ 2090	Current to ~ 2050	Current to ~ 2090
Stable	52735,229	13251,608	14610,246	1099,523
Loss	85427,213	128493,604	126941,278	140660,66
Gain	6519,304	162,293	1749,916	16,135
Unsuitable	635262,068	638036,689	636642,9	638168,473

Table 4. Spatial changes between the current and predicted distribution areas of *A. unedo* under the SSP2 4.5 – SSP5 8.5 scenarios for 2050 and 2090 in Türkiye (km^2).
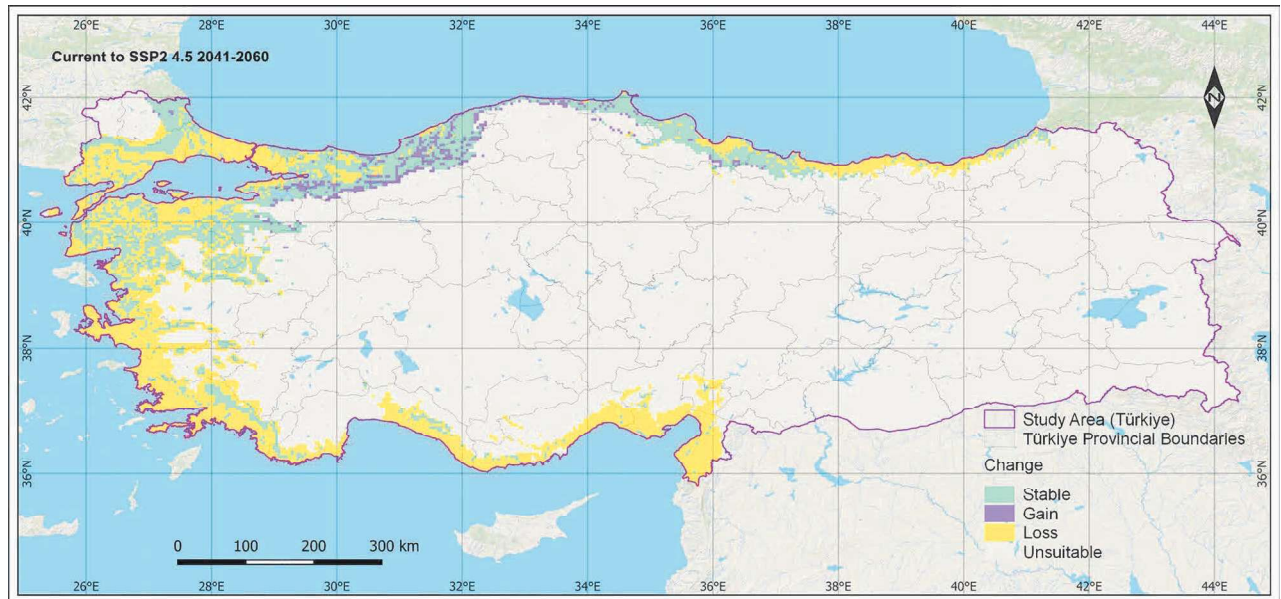
Figure 9. Spatial changes between the current and predicted distribution areas of *A. unedo* under the SSP2 4.5 scenario for 2050—created using QGIS v3.24[35].
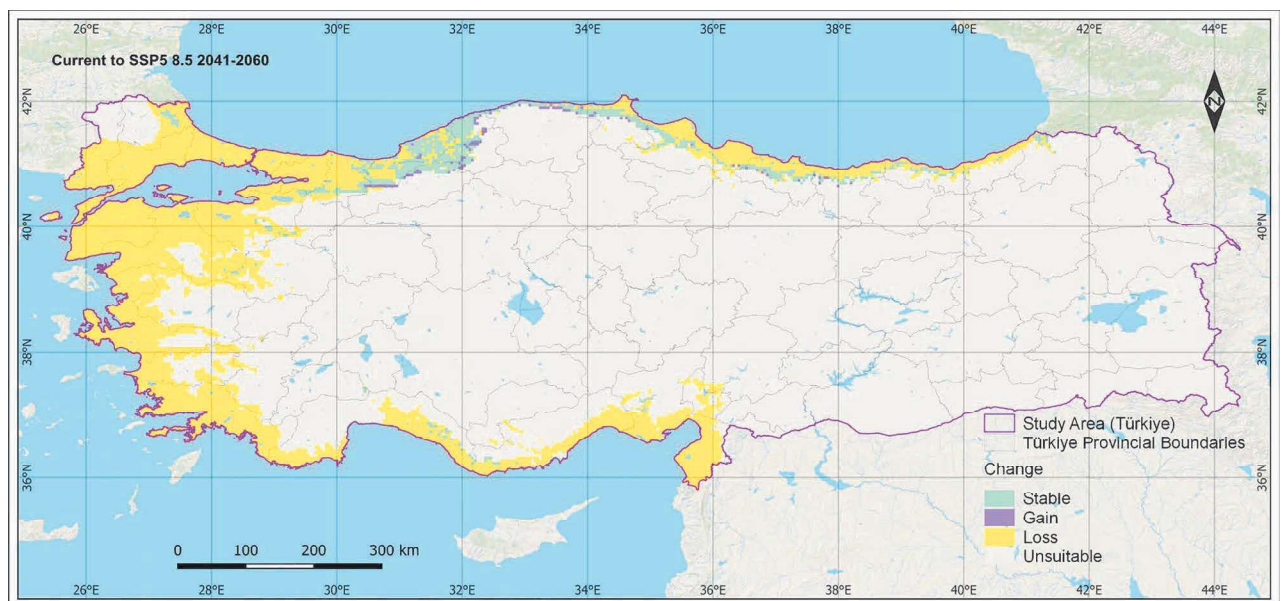

Figure 10. Spatial changes between the current and predicted distribution areas of *A. unedo* under the SSP2 8.5 scenario for 2050—created using QGIS v3.24[35].

Discussion

Sarikaya and Orucu[46], who studied *Arbutus andrachne*, which belongs to the same genus as *A. unedo*, modelled the present and future, ~ 2050 and ~ 2070 distribution areas of the species in their study. Their model indicated that the distribution of the species in the southern regions of Türkiye will decrease, but its distribution could expanded in the western and northern regions. The authors also noted that no potential habitat losses that would affect the distribution of *A. andrachne* would occur. Uzun and Sarikaya[47] modelled the current and future distribution areas of *Pistacia terebinthus* using the random forest algorithm, and the results of their study indicated that very suitable distribution areas of the species with ethnobotanical uses will be completely eliminated, and suitable areas will decrease to 15%. Arslan et al.[4] modelled the current and future distribution areas of *Rosa canina*, which has a wide distribution in our country, with MaxEnt; the model output suggested that the species distribution areas will shrink in the future.

According to the current and future distribution area models generated for *Arbutus unedo*, the potential distribution areas of the species in the future will gradually decrease. In the SSP5 8.5 model, which represents
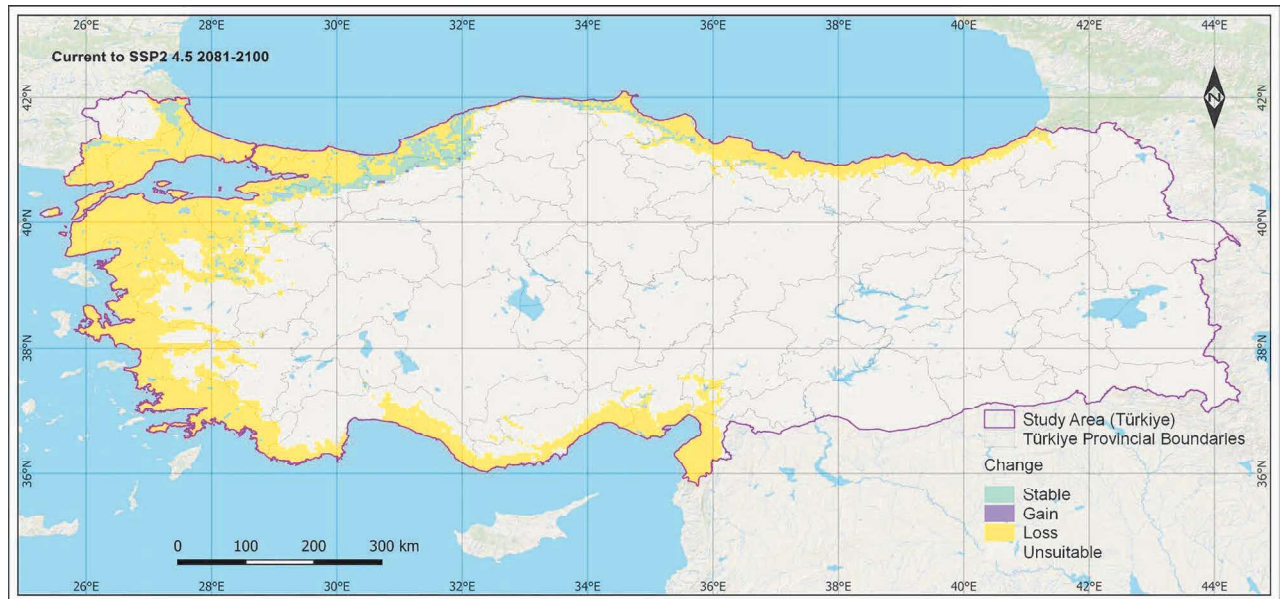
Figure 11. Spatial changes between the current and predicted distribution areas of *A. unedo* under the SSP2 4.5 scenario for 2090—created using QGIS v3.24[35].
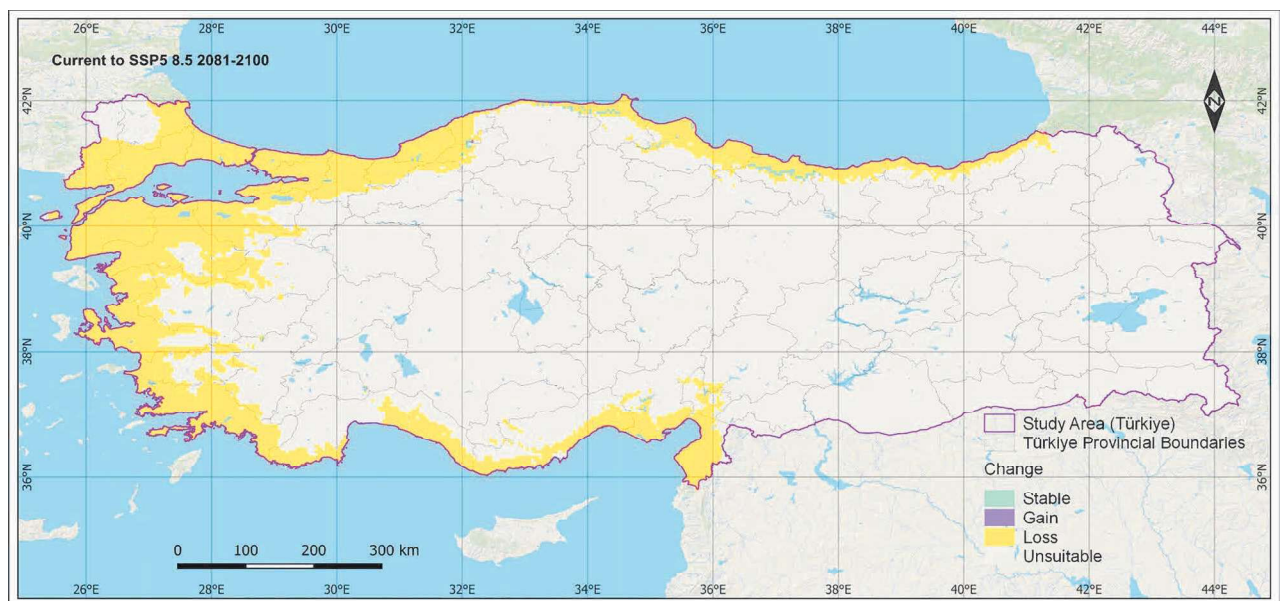

Figure 12. Spatial changes between the current and predicted distribution areas of *A. unedo* under the SSP2 8.5 scenario for 2090—created using QGIS v3.24[35].

the highest level of world's resources use this gradual decrease will reach its maximum level and there will be no suitable distribution area left for the species. This scenerio reveals that the species is endangered. Humans have a major impact on changes in the natural environment, especially with respect to vegetation, and are largely responsible for species distributions and habitat losses[4,48].

Many previous studies have shown that climate change is one of the most important factors causing habitat loss and declines in biodiversity. The diversity of habitats and species that arise due to differences in topography makes the prediction of climate change difficult. On the other hand, research shows that some species will migrate north and that some endemic species may become extinct[12,13,49–54].

Strawberry trees (*Arbutus unedo*) were included in the IUCN Red List in 2017 and are in the "Low Risk" but "Endangered" category[55]. Since the ethnobotanical and food use of this species is widespread in Türkiye, it is endangered, and as long as this level of use of the Earth's resources continues, extinction will be inevitable for the Strawberry tree and many other species. Climate change is important from a wide variety of perspectives, from the distribution of plant species to their protection and use. In the present study, the potential distribution areas where A. unedo grows were identified. The MaxEnt model predicted significant fluctuations in *A. unedo*

distribution areas in Türkiye over the next 50 years. Although the distribution areas of *A. unedo* are not significantly affected in the SSP2-4.5 projection from climate change, there is a significant decrease in the distribution area of this species in the SSP5-8.5 projection.

Sea level changes, which have profound effects on geomorphology, have undoubtedly also had great effects on human life[56]. Surrounded by sea on three sides, it is undoubtedly inevitable that Türkiye will be affected by global sea level changes. Coasts of country are home to approximately 30 million people and more than half of the country's gross national products–around 60%. The areas that will be most affected by sea level rise on the Turkish coast are; It has been determined that there will be provinces with low areas such as coastal deltas[57]. In our study, it is seen that *A. unedo* is currently spreading in these risky provinces and will cease its spread in the future periods. According to the same study, it was concluded that Türkiye is among the countries with medium level risk[58].

The rate of sea level rise is expected to increase, in part due to anthropogenic contributions to global warming. Additionally, other projected environmental changes, including changes in precipitation patterns, changes in the frequency of severe storms, and declining groundwater supplies of freshwater sources, may interact with sea level rise to affect the rate of change in terrestrial vegetation along coastlines[59–61].

Ultimately, this study conducted at the geographical boundaries of Türkiye showed that the distribution of Strawberry trees in the coming years will gradually decrease and the species will become more threatened. Based on the maps, its distribution, which is dense in the coastal strip, will not be maintained in the Aegean strip in the future, and will decrease by shifting to the northern latitudes in the western Black Sea and Marmara regions. Based on this observation, it is possible that this species, like many other species, will shift its distribution to northern latitudes, not only in Türkiye but also in other Mediterranean countries. To avoid economic and ecological losses related to Strawberry trees, it is important to conduct studies on a global scale rather than on local scales to ensure the future of Strawberry trees.

Data availability
No new data were created or analysed in this study. Data sharing is not applicable to this article. The data presented in this study are available upon request from the corresponding author.

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Acknowledgements

Author contributions

Ayse Gul Sarikaya and Almira Uzun performed background research and designed the study. Ayse Gul Sarikaya and Funda Dila Turan obtained the data and analysed them. The modelling results were reviewed by Almira Uzun. Ayse Gul Sarikaya wrote the manuscript. All authors discussed the results and commented on the manuscript. The order of the authors is based on the level of their contribution.

Competing interests

The authors declare no competing interests.

Additional information

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