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Modeling of present and future potential distribution areas of *Thymus praecox* opiz. in Turkey according to the Maxent algorithm

Abstract. *Thymus* L. genus of the Lamiaceae family, which has a cosmopolitan distribution that includes annual or perennial herbs, rarely shrubs or trees, known for their pleasant smell, has medicinal and aromatic species. Although the ethnobotanical use of individuals of the genus *Thymus* is quite common, its consumption is often preferred as spice and medicinal tea. In this study, *Thymus praecox* Opiz. forms the material of the study. In this article, potential present and future distribution areas were modeled in MaxEnt 4.1 to determine the effects of climate change on the distribution areas of *T. praecox* in Turkey. In the model, 2041-2060 (~2050) and 2081-2100 (~2090) periods of SSP2 4.5 and SSP5 8.5 scenarios in CanESM5.0.3 (The Canadian Earth System Model version 5) climate change model were used, together with sample points and bioclimatic variables. According to the study outputs, it is estimated that the estimated potential suitable and very suitable distribution areas of T. praecox today are 108411.705 km2 and according to the CanESM5.0.3 model, it will experience losses in very suitable and suitable distribution areas in the future, and very suitable distribution areas cannot be found in the SSP5 8.5 scenario 2081-2100 periods.
Key words: *Thymus praecox* Opiz, Species distribution model, MaxEnt, Turkey.

Introduction

The climate, which had a natural tendency to change since the existence of the world, is the most important environmental factor that determines the main characters and main distribution areas of habitat and plant communities [1-3]. Expected climate change and global warming may lead to changes in the natural distribution of species and the effects of harmful factors [4-6]. Turkey is one of the countries that will be most affected by global climate change due to its peninsula position surrounded by seas on three sides and its complex climate structure due to its topographic features [7-8]. It is important to understand both processes to plan conservation under climate change and manage the productivity of economically important plant populations [9-10].

Species distribution models (SDMs) provide some insight into future biogeographies [10]. Species distribution models use statistical relationships between species demographics (abundance, presence/absence) and environmental variables to produce probabilistic estimates of the occurrence of a species at a particular time and place [11-15].

The potential present and CanESM5.0.3 climate change model of *Thymus praecox* Opiz., which is known as Plateau Thyme among the people with its natural distribution especially in the northern parts of Turkey, with 2041-2060 (~2050) and 2081-2100 (~2090) climate change model. It is aimed to model the possible future geographical distribution areas in these periods and at the same time to reveal how the distribution areas will change from the present to the future temporally and spatially.

Materials and methods

The material of the study was *Thymus praecox* Opiz. Thymus sp. belongs to the Lamiaceae family. It is among the most common species in Turkey and in the world [16 -18]. Members of the Lamiaceae family, which are important in the pharmacology, food and perfumery industry due to their essential and aromatic oil content, are used to obtain ethereal oil, used as a spice and grown as an ornamental plant [19]. Species belonging to the genus *Thymus* are used as a stomachic, sedative, antiseptic, dewormer, stimulant of blood circulation and especially as a spice [20]. The flavonoids and phenolic compounds in thyme have significant potential for the development of industrial products in medicine and cosmetics due to their antioxidant and antibacterial properties

[18-21]. Their bracts resemble leaves but are often purple. Corolla ranges in color from purple to light purple, but rarely whitish, 5-7 mm. May – August constitute the flowering time. In Turkey, this plant can be seen in the range 1000-3600 m. on stony and rocky mountain slopes [22-23].

Figure 1 – Habitus of *Thymus praecox* Opiz.

Representing the natural distribution area of *Thymus praecox*, 10 of 11 records called sample points were obtained by internet resources (Global Biodiversity Information System and Turkish Plants Data Service) and 1 point was obtained by field observation in Bursa province [24-25]. Representative points are marked in the WGS84 coordinate system in the QGIS Firenza 3.28 environment, an open-source geographic information systems software, and the work area and the attribute information of the points are given in Figure 2 and Table 1 [26].

The MaxEnt algorithm, which is the most preferred by researchers, was used to determine the current and future potential distribution areas of the species. The model for today's potential distribution sites was constructed from the observed data (temperature, precipitation, solar radiation, wind speed, water vapor pressure, etc.) in WorldClim version 2.1 (Table 2) [27-30]. CanESM5.0.3 (The Canadian Earth System Model version 5) climate change model was preferred as the climate model to extract potential distribution areas for the future. In the study, SSP2 4.5 and SSP5 8.5 scenarios, which are among the scenarios developed for CMIP6 in the sixth Evaluation Report of the Intergovernmental Panel on Climate Change [31], and their respective periods 2041-2060 and 2081-2100 were used.

Area Under the ROC Curve (AUC) obtained from Receiver Operating Characteristic (ROC) analysis was used to measure the performance of the model [32-33]. If the AUC value is > 0.5, it indicates that the model performs better than a random estimation, and the closer the AUC value is to 1, the more sensitive and descriptive the model is [34-35]. Afterward, the MaxEnt Jackknife test was conducted to determine how important bioclimatic variables are for the species [36-37]. The model results were converted into scatter maps using the raster/vector conversion function with the QGIS 3.10.4 program. In the models created in the MaxEnt algorithm, the probability of the species being in the area is between 0-1, but the closer to 1, the probability of the related species being in the area increases. In the maps created as a result of the model, the suitability values for the potential distribution areas were determined as "0" is not suitable, "0-0.25" is very suitable, "0.25-0.50" is less suitable, "0.50-0.75" is suitable and "0.75-1" is very suitable. According to this classification, the estimated distribution areas are calculated as km^2 according to current and future scenarios [38-39].

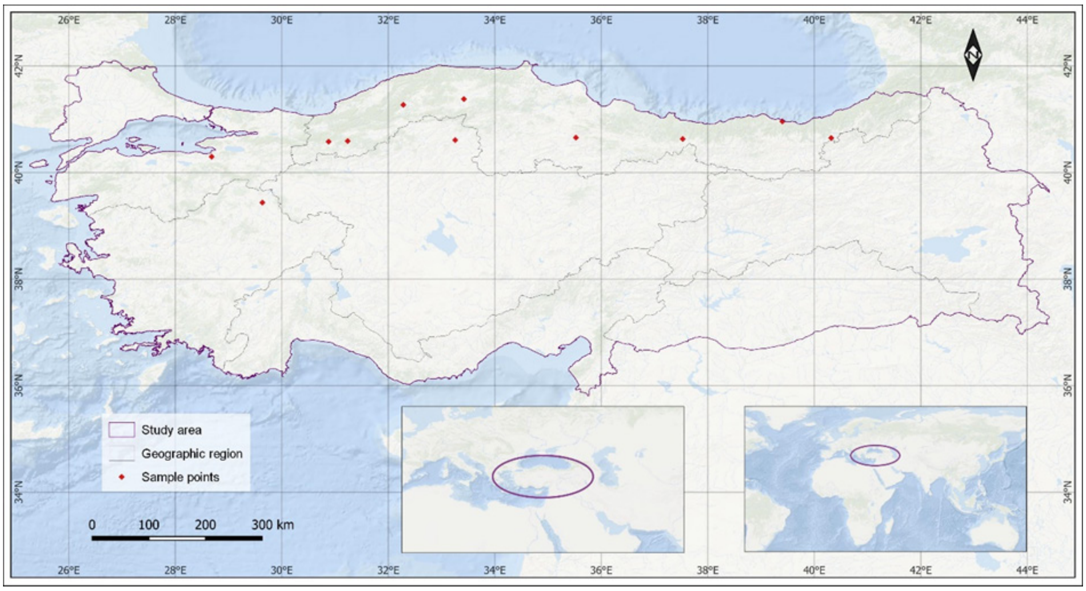

Figure 2 – Sample spots from *Thymus praecox* Opiz.

Table 1 – Attribute information of sampling points of *Thymus praecox* Opiz.

Thymus praecox Opiz.	X	Y	City	County	Altitude (m)	Temperature (°C)	Rains (mm)
1	37,9287	40,63189	Ordu	Karadüz	1832	4,6	55
2	33,8201	41,38085	Kastamonu	Merkez	929	9,37	43
3	35,9244	40,65632	Amasya	Merkez	1091	9,83	39
4	31,6372	40,59336	Bolu	Seben	1345	7,55	46
5	33,6569	40,60984	Çankırı	Merkez	857	11,15	35
6	29,0826	40,29744	Bursa	Osmangazi	278	14,16	50
7	30,0354	39,43729	Kütahya	Merkez	918	10,65	44
8	32,6821	41,27237	Karabük	Safranbolu	561	11,2	55
9	40,7167	40,65	Rize	İkizdere	2140	2,15	60
10	31,2801	40,58044	Bolu	Mudurnu	1126	9	46
11	39,8002	40,95989	Trabzon	Ortahisar	329	13,67	81

Table 2 – Information on bioclimatic variables.

Bio 1	Annual mean temperature
Bio 2	Mean diurnal range (mean of monthly (max temp min temp))
Bio 3	Isothermality (BIO2/BIO7) (*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 (BIO5-BIO6)
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 (coefcient 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

Results and discussion

In the obtained MaxEnt model, the AUC training data value was 0.925. Since this value is close to 1, the model created is sensitive and descriptive (Figure 3). According to the results of the Jackknife test, which is used to determine the contribution degree of bioclimatic variables, the environmental variables with the highest four gains when used in isolation are respectively "Seasonal precipitation amount (BIO 15)", "Seasonal temperature (BIO 4)", "Annual temperature change". range (BIO 7)" and "The highest temperature of the hottest month (BIO 5)" (Figure 4).

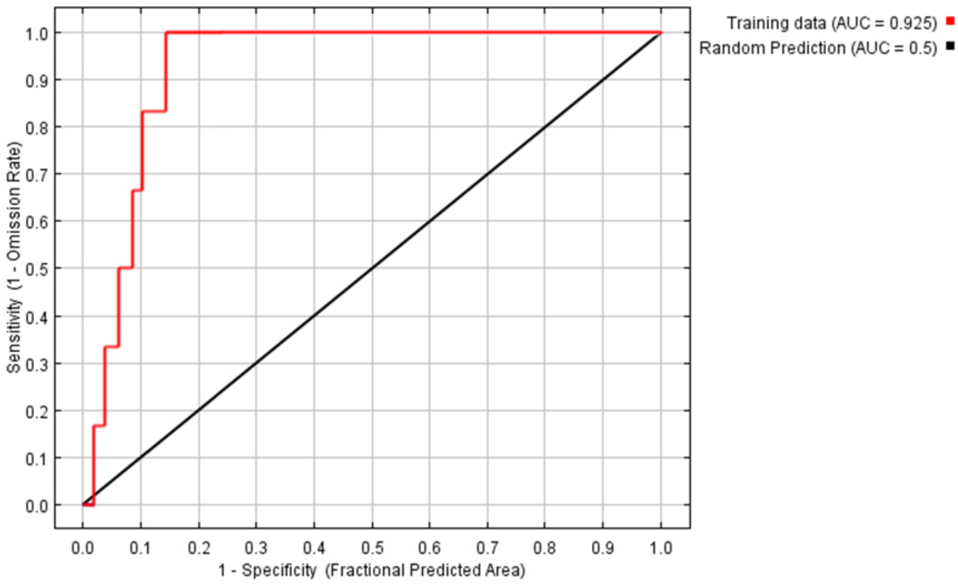

Figure 3 – ROC curve of the distribution model

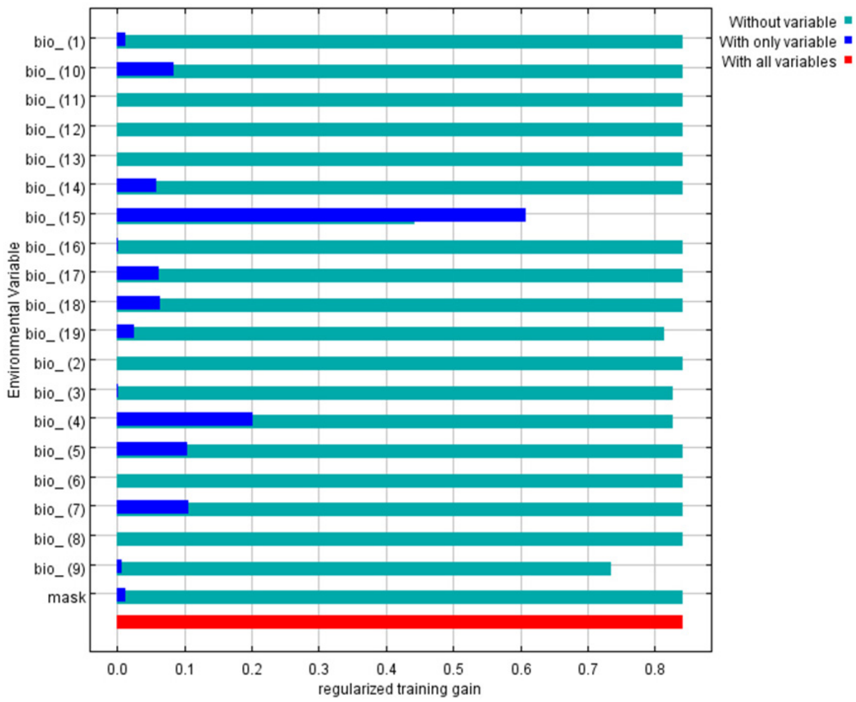

Figure 4 – Jacknife test result of bioclimatic variables

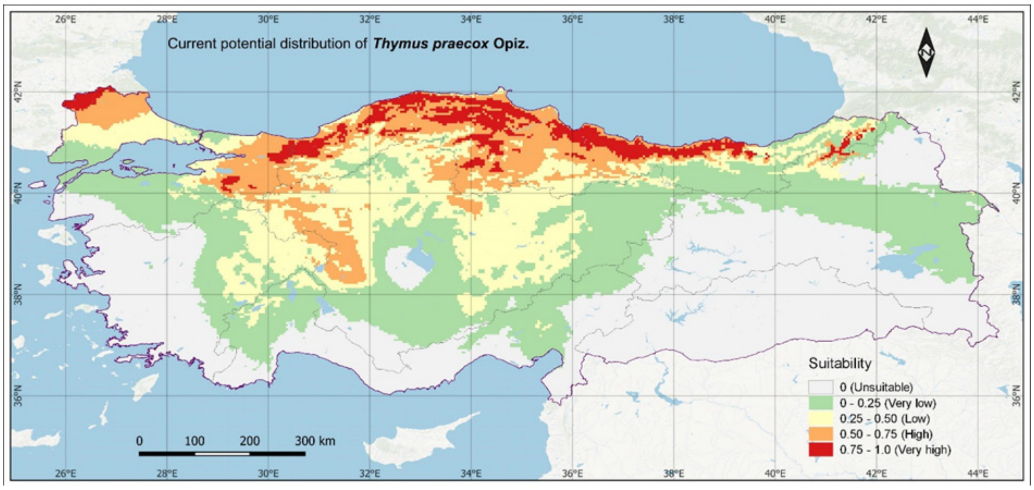

Figure 5 – Map showing present-day distribution of *Thymus praecox* Opiz.

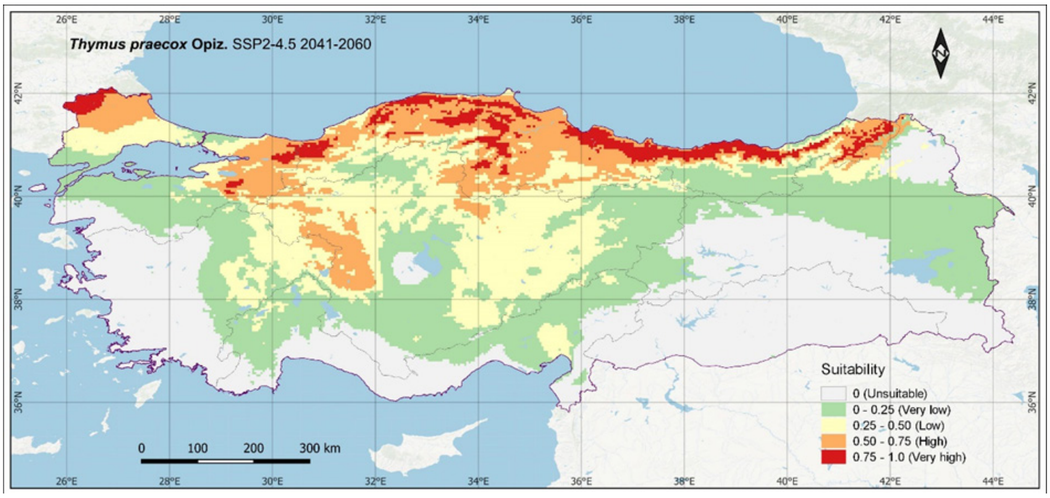

Figure 6 – Map showing the distribution area of *Thymus praecox* Opiz. in ~2050 according to the CanESM climate change model SSP2-4.5 scenario

According to the CanESM climate change model SSP2-4.5 scenario, it is seen that there will be local contractions in the distribution area, which is considered very suitable, within the 2040-2060 period, however, there will be an increase of approximately 10% with the transition from the suitable distribution areas to the suitable areas.

According to the CanESM climate change model SSP2-4.5 scenario, it is seen that there is a decrease of more than 30% when looking at the widespread areas in the 2080-2100 period. In the table that shows the areal distributions in Table 3, it is seen that there will be a decrease of approximately 6500 km^2 when the very suitable and suitable distribution area today is compared with the very suitable and suitable distribution areas in the SSP2-4.5 scenario ~2090.

Considering the SSP5-8.5 scenario, which is considered more stringent than the SSP2 scenario, in the 2041-2060 period, it directly stands out when looking at the map where there are serious reductions in very suitable areas outside the Eastern Black Sea line compared to today.

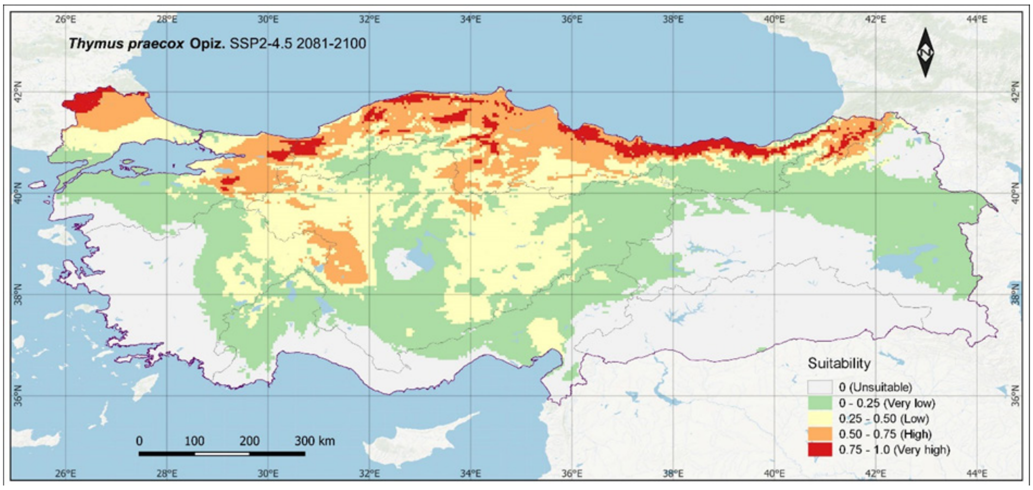

Figure 7 – Map showing the distribution area of *Thymus praecox* Opiz. in ~2090 according to the CanESM climate change model SSP2-4.5 scenario

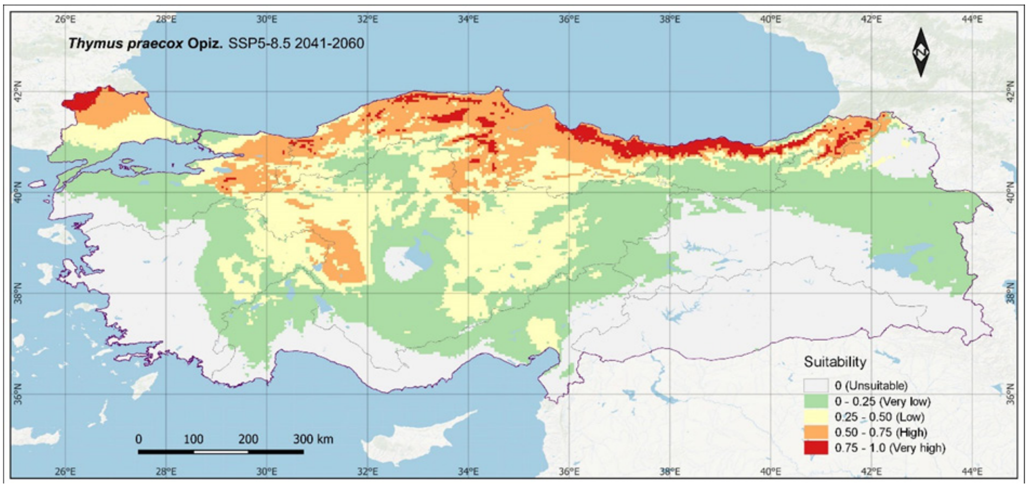

Figure 8 – Map showing the distribution area of *Thymus praecox* Opiz. in ~2050 according to the CanESM climate change model SSP5-8.5 scenario

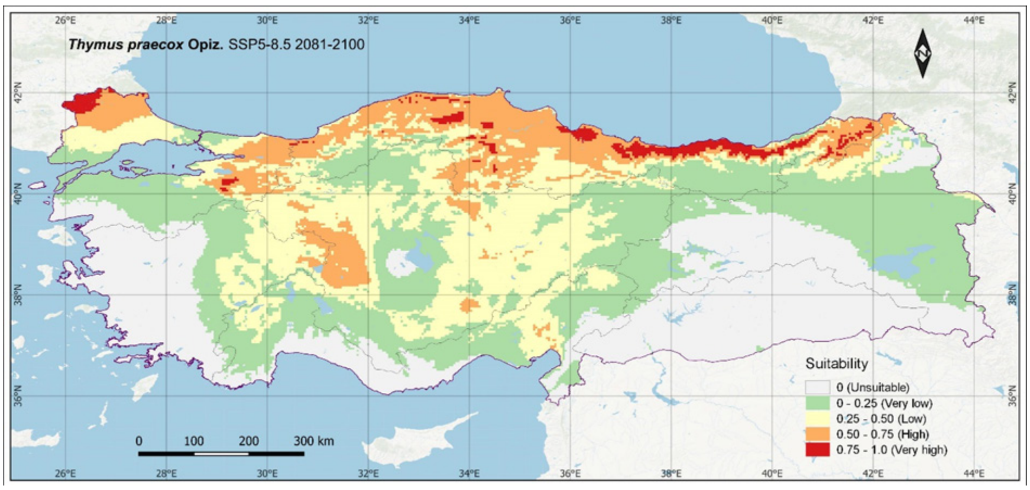

Figure 9 – Map showing the distribution area of *Thymus praecox* Opiz. in ~2090 according to the CanESM climate change model SSP5-8.5 scenario

Considering the very suitable distribution areas in the 2080-2100 period according to the CanESM climate change model SSP5-4.5 scenario, it is seen that the reductions in ~2050 continue to increase and leave their place in suitable areas. Considering the areal distributions in km2, it is seen that the very suitable areas have regressed to approximately 50%. The spatial distribution of the present and future distribution of *Thymus praecox* Opiz. is given in Table 3 in detail.

Table 3 – Current and future distribution of *Thymus praecox* according to SSP2 4.5 and SSP4 8.5 climate scenarios (km^2)

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***Thymus praecox* Opiz.**		**SSP2-4.5**		**SSP5-8.5**	
Habitat suitability	**Nowadays**	**~2050**	**~2090**	**~2050**	**~2090**
Unsuitable	296285.165	262117.2	255813.9	266956.5	224428.6
Low	236204.203	246513.9	266751	263520.4	266310.6
Moderate	139044.243	158300.2	155398	150373.3	186449.2
High	78498.03	86131.05	81518.85	81720.14	88997.31
Very high	29913.675	26883.84	20464.85	17376.46	13761.42

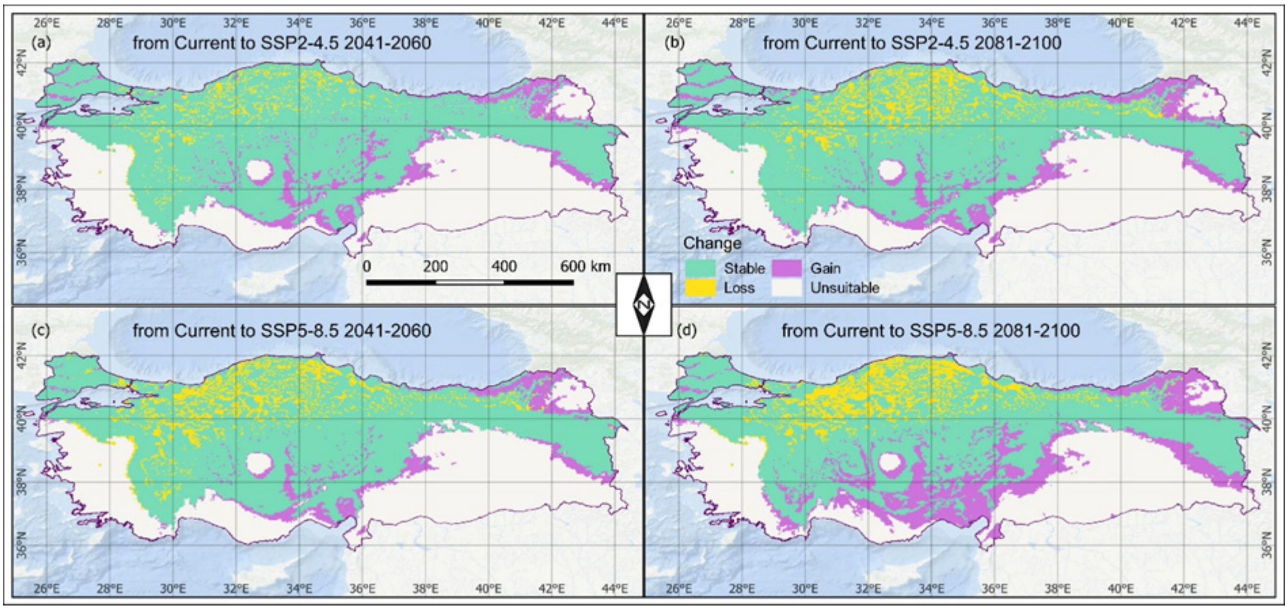

Figure 10 – Loss-Gain (Direction of Change) Map from Present to Future projections

Table 4 – Spatial distribution of Loss-Gain (Direction of change) status from Present to Future projections (km^2)

Change	**SSP2-4.5**		**SSP5-8.5**	
	From today to ~2050	**From today to ~2090'a**	**From today to ~2050'ye**	**From today to ~2090'a**
Stable	427032.383	407070.917	403797.407	359775.607
Loss	20386.308	44728.312	55068.95	57735.221
Gain	71316.313	72597.433	57111.627	139219.614
Unsuitable	261208.724	255546.69	263966.091	223213.659

The plant of *Thymus praecox* Opiz. is used as a spice as well as in the food, cosmetic and pharmaceutical industries. The essential oil obtained from its leaves and flowers is also used in different fields. As a result of the increase in the usage areas of the species, the pressure on the natural distribution areas is increasing due to the collection only from nature. It has been determined that the quality of the plant decreases, the distribution areas are destroyed and the plant yield decreases due to problems such as harvesting by unconscious collectors and lack of transportation. The distribution area of T. praecox, which is a member of Europe – Siberia and makes its main distribution in North Anatolia in Turkey, will tend to shift to North East Anatolia according to the SSP2 and SSP5 scenarios of the CanESM5 climate change model, and will decrease in other regions, even the SSP5 scenario. It is estimated that there will be no suitable habitats for the 2081-2100 period. It is seen that the gains are more than the Losses in the Loss-Gain maps created according to the direction of the field change. But the vast majority of these gains are in areas that turn from "not suitable" to "very little suitable". From this point of view, it can be said that this change, which is seen outside the natural habitat, can not be assumed as positive feedback for the continuity of the species in that region.

Pluhár et al. [40] stated that the species, which is usually found near limestone and rock surfaces, can survive erosion at the upper elevations of the hill, but disappears in communities down the slope where it is not advantageous in competition with stronger species. In their study in Hungary, they said that the emergence of *T. praecox* on chalky surfaces means that the plant has a high calcium tolerance, but that it would endanger the survival of the species under severe disturbances and overexertion conditions.

İspirli et al. [41] stated that Astragalus bicolor (3.62%) and Thymus praecox (3.22%) are the most common invasive species in today's pastures in Kastamonu province. Although it is mentioned as an invasive species for Kastamonu province. Also, it is seen that there will be decreases in the distribution areas of T. praecox under Turkish conditions, and even more than half of the very suitable areas for the SSP5-8.5 scenario will decrease in the ~2090 period.

Kekeç & Kadıoğlu [42] determined the future distribution areas of *Xanthium strumarium* L. in Turkey, and as a result of the study, they showed that the species will show a steady increase in the future and it is likely to be an invasive species. In another study, Dülgeroğlu & Aksoy [43] stated that when they modeled the distribution areas of *Origanum minutiflorum*, which is also one of the medicinal aromatic plants, in ~2070, suitable climatic conditions could not be provided for the species to survive, and if it could not find a new habitat, local extinctions would begin.

Not all changes in the habitats of species are due to climate change, but may also occur as a result of other human activities such as urban development and generally changing land uses [15-44]. *Thymus praecox*. Although it has not been evaluated by the IUCN (World Union for Conservation of Nature and Natural Resources), it is stated to be under threat in Europe according to the European Environment Agency [45-46].

Conclusion

It is thought that the study will be beneficial in terms of ensuring the collection of plants more consciously and preventing the economic losses that may arise from random plant collection and false information. It is necessary to raise the awareness of producers and consumers to protect the generation of the species and to obtain higher-quality products. For the continuity of this species, which is used in many different areas in our country, conservation and use studies such as Ex-situ and In-situ should be carried out and it should be aimed to protect the species extinction by taking it in the culture. Such studies should be increased in terms of protection and sustainable planning of non-woods forest products, which makes a significant contribution to the economy of our country and plays an important role, especially in the economy of rural areas, and to develop its usage areas.

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