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Determination of model maps for the potential distribution of Anatolian black pine (*Pinus nigra* Arnold.) in natural forest areas in the Central Black Sea region

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Abstract

The purpose of this study was to determine potential distribution modeling and mapping of Anatolian black pine in the Vezirköprü district. Presence / absence data of the species was collected from 586 sample areas. Environmental variables (elevation, slope, bedrock, radiation index etc.) were obtained from the digital maps. In addition, climatic variables were downloaded from WorldClim database. Generalized Additive Model and Classification and Regression Tree were used for potential distribution modeling of the species. The validation value of Generalized Additive Model was 0.84 while the cross-validation test value was found to be 0.82. Also, the ROC values of the tree model were found to be 0.804 for the training data set and 0.750 for the testing data set. According to the Classification and Regression Tree method, the locations above 650 m and without meta-sandstone are suitable for the potential distribution of the species. Under the condition that there is meta-sandstone, the areas where the temperature is between 7.6-11.0 °C and the slope degree is more than 23% coincide with the potential distribution of the species. Also, Generalized Additive Model showed that places where gabbro, ophiolitic melange, serpentine, and mixed material were seen as main bedrock type, sloping sites where average elevation was from 600 to 1150 m and temperature is between approximately 8.5-11.3 °C were the most suitable conditions for the potential distribution of the species in the district. In both models, it was determined that especially rock formations, climatic variable, and altitude are effective in the potential distribution of the species. On the other hand, although there are some differences in the variables in the models, the potential distribution maps formed by these variables overlapped quite. As a result, the information obtained in the study is important for the forestry practices such as afforestation, regeneration and monitoring the species under future climate change conditions.

Keywords: generalized additive model, classification and regression tree, species distribution model, Vezirköprü

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Orta Karadeniz bölgesindeki doğal orman alanlarında Anadolu karaçamının (*Pinus nigra* Arnold.) potansiyel dağılım model ve haritalarının belirlenmesi

Özet

Bu çalışma Vezirköprü yöresinde Anadolu karaçamının potansiyel dağılımının modellemesi ve haritalaması amacıyla gerçekleştirilmiştir. 586 örnek alanda türün var / yok verisi toplanmıştır. Sayısal yükseklik modeli kullanılarak çevresel değişkenler (yükselti, eğim, anakaya, radyasyon indeksi vb.) elde edilmiştir. Ayrıca, WorldClim veri tabanında iklim değişkenleri indirilmiştir. Türün potansiyel dağılım modellemesinde Genelleştirilmiş Eklemeli Model ve Sınıflandırma (GAM) ve Regresyon Ağacı Tekniği (CART) kullanılmıştır. GAM modele ait geçerlilik oranı 0,84, çapraz geçerlilik katsayısı ise 0,82 bulunmuştur. Ayrıca, CART modelin geçerlilik (ROC) değerleri eğitim verisi için 0,804, test verisi için ise 0,750 bulunmuştur. CART yöntemine göre, 650 m'nin üzerindeki yükseltiler ve meta-

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kumtaşının olmadığı yerler türün potansiyel dağılımına uygundur. Metakumtaşının olduğu kısımlarda ise, yıllık ortalama sıcaklığın 7,6 – 11,0 ° C arasında ve eğimin %23'ten büyük olduğu yerler türün potansiyel dağılım alanlarını oluşturmaktadır. GAM yönteminde gabro, ofiyolitik melanj, serpantin ve karışık anakaya tiplerinin olduğu, eğimli arazi yapısına sahip 600 – 1150 m arasındaki yükseltiler ve yıllık ortalama sıcaklığının 8,5 – 11,3 °C olduğu yerlerde türün potansiyel dağılımı ile örtüşmüştür. Her iki yöntemde anakaya tipleri, iklim ve yükselti değişenlerinin türün yöredeki potansiyel dağılım alanlarında daha etkili olduğu tespit edilmiştir. Modellerde yer alan değişkenlerde bir takım farklılıklar olmasına rağmen, elde edilen potansiyel dağılım haritaları oldukça örtüşmüştür. Sonuç olarak, çalışmada elde edilen bilgiler türün ağaçlandırma ve gençleştirme gibi ormancılık uygulamaları ile iklim değişimi gibi süreçlerde izlenmesi için önem arz etmektedir.

Anahtar kelimeler: genelleştirilmiş eklemeli model, sınıflandırma ve regresyon ağacı, tür dağılım modellemesi, Vezirköprü

1. Introduction

Human activities above the forests, climate change, carbon emissions, and wildfires are all global issues that have a growing impact on all living organisms, including plant species distribution. In addition to these problems, there has been a significant contraction in forest areas worldwide due to possible climate change, severe drought, wildfires, rapid population growth, excessive and unsustainable illegal cutting, overgrazing, and other problems in recent years [1]. In response to this situation, the forest administrations of the countries have tried to manage the forests with a system that is more planned and sustainable way. At this stage, ecosystem-based multiple-use forest management (EBMFM) applications have been of great importance to ensure the sustainability of forest areas in a planned manner [2]. Especially, the modeling and mapping of the potential distribution areas of tree species, which are directly subject to forest management, constitute an important step for the EBMFM applications.

Potential distribution areas of a tree species can be determined as a result of modeling and mapping of ecological environmental conditions by utilizing the current status of species in forest areas. There are a number of variables that limit the distribution of tree species in forest ecosystems. Therefore, the species distribution modeling based on ecological data has recently been very popular for the conservation planning of the forest ecosystems [3]. In parallel with this situation, the modeling and mapping studies on the potential distribution areas of tree species, which are subject to direct forest management for any country, have begun to be carried out increasingly [4]. These models and maps can provide valuable information about the future of a tree species apart from the current situation. Therefore, it is evident that these models and model maps obtained in the forestry studies are able to operate and sustain tree species in a planned manner. In other words, the integration of these model studies into forest management plans is essential [5].

Just like in the world, pine species are very important forest trees for Turkish forests. One of them is Anatolian black pine (Pinus nigra Arnold.) which occupies a very large area of approximately 4.7 million ha in the forest ecosystems of Turkey [6]. It is an important tree species due to its ecological (e.g. carbon storage, biodiversity, and soil protection), economic and social (e.g. recreation, rural tourism) characteristics. It is also known as one of the most suitable species for afforestation of arid and rocky terrains [7]. In Turkey, it also covers a wide latitudinal distribution range from the southern and western parts to the inner and the northwestern parts.

One of the most important distribution areas of this species in the northwestern parts of Anatolia is Kunduz forests in Vezirköprü district. Following the information given above, identification and mapping of potential distribution areas in forested areas of this species, which is of such importance for the global scale and for Türkiye, is considered to be an appropriate application. As a result, the aim of this study was to determine the potential distribution areas of Anatolian black pine in the Vezirköprü district. Accordingly, two different nonparametric model techniques were applied in the study, it is aimed to reach the information that can contribute to the sustainability of the species in this region.

2. Material and Methods

2.1. Study area

The study area was located within the boundaries of Kunduz, Sarıçiçek, Gölköy and Narlısaray Forest Divisions under the Forest Directorate of Vezirköprü affiliated to the Regional Forest Directorate of Amasya and Osmancık Forest Division affiliated to the Forest Directorate of Çorum. The situated hinterland of the Central Black Sea Region, the study area is surrounded by Samsun province in the northeast, Amasya province in the south and Çorum province in the southwest (Figure 1). Kunduz (Vezirköprü) locality situates in the hinterland of the Central Black Sea Region covers an area of around 59,000 ha. Kızılırmak River flow into the Black Sea from Bafra cape in the shape of an arch starting from the west of this locality. The study area is surrounded by Ilgaz Mountain in the west, Küre Mountain in the northeast a Canik Mountain in the east. The summit of Kunduz Mountain after which the locality was named is Keltepe that is 1791 m high. On the other hand, the coastal areas of Altınkaya Dam Lake located within the boundaries of Narlısaray Forest Division represent the areas of the locality with the highest elevation with around 190 m.

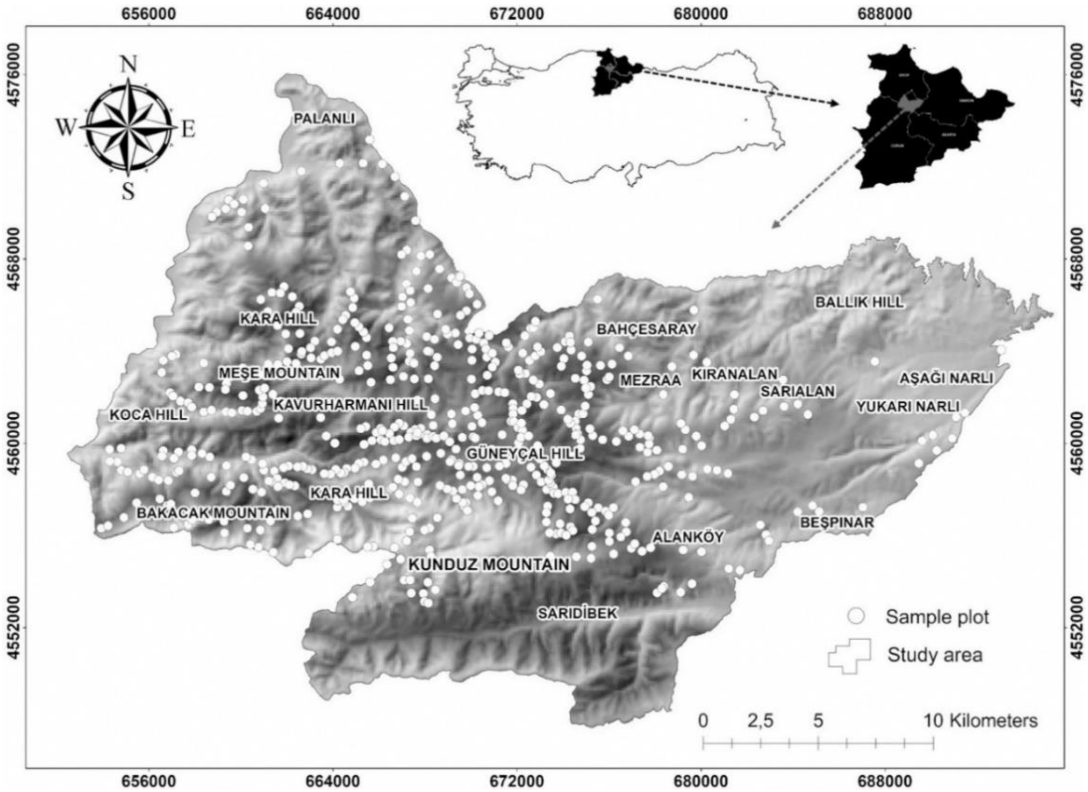

Figure 1. Location of the study area in the map of Turkey

It was found that the locality and its surrounding were located mainly on ophiolithic blocks containing sedimentary and magmatic rocks and belonging to Mesozoic Upper Cretaceous age [8]. Quartz minerals, gabbro, marble as well as different forms of magmatic basic rocks such as solid rock, tuff, and agglomerate in the Kunduz mountain mass. Ophiolithic rock blocks such as gabbro, amphibolite, pyroxenite, and spillite that are metamorphic rocks were found in Sarıdibek village and its surrounding [8].

Since the majority of the study area is located within the boundaries of Vezirköprü district, it represents the hinterland transition climate. According to the Köppen climate classification, the climate type in the vast majority of the study area is represented with warm winter and very hot summer while it is rainy in all seasons (Cfa); on the other hand, Çorum Osmancık section has cold semi-arid steppe climate (BSk) while the areas located within Amasya province have warm winter and very hot summer with an arid Mediterranean climate (Csa) [9]. The study area accommodates primary forest tree species such as Black pine, Brutian pine (*Pinus brutia*), Scotch pine (*Pinus sylvestris*), Nordmann fir (*Abies nordmanniana*), Crimean juniper (*Juniperus excelsa*), Beech (*Fagus orientalis*), Turkish oak (*Quercus cerris*) and Hornbeam (*Carpinus betulus*).

2.2. Data collection

Two sets of data (present: 1 – absent: 0) were collected from 586 sampling plots each with a size of 20x20 m. Stratified sampling method was used in the study [10]. Furthermore, the latitude and longitude of each sampling plot were recorded. On the other hand, environmental variables were created for potential distribution modeling and mapping (Table 1). Therefore, a Digital Elevation Model (DEM) with a cell size of 100×100 m was created taking into account the borders of the study area. DEM was used to generate topographic variables and the cell sizes of the variables obtained are 100×100 m. The elevation, slope and aspect maps were created based on the DEM in ArcGIS 10.2 software. A topographic position index map was created using the “Topographic Tool” extension in ArcGIS 10.2 software developed by Jennes [11]. Topographic position index is a variable that shows the structure of the landforms. Negative topographic position index values represent structures such as mainly canyons, valley floors, and values closer to zero represent flat areas, plains and lower slopes whereas positive values represent hills, mid-slopes, upper slopes, ridges, and mountain summits. The radiation index was obtained using the “TRASP” tool in the “Geomorphometric and Gradient Metrics Toolbox” extension in ArcGIS 10.2 software.

$$Radiation\ Index = [1 - \cos((\pi/180) \times (\theta - 30))] / 2 \qquad (1)$$

Where, θ in the equation represents aspect values. The values calculated ranged from 0 to 1. "0" represented the shadowy aspects in the north-northeast direction while values closer to "1" represented lands that were hotter and dry slopes in the south-southwest direction [12].

The geology map of the study area was obtained from the General Directorate of Mineral Research and Exploration. Then, each bedrock type was drawn as polygons and recorded in the attribute table. Each bedrock type in the study area was exported to a raster format using the conversion tools.

Finally, the mean annual temperature and annual precipitation values used in the study area were downloaded from http://www.worldclim.org [13]. By using the cubic transformation option with the "*Resample*" tool in ArcGIS 10.2 software, the cell sizes of the downloaded climate variables (~ 1 km^2) were adjusted based on the cell sizes of the environmental variables (100×100 m).

Table 1. Definition of environmental variables

	Variable	**Codes**
Topographic Variables	Elevation (m)	ELVTN
	Slope (°)	SLOPE
	Aspect (°)	ASPECT
	Topographic Position Index	TPINDEX
	Radiation Index (0 – 1)	RADIN
Climate Variables	Annual Mean Temperature (mm)	BIO1
	Annual Precipitation (°C)	BIO12
Parent Materials	Alluvium	ALVM
	Gabbro	GABBRO
	Melange	MELANGE
	Metasandstone	METASAND
	Other types	OTHTYPE
	Sandstone, Mudstone	SANDMUD
	Sandstone, Mudstone, Limestone	SANDMUDLIM

2.3. Statistical assessment

In order to develop the potential black pine distribution model, the Generalized Additive Model (GAM) and Classification and Regression Trees (CART) technique were used. GAM is known to be the modified and non-parametric version of the generalized linear model. Non-linear distributions show higher associations in assessing the values [14, 15, 16]. It is often preferred in species distribution studies owing to the fact that it determines curvilinear relationships between dependent variable and independent variables. Different assessment methods are depending on the data type (such as presence-absence data, frequency, continuous between 0 and 1, counts, richness, positive integers, weights, size, biomass, etc.) of the dependent variable. In the study, GRASP (*Generalized Regression Analysis and Spatial Prediction*) plugin included in S - Plus 6.1 software was used [15]. Binomial distribution family was used to construct the model because of the fact that the data type of the target species is binary data. Different statistical methods are included in the GRASP extension and have model validations according to different tests. Among these statistical methods, the F test was selected and model was created.

On the other hand, CART is a rules-based non-parametric method. Independent variables were divided into homogenous sub-groups on the basis of the dependent variable and a tree model was created. The tree model obtained in a hierarchical order was connected through leaves and nodes. In the last node, the independent values are taken into consideration to write rules and prediction values are created [16]. The dependent variable in the study was categorical (present: 1 – absent: 0); thus, the method is named as classification tree. "*If then*" rules were written to calculating prediction value by using the value of the environmental variable in each terminal node [17]. On the other hand, using prediction values of the obtained CART model, the distribution map was visualized based on each cell value (100×100 m) of the study area (totally for 57603 grids).

The accuracy and performance of the models obtained from GAM and CART methods were checked by using Receiver Operating Characteristic (ROC) curve.

3. Results

The purpose of the study was to create the potential distribution model and map using the GAM and CART methods based on the present-absent data of black pine in 586 sampling plots. Elevation, slope, aspect, topographic position index, radiation index and bedrock types from the environmental variables and the mean annual temperature and annual precipitation from the climate variables were used for the potential modeling mapping stage of the study.

The model obtained from the GAM technique was constituted by elevation, slope, bedrock types, and the mean annual temperature. The maximum contribution to the model came from bedrock types followed by elevation. The individual contribution of each variable was ranked as bedrock types (122.9403), mean annual temperature (121.9179), elevation (115.9843) and slope (11.2255).

The descriptive graphs relate to the GAM obtained after the analysis are presented in Figure 2 – 3. The graphs showed that black pine was potentially distributed at an elevation of approximately 700-1100 m, while its distribution decreased from about 1200 m to higher elevations. In particular, it preferred areas with a mean annual temperature of around 8.5 – 11.5 °C. On the other hand, slope is another variable that affected the potential distribution of black pine in the site, while areas with a slope of 10% - 30% were the most appropriate ones for the potential distribution of this species. Finally, the mixed formation of sandstone – pebble stone – limestone and melange were the most important rock formations that affected the potential distribution of black pine in the area while also gabbro and serpentine were the second most appropriate bedrock types for its potential distribution.

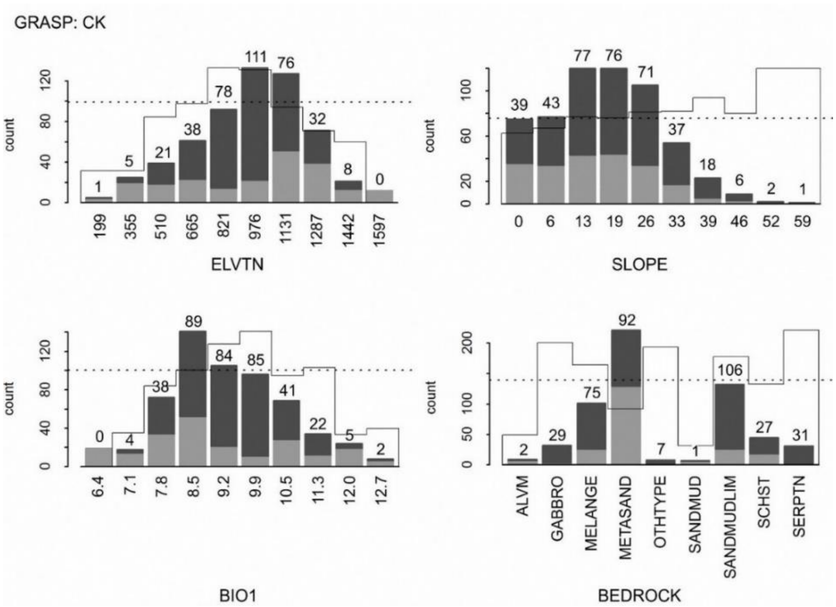

Figure 2. Histograms of the environmental variables to the modeling of Anatolian black pine predictive distribution.

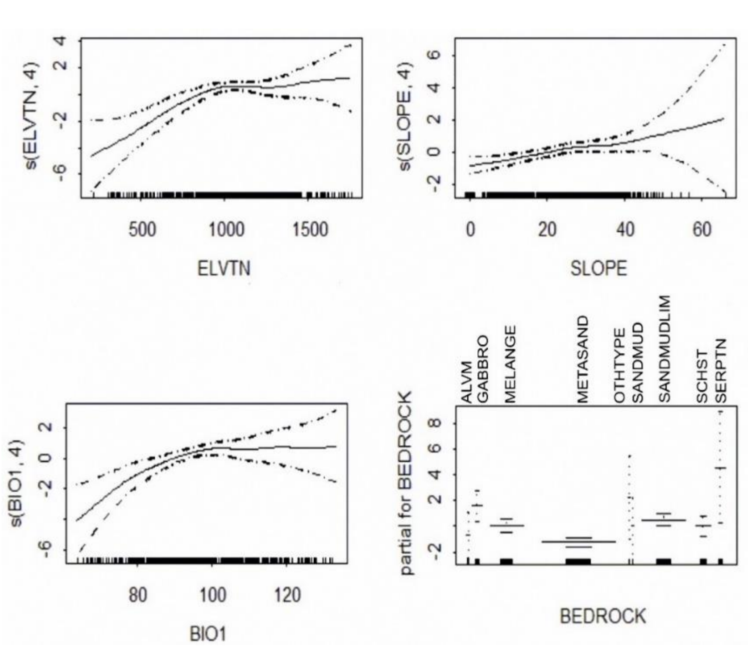

Figure 3. Partial response curves of the environmental variables to the modeling of Anatolian black pine predictive distribution

The validation value of the model for the main data set was 0.84 while the cross-validation test result was found to be 0.82. The potential distribution equation of black pine was obtained as Equation 2 from the model. In this formulation, 4 represents freedom.

$$CK \sim s(ELVTN, 4) + s(SLOPE, 4) + s(BIO1, 4) + BEDROCK \quad (2)$$

Where, CK is *Pinus nigra* Arnold., s represents spline smoother.

The tree model derived from the CART applied as the second method to model the potential distribution areas of the species under this study was structured with metasandstone, elevation, slope and mean annual temperature, respectively, as the variables according to their contribution (Figure 4).

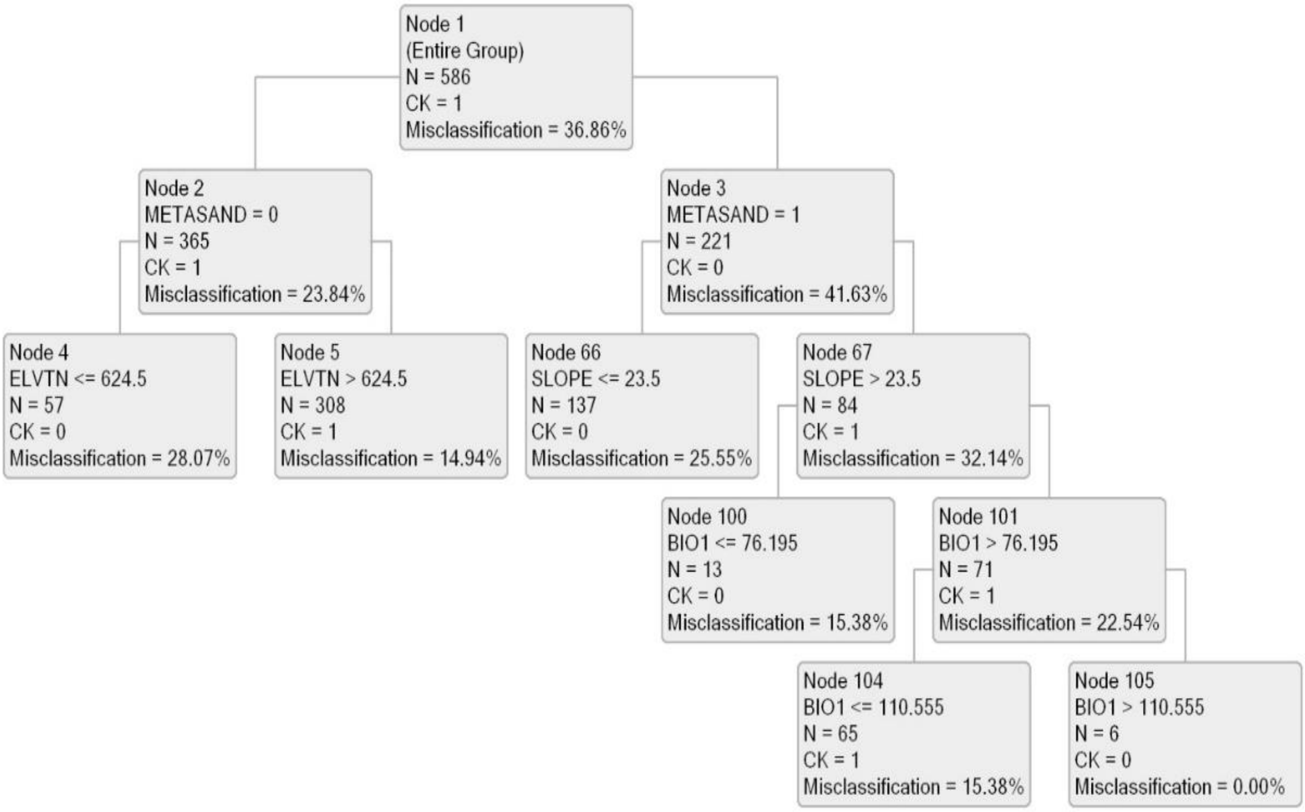

Figure 4. Classification tree of modeling black pine potential distribution

The decision tree of the CART model is shown in Figure 4. According to the tree model with 6 different terminal nodes, areas without metasandstone and areas with an elevation higher than 625 m were found to be the most appropriate potential distribution area of the species. On the other hand, in those sites with metasandstone, areas with a slope greater than 23.5% and mean annual temperature of 7.6 – 11 °C were also appropriate for the potential distribution of black pine. The ROC values of the tree model were found to be 0.804 for the training data set and 0.750 for the testing data set.

Finally, the potential distribution map of the GAM and CART created for black pine and intersection map of potential distribution of black pine using GAM and CART techniques was visualized in ArcGIS 10.2 software (Figure 5).

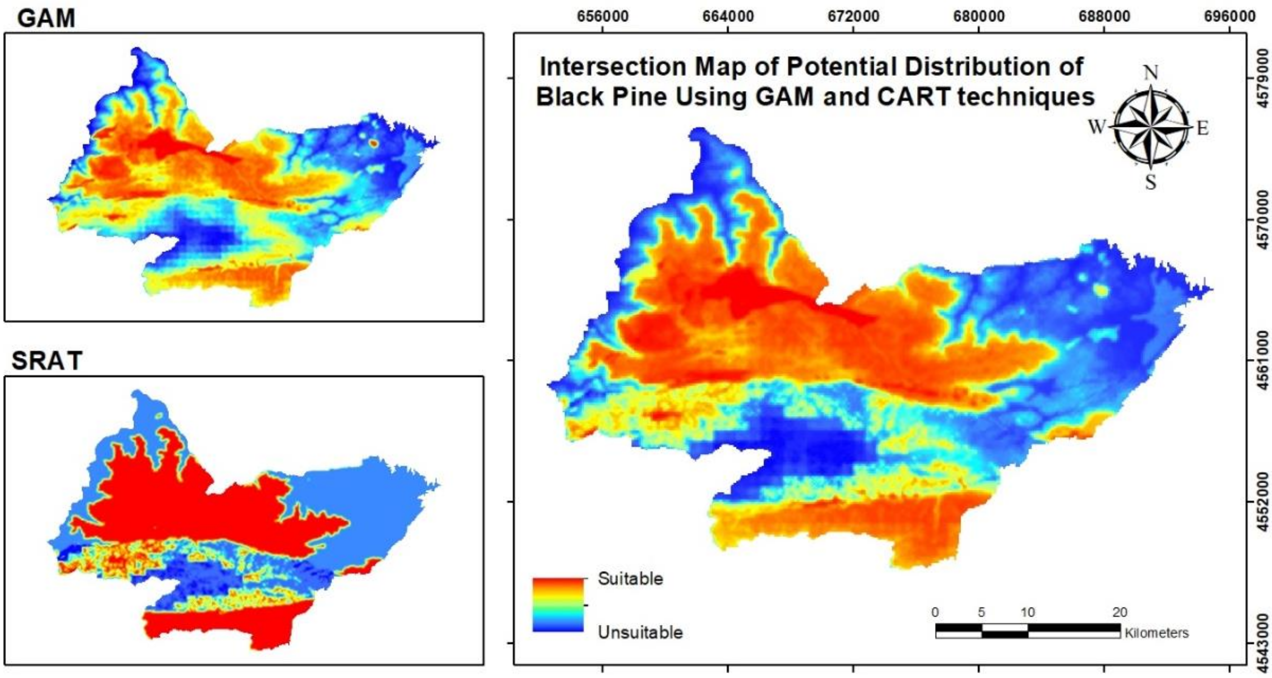

Figure 5. Intersection map of potential distribution of black pine

4. Conclusion and Discussion

The validity tests applied to the models developed through two analysis techniques used to determine the potential distribution areas of black pine revealed that these models had a high explanatory power. As a result of the model techniques applied, the descriptive variables that were statistically significant in the potential distribution areas of the species in that locality were bedrock, elevation, mean annual precipitation and slope according to the GAM technique and metasandstone, elevation, slope and mean annual precipitation according to the CART technique. In both models, it was determined that especially rock formations and climatic variables are effective in the potential distribution of the species. The results obtained from the models showed that in general, the best potential distribution areas for black pine were the ones located at an elevation of 650 – 1100 m with a mean annual temperature of 7.5 – 11.5 °C. Bedrock formation is another important variable that had an impact in that elevation a temperature range, while the mixed formation of sandstone– pebble stone– limestone as well as ophiolitic melange were the most appropriate geological formations for the potential distribution of black pine. On the other hand, gabbro and serpentine were the other appropriate formations for its potential distribution in the locality, whereas metasandstone was a limiting factor for its potential distribution. Moreover, the slope was another important variable found to be important in the models, while the potential distribution of the species increased especially at moderate and high slopes [16].

The association between black pine and elevation in the region can be explained with the fact that this species could meet appropriate climate requirements depending on that variable. The presence of the mean annual precipitation in the model supports this finding. As a matter of fact, in a study that determined the distribution areas of black pine in Turkey, they found that it was distributed on valley slopes and tectonic corridors in the Black Sea hinterlands starting from 600 m to 1400 m [17]. Moreover, they also showed that there was a significant variance in the distribution and productivity of black pine depending on elevation and temperature and its productivity decreased in general at elevations higher than 1400 m. Therefore, the findings regarding the associations with elevation and climate in the models developed for the potential distribution of black pine were also consistent with the results of the previous study. Furthermore, another study conducted in Aydınca (Amasya) to identify the potential distribution area of black pine in the hinterlands of the Central Black Sea showed that the elevations of 800 – 1100 m were the best distribution areas for this species. On the other hand, the main factor that had an actual impact was the climate conditions that altered depending on elevation. As in this study, it was stated that changing climate conditions with the increase in altitude affect the distribution of black pine [18].

In addition to the associations with climate requirements, as regards the rock formation which was another ecological condition that affected the distribution of black pine, the results of this study were consistent with the literature. It was reported that black pine trees could extend their roots deeper through the cracks and fractures of especially Mesozoic and Palaeozoic aged limestone rocks, and exploit the physiological depth and could establish pure and productive forests on this rock type in many areas [19]. It was also stated that very productive black pine forests were present on sandstone rock type at an elevation of around 1400 m in the west of Kastamonu tableland in the west Black Sea Region that also had similar habitat characteristics as that area [20]. Moreover, that study also showed that very productive and widely distributed black pine stands were present in different parts of the Mediterranean Region (Pos-Karsantı area in the north of Çukurova, south slopes of Nur Mountain, Sütçüler and Eğirdir districts of Isparta province) and some locations of the Black Sea Region (for example, Dirgine and Camiyanı regions) as long as deep soil and good aeration conditions were available on serpentine bedrock. On the other hand, black pine trees could find cracks with their strong root systems on this rock formation, exploited the physiological depth and thus create an appropriate environment for their potential distribution. Therefore, it can be argued that all these rock types were suitable for the physiological depth for black pine and areas where it can be potentially present are formed when this condition exists. On the other hand, metasandstone was found to be a negative limiting factor for the potential distribution of black pine. This formation which is a metamorphic rock type is classified as semi-elastic very hard rock [21]. For that reason, as this is a very hard rock, insufficient soil formation is considered to be an important factor that limits the potential distribution of this species.

In our study, the slope was found to be another environmental factor that had an impact on the potential distribution of black pine. There aren't any literature findings that show the impact of this variable on the potential distribution of black pine. However, some studies found a positive association between slope and the productivity of black pine [22]. This can be explained as follows from a holistic perspective: the slope is an important factor that changes the environmental conditions such as erosion, soil depth, soil texture, the content of soil skeleton, surface runoff, soil temperature, water and nutrient economy [23]. Topographic factors such as elevation, different landforms, slope positions, slope degree play an important role in the distribution of black pine. Different landforms and degree of slope are important factors in the productivity of black pine. In general, while it is known that the productivity of black pine is low in areas with high slope degree, it is higher in places with low slope degree [24]. Güner et. al. [7] mentioned that the species was distributed in the degree of slope between 1-80% in the black pine afforestation in the study area. In addition, they determined about a positive relationship between the increase in the degree of slope and the height growth of black pine. Negiz et al. [25] found a negative relationship between the productivity of black pine and slope degree. In addition, as a result of obtained model, they were stated that the productivity of black pine on plain and lower slopes increased. As can be seen, the presence of black pine at many degree of slopes can be mentioned. Particularly, the distribution of black pine means that it can be possible even in areas with high slope degree. While the black pine potentially distributed in the slope values which were obtained to in the models, it was showed actual distribution in the other slope degrees of the species. That is to say, actual distribution of the black pine at high slope degrees in the district can be mentioned. Thus, it is more accurate to interpret the associations between the distribution and productivity of a species with the changing environmental conditions due to slope rather than directly based on slope. As a result, it can be suggested that the suitability of moderate and high slopes for black pine as found in this study should be explained with the other environmental conditions depending on the slope. In summary, black pine with a strong root system and the trunk has a better ecological tolerance to the abovementioned conditions compared to the other species present in the area, which increases its potential distribution at moderate and high slopes. For this reason, rather than claiming that these areas are the best places for its potential distribution, it is more accurate to suggest that these are the areas that are compatible with the ecological tolerance of the species.

Anatolian black pine is an economically and ecologically important species. The information obtained in this study can be used in certain forestry practices such as afforestation and regeneration a regional scale. The findings of the study are important in terms of ensuring the sustainability of the species in the region and observing the future changes about this species.

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