DETERMINING POTENTIAL NICHE COMPETITION REGIONS BETWEEN KAZDAGI FIR (Abies nordmanniana subsp. equi-trojani) & ANATOLIAN BLACK PINE (Pinus nigra subsp. pallasiana) AND CONSERVATION PRIORITY AREAS UNDER CLIMATE CHANGE BY USING MAXENT ALGORITHM

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ABSTRACT

DETERMINING POTENTIAL NICHE COMPETITION REGIONS BETWEEN KAZDAGI FIR (ABIES NORDMANNIANA SUBSP. EQUI-TROJANI) & ANATOLIAN BLACK PINE (PINUS NIGRA SUBSP. PALLASIANA) AND CONSERVATION PRIORITY AREAS UNDER CLIMATE CHANGE BY USING MAXENT ALGORITHM

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Kazdagi Fir (*Abies nordmanniana* subsp. *equi-trojani*) is an endemic coniferus tree subspecies in Turkey. The species has a narrow distribution and its conservation status defined as EN (Endangered) by IUCN (International Union for Conservation of Nature), due to its decreasing population size. Besides the human activities unfavoring the species viability, it also suffers from a severe competition which has overlapping distribution with Kazdagi fir; Anatolian Black Pine *(Pinus nigra* subsp. *pallasiana).*

The study presented here, aimed to detect conservation priority areas for Kazdagi fir. In order to achieve this, species distribution modeling approach by using MAXENT algorithm was used to model both Kazdagi fir and Anatolian Black Pine's potential distributions in 2050 by considering the possible effects of global climate change in near future. Then, a series of overlay analyses were made to be able to detect the areas which are better habitats for Kazdagi fir than Anatolian black pine.

The results of the study revealed several regions. Yet, considering the current distribution of the species and its dispersal limits, this study proposes two conservation priority areas for Kazdagi fir; Uludag and Kazdagi (Mt. Ida). The assessed regions are the most important habitats for both species according to both currently and in 2050 climate scenarios. Thus, it is crucial that forestry and conservation practices should be taken into consideration in these areas.

Keywords: Abies nordmannianna subsp. equi-trojani, Climate Change, Maxent, Conservation, Species Distribution Models

ÖZ

KORUMA ÖNCELİKLİ ALANLARIN BELİRLENMESİ İÇİN KAZDAĞI GÖKNARI(Abies nordmanniana subsp. equi-trojani) VE KARAÇAM (Pinus nigra subsp. pallasiana) ARASINDAKİ İKLİM DEĞİŞİKLİĞİNE BAĞLI OLASI HABİTAT REKABETİ BÖLGELERİNİN MAXENT ALGORİTMASI KULLANILARAK TESPİTİ

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Kazdağı Göknarı (*Abies nordmanniana* subsp. *equi-trojani*), Türkiye'de dar bir dağılım gösteren, Dünya Doğa Koruma Birliği (IUCN) tarafından koruma statüsü tehlikede (EN) olarak tayin edilmiş, iğne yapraklı bir alt türdür ve populasyon durumu gittikçe azalan olarak belirlenmiştir. Türün habitatını ve yaşayabilirliğini olumsuz yönde etkileyen insan aktivitelerinin yanı sıra, bir başka iğneli yapraklı bir alt tür olan Karaçam *(Pinus nigra* subsp. *pallasiana)* ile habitat rekabeti içindedir. Bu rekabet, son yıllarda iki türün çakışan habitatlarında yapılan ağaçlandırma çalışmalarının Karaçam'ı destekleyecek yönde gerçekleştirilmesiyle daha da şiddetli hale gelmiştir.

Bu çalışmanın amacı, Kazdağı Göknarı için koruma öncelikli alanların belirlenmesidir. Bunu gerçekleştirmek için MAXENT algoritması aracılığıyla tür dağılım modellemesi yaklaşımı kullanılmıştır. Modelleme çalışmalarıyla, iki türün de 2050 yılındaki, iklim değişikliğine bağlı potansiyel habitatları tespit edilmiş, daha sonra bu haritalar aracılığı ile hangi bölgelerin Kazdağı Göknarı için Karaçam'dan daha uygun iklimsel koşullar taşıdığı belirlenmiştir. Aynı işlemler Karaçam için tekrar edilmiştir.

Sonuçlar birden fazla alan sunmaktadır. Fakat türlerin bugünkü dağılımı ve dispersal limitleri göz önünde bulundurularak Kazdağı Göknarı için Kazdağı ve Uludağ öncelikli alanlar olarak belirlenmiştir. Bu alanlar hem günümüzde, hem de 2050 yılı iklim senaryolarında türler için yüksek dağılım olasılığına sahip alanlardır. Bu doğrultuda bu alanlarda yapılan ağaçlandırma, yeniden ağaçlandırma ve koruma çalışmalarının türler için öncelikli alanları gözetecek doğrultuda olması; Kazdağı Göknarı'nın yakın gelecekte neslinin tükenmemesi, Karaçam'ın ise neslinin tehlike altına girmemesi için önem taşımaktadır.

Anahtar Kelimeler: Abies nordmanniana subsp. equi-trojani, İklim Değişikliği, Tür Dağılım Modelleri, Doğa Koruma, Maxent

For those who ever tried, ever failed.
Tried again. Failed again. Failed better.

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LIST OF ABBREVIATIONS

ABBREVIATIONS	
AUC	Area Under Curve
EN	Endangered (IUCN Category)
GEF	Global Environment Facility
IUCN	International Union for Nature Conservation
SDM	Species Distribution Models
ROC	Receiver Operating Characteristic

CHAPTER 1

INTRODUCTION

1.1. Kazdagi Fir (*Abies nordmanniana* subsp. *equi-trojani*)

Kazdagi fir (*Abies nordmanniana* subsp. *equi-trojani*) is an endemic coniferous tree species belonging to *Pinaceae* family. The species distribution starts from the Kazdağı (Mount Ida) which located in the Northwest Anatolia follows the Black Sea cost until Sinop Province. The scientific name *equi-trojani* is a reference to the ancient tale of the Trojan horse, which might well have been constructed of wood from this species as it grows nearby to the location of ancient Troy.

The species can grow up to 30 meters long. Buds contain high amounts of resin. The number of buds at the tips of the side shoots variates from 5 to 7. The cones form on the shoots which are located on top of the tree and lasted from previous year. They can stand upright on the shoot and can be 15-20 cm long. The outer scales of the cylindrical cones are longer than the inner scoops and the ends are curled backwards. In older trees, the crust is thick and cracked. Needle leaves are arranged on long shoots in comb-like form.

Needle leaves are narrow towards the shoot end. The ends of the leaves are pointed, and the others are blunt or incised. Leaves are flat and two-sided. The upper face of the lobe is slightly chiseled, and the lower face has two distinctly silvery white stoma bands. Needle leaves stay on shoots for a long time such as 7-10 years. When it falls or broken, it leaves a trail of round, double circle circles on the shoot. The body shell of the Kazdağı fir is light gray, thin and smooth.

Figure 1: *Abies nordmanniana* subsp. *equi-trojani*. Left: tree, Top Right: shoots, Down Right: Male cones

zhe most important and endangered populations of the species are located on the Kazdağı. The Kazdağı reaches its highest point in Kartaltepe (1767m), which is located on the east of Babadağı. The ridges starting from this point, follows a path through to the north and northeast and forms the Kazdağı. The peaks formed by different ridges are 30-40 km apart from each other. The Gürgendağı (1434m), Katrandağı (1300m), Eybekdağı (1295m), Susuzdağı (1000m) ve Eğrikabaağaç (800m) are main peaks which form Kazdağları. Kazdagi fir (*Abies nordmannian*a subsp. *equi-trojani)* occupies small areas on the northern aspects of these mountain peaks (Ata, 1984). Populations of the species are isolated from each other and do not represent a continuous distribution.

According to the study which carried out by Ata, there are 6 disconnected populations of Kazdağı fir as listed below:

1. Kalabaktepe foothills, 122 ha, only north aspects, between 1200-1600m altitude, mixed with *Pinus nigra*;
2. Gürgendağı, largest population, 2530 ha, only north aspects, between 1000-1434m altitude;
3. Eybekdağı, dispersed population, 1300 ha, only north aspects, between 700-1250 m altitude;
4. Susuzdağ, very dispersed population, 1000 ha, only north aspects, between 700-1295m altitude;
5. Eğrikabaağaç, dispersed population, 410 ha, only north aspects, between 650-800m altitude;
6. Ağıdağı, foothills and river sides, 150 ha,

While total coverage area of Kazdagi fir according to the study of Ata is 5512 ha, more recent studies proposes narrower coverage such as 3600 ha (Aslan, 1986). The species covers different sized and disconnected areas from 120 ha to 2400 ha on Kazdağı. Altitude range is defined as between 400-1650m (Aslan, 1986).

Uludağ population of Kazdagi fir, formerly treated as a different subspecies of *Abies nordmanniana* named *Abies nordmanniana* subsp. *bornmülleria.* It also has a restricted population on the high altitudes of Uludağ. It is isolated from both Kazdağı populations and Western Black Sea populations.

Western Black Sea populations were also treated as a different subspecies of *Abies nordmanniana* named *Abies nordmanniana* subsp. *nordmanniana.* This populations are healtier and less threatened populations among all. They form continuous forests as mixed stands with beech and oak.

1.1.1. Taxonomy of Kazdagi Fir (*Abies nordmanniana* subsp. e*qui-trojani*)

The name "*equi-trojani*" was first used on an herbarium label (Sintenis, 1883, pl. exicc. Iter trojanum, No 523) for the specimens collected from a nearby location to Troja (Çanakkale). The diagnosis of the species came later on from Boissier (1884), who treated the specimens collected by Sintenis as *Abies pectinata* DC. var. *equi-trojani* Asch. & Sint. ex Boiss. Shortly thereafter, this taxon was included as a variety of *Abies nordmanniana* Spach by Guinier (Doğu Karadeniz fir) and Maire (1908): *A. nordmanniana var. equi-trojani* (Asch. & Sint. ex Boiss.) Guinier & Maire; and later as a subspecies of silver fir: *Abies alba Mill.* subsp. *equi-trojani* (Asch. & Sint. ex Boiss.) Asch. & Graebn.

In following years, a shift in the schools of taxonomy from using morphological traits to internal traits due to the fact that morphological traits vary depending on the growing environment of the individual; and internal morphology and palynological privileges would better reflect the hereditary qualities. It became evident that these characteristics could not be used alone in plant referencing and classification practices. The examinations based on this shift showed that the species is a natural hybrid of *Abies cephalonica* (Greek fir) and *Abies bornmülleriana* (Uludağ fir) (Aytuğ, 1959).

Abies equitrojani defined as a distinct species by Ata & Merev (1987), *Abies bornmülleriana* accepted as subspecies of *Abies nordmannianna* in 1990, classified as subspecies of *Abies cephalonica* (T.S Lui, 1972) & as *Abies nordmanniana* subsp. *equitrojani* (Govaerts,1975).

As pictured above, the classification of *Abies equitrojani* had been uncertain due to its intermediate position between *Abies cephalonica* Loudon and *Abies nordmanniana* geographically and morphologically (Mattfeld, 1928; Aytug, 1959; Liu, 1971; Bagci & Babaç, 2003; Kaya et al., 2008; Kurt et al., 2016). Based on detailed studies of *Abies equi-trojani* and *Abies cephalonica,* Kazdagi fir appeared to be distant genetically (Scaltsoyiannes et al., 1999; Liepelt et al., 2010) and biochemically (Mitsopoulos and Panetsos, 1987). Later multivariate analyses showed that *Abies equitrojani* appeared to be closer to *Abies bornmuelleriana* than *Abies cephalonica* (Bagci and Babaç, 2003). Then, Uludağ fir classified as *Abies nordmanniana* subsp. *bornmuelleriana* (Mattf.) Coode & Cullen, hence Kazdağı fir become more related to Doğu Karadeniz fir (*Abies nordmanniana*) than previosly it is to be thought.

In more recent studies, *Abies equitrojani* treated as subspecies of *Abies nordmanniana* rather than a subspecies of *Abies bornmullieriana* (Schütt, 1991; Yaltırık, 1993; Gülbaba et al. 1996; Velioğlu et al., 1998; Kaya et al., 2008; Debreczy and Rácz, 2011; Kurt et al., 2016, Jasinska et al., 2017). It also is considered as subspecies of *Abies nordmanniana* in IUCN Redlist (Knees, S. & Gardner, M. 2011).

Table 1: *Abies* species distributed in Turkey

NAME	**COMMON NAME**	**COMMON TURKISH NAME**
Abies cilicica	Cilician Fir	Toros Göknarı
Abies cilicica subsp. *isaurica*		Bozkır Göknarı
Abies nordmanniana subsp. *nordmanniana*	Caucassian Fir	Doğu Karadeniz Göknarı
Abies nordmanniana subsp. *equi-trojani*	Kazdağı Fir	Kazdağı Göknarı

In the most recent study of the taxonomic position of *Abies equi-trojani*; the needle characteristics were used to distinguish *Abies* species and the results indicates that using single character does not distinguish *Abies* species but applying several characters shows significant differences among other species. Pairwise comparisons of 39 characters measurements between *Abies equi-trojani* and other *Abies* species shows the highest number of characters differs significantly from *Abies cephalonica* (30) and *Abies alba* (25). The closest relationships to *Abies equi-trojani* were revealed to be *Abies bornmuelleriana* and *Abies nordmanniana*, with 16 characters significantly varied between (Jasinska et al., 2017).

The current accepted taxonomy of *Abies* species in Turkey were given in Table 1. Yet, to be able to clarify all the confusions of *Abies* taxonomy, all synonims for *Abies nordmanniana* subsp. *equi-trojani* were given in the Table 2 (http://www.theplantlist.org).

Table 2: All synonims of *Abies nordmanniana* subsp. *equi-trojani*

NAME
Abies alba subsp. *equi-trojani* (Asch. & Sint. ex Boiss.) Asch. & Graebn.
Abies bornmuelleriana Mattf.
Abies cephalonica var. graeca (Fraas) Tang S.Liu
Abies cephalonica var. greaca (Fraas) T.S. Liu
Abies equi-trojani (Asch. & Sint. ex Boiss.) Mattf.
Abies nordmanniana subsp. *bornmuelleriana* (Mattf.) Coode & Cullen
Abies nordmanniana var. bornmuelleriana (Mattf.)
Abies nordmanniana var. equi-trojani (Asch. & Sint. ex Boiss.)
Abies olcayana Ata & Merev
Abies pectinata var. equi-trojani Asch. & Sint. ex Boiss.
Abies pectinata var. graeca Fraas

1.1.2. Conservation Actions

Kazdagi fir one of the target species in the In-Situ Conservation of Plant Genetic Diversity Project (28632-TU) supported by World Bank Global Environment Facility (GEF). Based on the survey and inventory studies performed by a team from the Ministry of Agriculture, and Ministry of Forestry in 1994, Gürgendağ population of Kazdağı fir declared as Gene Management Zone (GMZ). The Gürgendağ is the area where plant species have very rich genetic diversity and are under the threat of extinction or important from economical aspects. in order to maintain genetic diversity and evolution in and between populations.

The Kazdağı National Park is an active conservation area since 1993 and includes small Kazdağı fir populations as one of 77 other endemic species, 29 being local endemic. Yet, the study which conducted by Satil (2009) reports habitat degradation caused by the amount of visitor numbers to the National Park, especially as a result of the annual Sarikiz Festival which is held on the summit in August; the negative effects are caused through a lack of suitable facilities for large numbers of visitors.

1.2. Anatolian Black Pine (*Pinus nigra* subsp. *pallasiana)*

Anatolian Black pine (*Pinus nigra* subsp. *pallasiana)* is a coniferous tree species from Pinaceae family. Genus Pinus has 5 subspecies native for Europe and distributed along the Mediterranean Sea costs (Spain, Portugal, Italy, France, Greece), middle Europe (Austria, Macedonia), Black Sea costs (Russia and Crimes), Balkan Peninsula (Romania & Bulgaria), Anatolia (Turkey), islands (Cyprus, Sicily and Corsica) and lastly with outliers in Algeria and Morocco.

Table 3: *Pinus nigra* subspecies

NAME	**LOCATION**
Pinus nigra subsp. *salzmannii* (Dun) Franco	Central and southern Spain
Pinus nigra subsp. *laricio* (Pior.) Marie	Corsica, Calabria and Sicily
Pinus nigra subsp. *nigra*	Austria, Italy, Balkans and Greece
Pinus nigra subsp. *dalmatica* (Vis.) Franco	Croatia and Dinaric Alps
Pinus nigra subsp. *pallasiana* (Lamb.) Holmboe	Balkans, southern Carpathians, Crimea, Turkey, Cyprus and Syria.

Pinus nigra subsp. *pallasiana* (Lamb.) Holmboe has the widest distribution among all *Pinus nigra* subspecies. It has 5 varietes in Turkey (Akkemik *et al*. 2011). The species is wide-spread all along Anatolia, Black Sea and Mediterranean regions (Davis, 1965). It has 4.2 million ha forest coverage yet 1.5 ha of the forests are damaged, degraded or fragmented (Ormancılık İstatistikleri 2015). Anatolian Black Pine generally forms pure stands at 400-1400 m elevations, after 1400 m it forms mixed stands with *Pinus sylvestris*, *Abies* spp., and *Quercus* spp. at lower elevations.

Anatolian Black Pine differentiated from other *Pinus nigra* subspecies by its needle and cone length & the crown shape (Yaltırık, 1993). Seedling's crowns are generally conical, as the individual grows it becomes more rounded and flat-topped. It has a thick, scaly furrowed bark colored dark-grey to black in younger individuals; as tree gets older the color becomes paler. It can grow up to 20-40 m (Yaltırık, 1988).

Table 4**:** *Pinus nigra* subsp. *pallasiana* varietes

NAME
Pinus nigra Arn. subsp. *pallasiana* (Lamb.) Holmboe var. *pallasiana*
Pinus nigra Arn. subsp. *pallasiana* (Lamb.) Holmboe var. *şeneriana* (Saatçioğlu) Yaltırık
Pinus nigra Arn. subsp. *pallasiana* (Lamb.) Holmboe var. *yaltirikiana* Alptekin
Pinus nigra Arn. subsp. *pallasiana* (Lamb.) Holmboe var. *fastigiata* Businsky
Pinus nigra Arn. subsp. *pallasiana* (Lamb.) Holmboe var. *columnaris-pendula* Boydak

1.3. Species Distribution Models (SDMs)

Species distribution models are numerical tools for predicting potential distribution of species with combined data of observed occurrences of species and environmental variables within the study area. They are used to gain ecological and evolutionary insights and to predict distributions across landscapes, sometimes requiring extrapolation in space and time (Elith et al., 2006). These models help to visualize the available habitats of species which have different habitat requirements, both in the past and future climates (Kozak, 2008).

Species distribution models are also known as ecological niche models due to fact that defining a geographical range (distribution) of a species, also means defining the ecological niche of the species. Ecological niche can be defined as the combination of the whole environmental conditions which allows a species to sustain its population size (Pulliam, 2000). Species distribution models or ecological niche models are related with the “Fundamental Niche” and “Realized Niche” which are defined by Hutchinson. According to Hutchinson (1957), while fundamental niche defines a 'multidimensional and high-density' space in which a species can exist without competing with another species; realized niche is a more restrictive niche due to interspecific interactions of species such as competition.

Widespread use of species distribution models raised the questions that which niche (fundamental or realized) of the species can be represented by modeling predicted distribution of species. In their study, Soberon and Peterson (2005), assumed that the combination of 3 different components form the ecological niche of species; which are A) abiotic factors (such as soil type and climate aspects), B) biotic factors (interspecific relationships such as mutualism and prey-predator relations) and M) parts of the world “accessible” to the species in some ecological sense, without barriers to movement and colonization. Here, A may be regarded as the geographic expression of the Fundamental Niche (FN) and intersection of A and B represents the geographic extent of the Realized Niche (RN) of the species while the intersection of A and B and M is the right set of biotic and abiotic factors and that is accessible to the species, and is equivalent to the geographic distribution of the species. Based on the representation of the components of the potential distribution of species, they discuss that ‘ecological niche modeling’ algorithms generally produce estimates of the FN (or at least something more general than just the distribution). There are other researchers suggest that species distribution models predict species-climate relationships are also constrained by non-climatic factors, suggesting that the models reflect the realized niches (Gusian and Zimmermann, 2000; Pearson et al., 2003). It is also proposed that using fundamental niche and realized niche concepts in species distribution models is not useful. Niche is redefined by Chase and Leibold (2003) as environmental conditions which have minimum requirements for survival that allow birth rate in the population to be equal to or greater than the death rate. Although this niche concept seems to be more useful for model applications, it is still open to debate for being relative to the model (Araújo and Guisan, 2006).

One of the fundamental inputs of species distribution models is the locations of species on earth coordinate system. There are algorithms which use presence-absence data as well, yet a collecting absence data is both time consuming and unreliable process such as in the case of birds. Since they change their locations seasonally, and cover a very large distance, it is hard to collected absence data might be misleading. For plants which sprout once in two years or more, the absence data also might be unreliable, since the year which data collected might be overlapped with the hibernation year of the plant. Yet there are varied sources of presence data such as herbariums, natural history museums and online databanks which make easier to find necessary data for species distribution models. Elith et al (2008), conducted a study to compare the models which need presence only data and presence-absence data. They used 226 species from 6 regions of the world for model comparison presence-only data to fit models, and independent presence-absence data to evaluate the predictions. After they compare 16 different models, they found out that presence-only data requiring models are as predictive as presence-absence data requiring models, especially in machine-learning algorithms. Table 5 shows the online databanks for species presence data, covering world-wide geographical range. There are also available regional databanks of different countries, continents and biogeographical regions.

Table 5: Examples of open source species distribution databanks

NAME	**URL**
Global Biodiversity Information Facility (GBIF)	www.gbif.org
World Information Network on Biodiversity	www.conabio.gob.mx
HerpNET	www.herpnet.org
Ornithological Information System (ORNIS)	www.ornisnet.org

The other fundamental input for a species distribution model is environmental variables which might be climatic variables as well as elevation, land cover, soil type. Data sets containing these variables can be created by users with the help of geographical information systems (GIS) programs or they might be available in online data sets. There are many institutions and organizations that offer data sets over the internet (Table 6).

The environmental variables used in species distribution models are depend on the range of the study area. Indirect variables (e.g. elevation) provide more accurate results while modelling relatively small-scaled areas or topographically complex areas. On the contrary, direct variables (e.g. pH, temperature) provide more accurate results when the study area is large because the predictive power of indirect variables is very low for such areas of low resolution (Guissan & Zimmermann, 2000).

Table 6: Examples of environmental datasets

NAME	**DATA CLASS**	**URL**
WORLDCLIM	Climatic variables	http://www.worldclim.org/
CORINE	Land cover data	https://land.copernicus.eu
FAO Soils Portal	Soil type data	http://www.fao.org/
ASTGTM	DEM	https://lpdaac.usgs.gov/

Species distribution modellings have become a very important component of conservation biology. It has been used as a tool to assess both land use and environmental and climate change effects on the distribution of species (Kiensast et al., 1996; Guisan and Theurillat, 2000). Since assessing biodiversity priority areas one of the key components of conservation biology, the most popular application of species distribution models is in setting up conservation priority areas (Margules and Austin, 1994).

Setting priority areas is very important in conservation for rare, endemic and species whose range is known to be declined over the years. Since one of the challenging threats for all living species is climate change (reference), modeling the distributions of species under climate change scenarios has become one of the most widely used tool to assess conservation status of a species (Martínez-Meyer et al., 2004).

1.3.1. MAXENT Approach

Species distribution models requires algorithms to properly process species observation and environmental data. There are several softwares based on different algorithms can be used to build SDMs (Table 7), among them MAXENT is one of the most widely used algorithms (Philips et al., 2006).

MAXENT algorithm is based on the principle of maximum-entropy which states that probability distribution which best represents the current state of knowledge is the one with largest entropy, in the context of precisely stated prior data (Jaynes, 1957). In other words, it takes testable information or precisely stated prior data about a probability distribution function and considers the set of all possible probability distributions that would encode the prior data. Application of MAXENT algorithms to SDMs is a machine learning software named MaxEnt, which takes a set of environmental (e.g., bioclimatic) grids and georeferenced species occurrence data (e.g. mediated by GBIF) and build a model to expresses a probability distribution where each grid cell has a predicted suitability (a value) of habitat conditions for the subjected species. A higher value of the function at a particular grid cell indicates that the grid cell is predicted to have more suitable conditions for that species. It has the advantage of allowing the use of both categorical and continuous variables (Baldwin, 2009).

MaxEnt can generate output data in raw, cumulative and logistic format (Philips et al., 2008) Maxent's primary output is raw, yet these data are difficult to interpret because the output values are often too small for each data point. The cumulative data format gives the probability of finding the species of interest for each location on a scale. This scale is between 0-1 and this output format is more understandable when transferred into geographical information system (GIS) (Philips et al., 2006). Yet, the values are not proportional to each other in cumulative data format, which causes improper visualization of results in GIS programs. Logistic format more accurately reflects the difference in output values which are between 0-1 scale thus it is more useful over other output formats (Baldwin, 2009).

Table 7: Examples of SDM algorithms

Algorithm	**Software**	**URL**
BIOCLIM	DIVA-GIS	www.diva-gis.org
Domain	DIVA-GIS	www.diva-gis.org
GARP	DESKTOPGARP	https://desktop-garp.software.informer.com/
Generalized Additive Model (GAM)	GRASP	https://www.unine.ch/cscf/grasp
MAXENT	MAXENT	https://www.cs.princeton.edu/~schapire/maxent/

MaxEnt also allows to measure variable importance on predicted distribution. It can be determined in two ways. First, in the final model MaxEnt provides the percentage of contribution for each variable. In case of existence of correlation between two or more variables, results are prone to indicate more importance to them than actual. Second method is jackknife approach which excludes one variable at a time when running the model. In so doing, it provides information on the performance of each variable in the model in terms of how important each variable is at explaining the species distribution and how much unique information each variable provides (Baldwin, 2009).

Other important feature of MaxEnt is that it allows to evaluate the model to determine its relevance. As with any modeling approach, it is important to determine the fit or accuracy of the model. Model evaluation primarily has been done in two ways. First method is to calculate area under curve (AUC) of receiver operating characteristic (ROC) plot. The scale of AUC value is between 0 and 1. Values close to 0.5 indicate a fit no better than that expected by random, while a value of 1.0 indicates a perfect fit (Baldwin, 2009).

1.3.2. SDMtoolbox for ArcGIS

SDMtoolbox (Brown, 2014) is a python-based ArcGIS (ESRI 2011) toolbox for spatial studies of ecology, evolution and genetics (Brown, 2014; Brown et al., 2017). The toolbox automates repetitive and complicated and spatial analyses. By carefully processing of occurrence data, environmental data and model parameterization it maximizes each model’s discriminatory ability and minimize overfitting.

SDMtoolbox directly interfaces with Maxent. Besides it provides many of other analyses are for use on other species distribution modeling methods (see: Universal Tools). The current version contains a total 78 scripts that are applicable in fields such as landscape genetics, evolutionary studies and macroecology. For example;

- Species richness calculations,
- Corrected weighted endemism calculations,
- Generation of least-cost paths and corridors among shared haplotypes,
- Assessment of the significance of spatial randomizations
- Enforcement of dispersal limitations of SDMs projected into future climates

Also, there are several generalized tools for conversion of GIS data types or formats and batch processing. For example, it allows to arrange the same coordinate system format for all type of datasets at the same time. The other batch processing example is that it allows to mask several data in same extent at the same tam.

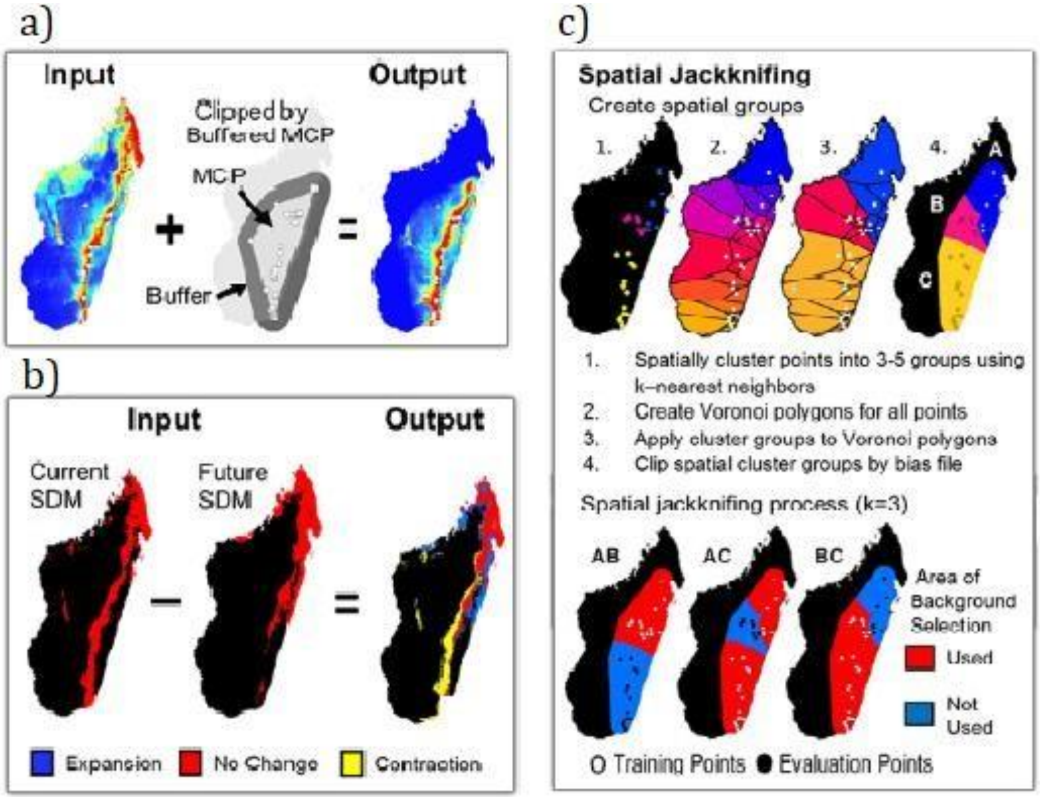

Figure 2: Examples of SDMToolbox for ArcGIS

1.4. Justification of Study

While Kazdagi fir is an endemic subspecies in Turkey, it is known that it has shadow pressure on Anatolian Black pine in Kazdagi region (Ata, 1975). On the other hand, the forestation practices favored Anatolian Black pine plantations following a wildfire in 1975 in formerly known pure Kazdagi fir stands, turned into Anatolian Black pine stands, artificially (Asan, 1984). It is also reported that in small habitat patches, Kazdagi fir naturally took over stand dominance in mixed stands with Anatolian Black pine (Asan, 1984).

The aim of the study is to resolve both niche competition and conservation priority competition between species by using an unbiased modeling method. The determination of the priority areas based on the ecological factors for species will both ease the future conservation practices and decrease the extinction risks.

CHAPTER 2

METHODS

2.1. Species Occurrence Data

One of the most favorable features of MAXENT is that it allows to build species distribution models with presence-only data. Since to prove the absence of a species in a certain area requires very-long term fieldworks and careful analysis, presence-only data were used in this study.

There are several methods to collect species occurrence (presence) data such as observatory fieldworks, herbarium records and museum collections. Current computational techniques allow to record and share all type of species occurrence data, including online data. For example; Global Biodiversity Information Facility – GBIF (https://www.gbif.org) is an international network and research infrastructure funded by the world’s governments and aimed at providing open access to data about all species presence as coordinate information. There are more than 1.000.000.000 occurrence records on the network. Such network built in Turkey, to collect biodiversity of Turkey named Nuhun Gemisi (Noah’s Ark), yet the information sharing of the network is very limited and requires special permissions.

Yet, the data on endemic species is very scarce on GBIF, hence there are only 3 occurrences of *Abies nordmanniana* subsp. *equi-trojani*. Eventhough, there are more than 50 records of *Pinus nigra* subsp. *pallasiana*, the geographical distribution of the data does not cover the actual distribution of the species.

Forest stand maps - the basic unit of forest mapping; a group of trees that are more or less homogeneous with regard to species composition, density, size, and sometimes habitat- are other useful tools to collect occurrence data for tree species. In Turkey, General Directorate of Forestry published an open access web-tool for forest stand map of Turkey named “e-Harita” (https://www.ogm.gov.tr/Sayfalar/OrmanHaritasi.aspx).

The e-Harita has several information about both the species and the forest which are available online. It has the most dominant 1 to 3 species information (Table 9), the species’ growth-age information and the cover ratio of the area (Table 8). It uses symbols for all three types of information. It has the land/forest cover class information represented by colors (Figure 3). It also has the tool to take coordinate information of any point on the map.

Table 8: Cover ratio symbols on the e-Harita

Symbol	Class	Cover Ratio (%)
0	Forestration	-
ÇB	Severely degraded stands	CR < 10
B	Degraded stands	10 < CR < 40
2	-	40 < CR < 70
3	-	CR > 70

In this study, e-Harita was used to collect occurence data for *Pinus nigra* subsp. *pallasiana* and *Abies nordmanniana* subsp. *equi-trojani*. Based on the distribution areas which are defined on Flora of Turkey, the forest stand maps were scanned carefully to detect all the stand of both species are present pure or mixed, and then one or two coordinate information were taken from inside of the stands. For the coordinate (presence data) to be taken, stands required to have the conditions;

- Natural stand – no reforestration / regenation / plantation
- The most or the second dominant species in the stand
- Age status a, ab, b, bc, bd, c, cd, d
- Cover ratio > 10

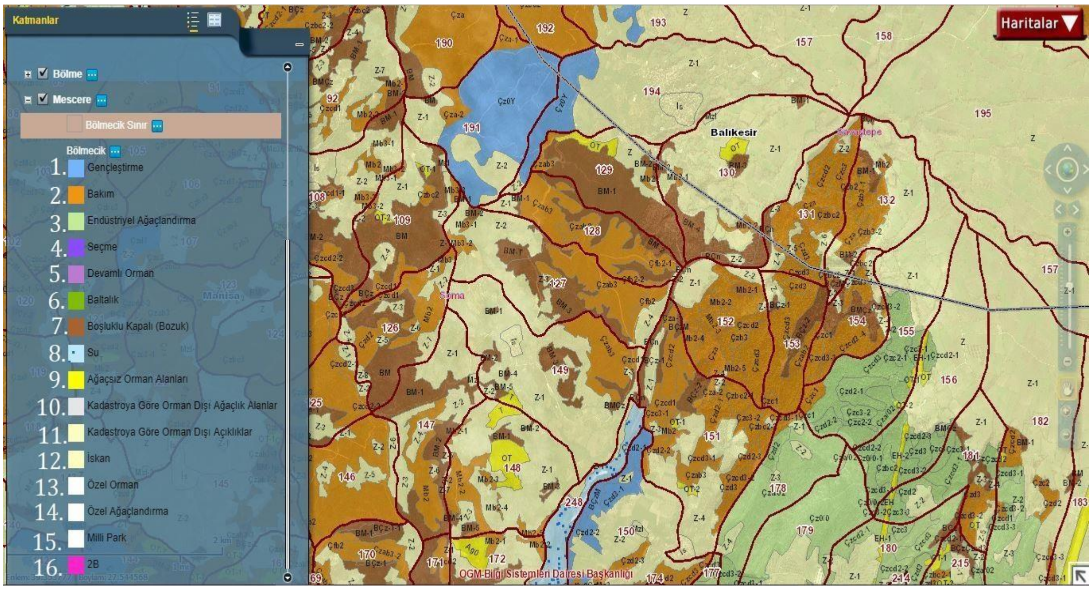

Figure 3: A view of the forest stand map of Turkey from the GDF's e-Harita.

Colors on the left-hand side represent forest/land cover classes on e-Harita, symbols in the middle of brown outlined divisions (stands) carries the information about the most dominant species in the stands, their average age and the cover range. 1. Generation, 2. Silvicultural Practices, 3. Industrial plantation, 4. Managed forests, 5. Continious forest, 6. Marshland, 7. Damaged stand, 8. Water, 9. Woodless forest area, 10. Non-forest woodland, 11. Non-forest woodless area, 12. Settlement area, 13. Private forest, 14. Private plantations, 15. National park, 16. 2B

Table 9: Tree species and their symbols on the e-Harita

CONIFERUS TREES		DECIDUOUS TREES		DECIDUOOUS TREES	
Species	**Symbol**	**Species**	**Symbol**	**Species**	**Symbol**
Turkish pine	Çz	Beech	Kn	Walnut	Cv
A.Black pine	Çk	Oak	M	Olive	Zy
Scotch pine	Çs	Hornbeam	Gn	Valonia oak	Mp
Fir	G	Alder	Kz	Common oak	Ms
Spruce	L	Poppler	Kv	Sessile oak	Mz
Cedar	S	Chesnut	Ks	Hungarian oak	Mc
Juniper	Ar	Ash	Dş	Downy oak	Mt
Stone pine	Çf	Linden	Ih	Aleppo oak	Mm
Cypress	Sr	Maple	Ak	Turkish oak	Ml
Yew	P	Elm	Ka	Evergreen oak	Mr
Aleppo pine	Çh	Boxwood	Ş	Kermes oak	Mk
Maritime pine	Çm	Plane	Çn	Arbutus	Ko
Monterey pine	Çr	Ocalyptus	Ok	Scrub	Ma
Douglas fir	D	Sweetgum	Sğ	Birch	H
Syrian juniper	An	Hazelnut	Fn	Rhododendron	O
Other conifers	Di	Willow	Sö	Others	Dy

2.2. Environmental Data

One of the most widely used environmental datasets is WORLDCLIM-Global Climate Data. WORLDCLIM database offers climatic models which are created with different modeling techniques and in different resolutions.

Currently, there are two climate datasets offered by WORLDCLIM. The data in Version 1.4 are provided by CMIP5 (IPPC - Intergovernmental Panel on Climate Change Fifth Assessment) climate projections from global climate models (GCMs) and there are both current, future & past climate data sets while in Version 2, only current climate datasets are available. These data were created based on the global and regional data from meteorological stations. WORLDCLIM also offers climate scenarios in 4 resolutions; 10 arc-minutes, 5 arc-minutes, 2.5 arc-minutes, 30 arc-seconds (~1 km^2) and for two different years; 2050 and 2070.

Table 10 shows the available global climate models on WORLDCLIM. The climate data offers 3 RCP values for each scenario, which are 2.6, 4.5 and 8.5, from mild climatic change to severe climatic change, respectively. In this study all 15 GCMs which are available in RCP 2.6 were used in both modeling of Kazdagi fir and Anatolian Black pine for only year 2050.

Table 10: WORLDCLIM Global Climate Models for 2050

GCMs	**Codes**	**Available RCPs**
ACCESS1-0	AC	4.5, 8.5
BCC-CSM1-1	BC	2.6, 4.5, 6.0, 8.5
CCSM4	CC	2.6, 4.5, 6.0, 8.5
CESM1-CAM5-1-FV2	CE	4.5
CNRM-CM5	CN	2.6, 4.5, 8.5
GFDL-CM3	GF	2.6, 4.5, 8.5
GFDL-ESM2G	GD	2.6, 4.5, 6.0
GISS-E2-R	GS	2.6, 4.5, 6.0, 8.5
HadGEM2-AO	HD	2.6, 4.5, 6.0, 8.5
HadGEM2-CC	HG	4.5, 8.5
HadGEM2-ES	HE	2.6, 4.5, 6.0, 8.5
INMCM4	IN	4.5
IPSL-CM5A-LR	IP	2.6, 4.5, 6.0, 8.5
MIROC-ESM-CHEM	MI	2.6, 4.5, 6.0, 8.5
MIROC-ESM	MR	2.6, 4.5, 6.0, 8.5
MIROC5	MC	2.6, 4.5, 6.0, 8.5
MPI-ESM-LR	MP	2.6, 4.5, 8.5
MRI-CGCM3	MG	2.6, 4.5, 6.0, 8.5
NorESM1-M	NO	2.6, 4.5, 6.0, 8.5

2.3. Modeling

2.3.1. Variable Correlation

The bioclimatic variables and their explanations available are shown in Table 11. Since most of them are derivatives of elevation, they tend to correlate. Using correlated variables in modeling studies causes overfit problems in Maxent algorithms which means that the predicted occurrences of the subjected species mostly occur around the observation points. To reduce the overfit problem, the most correlated variables among the 19 climatic variables were eliminated from the dataset.

One of the most widely used methods to eliminate correlated variables is vifcor (variance inflation factor) analysis in R (https://cran.r-project.org/) ‘usdm’ package (Naimi, 2010). It calculates multicollinearity among climatic variables and eliminates correlated variables above a threshold (0.85).

Yet, automatically deletion of variables from datasets might cause loss of an ecologically important variable. One other method alternative for reducing the loss of important variables during vifcor analysis, is to construct correlation matrices and manually check each correlated variables to decide which one of the coupled variables is more important for the species, in terms of the ecology, morphology, survival and the distribution of the species.

In this study, correlation matrices for bioclimatic variables of both Anatolian black pine and Kazdagi fir were created by using SDMToolbox -> Explore Climate Data -> Correlation and Summary Stats. The reason to construct correlation matrices species-specific is that the models for each species vary in extent which might result as different correlations for variables. After the construction of correlation matrices, the variables were examined for both species and the less ecologically important variables for species among the correlated couples were deleted from datasets.

Table 11: WorldClim climatic model variables

Bioclimatic Variables	**Definitions**
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
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 (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

2.3.2. Pseudo-Absence Sampling Bias

One of the other error causes of MAXENT models are pseudo-absence sampling biases, where some areas in the landscape are sampled more intensively than others (Phillips et al. 2009). Accumulated occurrences on one sampling area again will cause the overfit problem mentioned above. To reduce the pseudo-absence sampling bias, ArcGIS SDMToolBox offers 4 bias reducing tools.

1) **Gaussian Kernel Density of Sampling Localities:** This tool creates a Gaussian Kernel Density of sampling localities. Output values of 1 reflect no sampling bias, whereas higher values represent a high occurrence of sampling bias.
2) **Sample by Buffered Local Adaptive Convex-Hull:** This tool limits the selection of background points to an area encompassed by a buffered regional convex-hull based on species occurrences.
3) **Sample by Buffered MCP**: This tool limits the selection of background points to an area encompassed by a buffered minimum-convex polygon based on observed localities.
4) **Sample by Distance from Observation Points**: This tool limits the selection of background points to an area encompassed by a buffered applied to each observation locality.

In this study, bias selection for both Kazdagi fir and Anatolian Black Pine was made with Sample by Distance from Observation Points since it reflects the best the occurrence data collection method. Buffer distance was selected as 5 km for each case.

2.3.3. Occurrence Rarefaction

Most SDM techniques require an unbiased sample. SDMToolbox has Spatially Rarefy Occurence Data for SDMs (reduce spatial autocorrelation) tool which removes spatially autocorrelated occurrence points by reducing multiple occurrence records to a single record within the specified distance. For both species 5 km distance was used to rarefy occurence data. The distribution of rarefied Kazdagi fir and Karacam are shown in Figure 4 and Figure 5, respectively.

Figure 4: Spatially rarefied occurrence data for Kazdagi fir

Figure 5: Spatially rarefied occurrence data for Anatolian Black Pine

2.3.4. Modeling

SDMs of year 2050 projections for Kazdagi fir and Anatolian black pine were made with MAXENT.

In this study, the extents of models for both species were selected different from each other. Since Kazdagi fir is an endemic species and have a relatively narrow distribution than Anatolian Black Pine, using a large extend could cause overfitting problems mentioned above. Considering the wider distribution of Anatolian Black pine, limiting its model in an area which does not cover its extant distribution would cause a wrong prediction since large number of occurrences would be excluded from the modeling. For Kazdagi fir the extent was 25.5 west,36 east, 42.5 north and 39 souths, while for Anatolian Black pine it was 43.5 north, 35.5 east, 25.5 west and 45.5 east.

Since the extents were different, vifcor analysis for correlated climatic variables gave different results for both models. For Kazdagi fir BIO3, BIO7, BIO13, BIO17 and BIO18; for Anatolian Black pine BIO1, BIO2, BIO3 and BIO6 were excluded from the modeling process.

Bias files (correcting the pseudoabsence selection) were used for both models. Regularization parameters were taken as 1. Crossvalidation method was selected to run the model since the number of occurrences were relatively high. Each model repeated 10 times. Threshold rule selected as maximum training specify and sensitivity by following Liu (2013) and threshold settings were selected as automatic. The modelling process was repeated for 15 climate scenarios, then the mean of the future predictions of the 15 different climate scenarios were taken to decide the final future prediction result, by using DIVA-GIS software (http://www.diva-gis.org). For further overlay analyses, both future and current models of Anatolian black pine were extracted as the same extent of Kazdagi fir.

2.3.5. Overlay Analyses

A series of numerical analyses were made during the study to assess conservation priority areas for both Anatolian Black pine and Kazdagi fir.

Model results are raster files, which means every pixel of the data file has a number value, in this case they refer to the probability of distribution of the subjected species in terms of climatic adaptations. Model results being numerical values gives the chance to do multiple analyses using them.

The first analysis was done to detect the habitats which have high habitat suitability coefficient (the numeric value of each cell varying from 0 to 1) of Kazdagi fir and Anatolian Black pine. Steps fir intersection analysis are given below:

1. 2050 model results give a probability for each cell a value between 0 and 1. The cells have value 1 represents the highest probability of presence. To be able to do an intersect analysis, a threshold must be chosen to overlay both species model results. For this study, 0.85 selected as a threshold to take consideration only the highest probability areas in further analyses.

    - Spatial Analyst Tools -> Reclass -> Slice (15 Natural Breaks)
    - Spatial Analyst Tools -> Extraction -> Select by Attributes (Cell Value > 0.85)

2. First, the areas which have higher probability then 0.85 were selected and assigned to a different raster files. Then they converted into shapefiles which "Intersect" tool of ArcMap 10.2 requires.
    - Conversion Tools -> Raster to Feature

3. The two shapefiles, one is the probability of distribution of Kazdagi fir higher than 0.85, the other for Anatolian black pine were intersected.
    - Analysis Tools -> Overlay -> Intersect

4. Results of intersection analysis were saved as a shapefile.
    - Export Data

Finaly, the intersection map shows the potential niche competition regions for both species due to 2050 climate scenarios. Yet to assign conservation priority areas requires further analysis. Since Kazdagi fir has conservation priority over Anatolian black pine due to IUCN, the first selection was done for Kazdagi fir. Steps for selection of conservation priority areas for Kazdagi fir are given below:

1. 2050 model results of both species were taken and extracted the areas which Kazdagi fir has higher probabilty of distribution than Anatolian black pine.
    - Spatial Analyst Tools -> Local -> Higher Than Frequency Analysis
2. The result of analysis, which shows the areas which Kazdagi fir has higher probability of distribution, is saved as a shapefile to use in further intersect analysis.
3. First intersection map was used for mask to extract raster values from model results since they lost the cell value information in the conversation to shapefile step.
4. The potential niche competition regions map and the areas which have higher probability of distribution for Kazdagi fir than Anatolian black pine map was again intersected to assign the conservation priority areas for Kazdagi fir.

To be able to visualize the distribution change through ~30 years span, two maps; by using 0.85 habitat suitability coefficient threshold, current SDMs were also extracted and mapped together with the future SDMs for both species (Figure 11 & Figure 12).

2.3.6. Extinction Risk Assessment for Kazdagi Fir

IUCN (International Union for Nature Conservation) introduced two concepts for extinction risk assessments criteria of Redlist Species (2011), Area of Occupancy (AOO) and Extent of Occurrence (EOO). Area of occupancy defined as the measure of the area that is occupied by an ecosystem type and extent of occurrence as the measure of the area within which all occurrences of an ecosystem type exist. Both terms are metrics representative of a species' geographic range and are used to assess extinction risks and the Red List status of species (criteria B in the IUCN Red List).

Generally, during the extinction risk assessment process; published data and expert reports about population, and status about the species are used. Recently, the two terms AOO and EOO become more important due to their capability of identifying important species characteristics (i.e. distribution) and allowed to make trait-based assessments. IUCN also recommends that either the known, inferred or projected sites of occurrence could be used to estimate the species range, predicting suitable range for the species based on their ecological requirements through a species distribution modeling (SDM) procedure is a highly suitable tool for conservation assessments. Consequently, SDM has widely been used to estimate EOO and AOO, considering the total number and extent of grid cells predicted to provide suitable habitat for a target species (Boitani et al., 2008; Jiménez-Alfaro et al., 2012, Syfert et al., 2014; Ahmadi et al., 2019).

Thuiller (2005), defined new criteria for assessment of extinction risks. In their study, the count of suitable habitat cells (every cell which have a habitat suitability coefficient greater than zero) of current model and future model were subtracted from each other and the result gave the change in AOO. Then, by following IUCN Redlist criterion A3(c), threat levels are assigned based on the projected AOO losses, with 1: 100%, 2: <100% and > = 80%, 3: <80% and > = 50%, and 4: <50% and > = 30% (Mariano et al., 2011; Ahmadi et al., 2019).

To be able to analyze the percentage loss of AOO of Kazdagi fir; first, both future and current models were converted in binary format by using the threshold of minimum habitat suitability coefficients for both models. Results provide a data which assigns 1 to suitable habitat cells (cells have a value greater than zero) and 0 to non-suitable habitat cells. Then the two binary models (future and current) were subtracted from each other. The cell counts of current model, future model, and the subtracted model were used to calculate the percentage area loss for Kazdagi fir. Results indicates 90.4% habitat reduction for Kazdagi fir (Threat level 1).

CHAPTER 3

RESULTS

3.1. SDM Results for Kazdagi Fir & Anatolian Black Pine

Logistic format was used for the model outputs created in MaxEnt. Each cell created by the software contains values ranging from 0 to 1 according to the possibility of the species being present in the cell (~1km^2 square) in question. The lowest probability is indicated by 0 and the highest probability is indicated by 1. Model for each color group, the value range for each color group is 0.2. In graphic-wise red colors represent the highest probability, while blue colors represent the lowest probability of distribution. Yet the same colors for different SDM result map might not mean that the same cell values, because several GIS software assign the color of highest possibility to the highest value of the model which means parts of models might be represented with the same color while one model has 0.79 highest cell value and the other has 0.97.

SDM results for both species shows available habitat decrease for both species (Figure 11 & Figure 12). This means that climate change will affect both species, negatively. Considering the potential niche overlaps between species, makes species more vulnerable to future changes.

The AUC values of models were 0.979 for Kazdagi fir, and 0.928 for Anatolian black pine (Figure 8). The most important contributor according to jackknife analysis was BIO14 (Precipitation of Driest Month) for Kazdagi fir which is consistent with the results of a study conducted by Linares (2010) proposing that drought has sudden growth reduction effect on *Abies* species while almost all *Pinus* species were able to maintain drier conditions almost constant survival ratio (see Appendices). For

Kazdagi fir; the environmental variable with highest gain when used in isolation is BIO18, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is BIO7, which therefore appears to have the most information that is not present in the other variables.

The probability distribution maps of both species shown in Figure 7 and Figure 8. Kazdagi fir has probability to presence in 2050 more than expected since it is considered an endemic tree subspecies. Although all the high probability areas than the actual occurrence areas are already habituated by either subspecies or species of genus *Abies*. Besides the AUC value of the model, this fact provides a proof for model being realistic.

Species distribution modeling result of Kazdagi fir (Figure 6) using current climatic variables shows the habitats which are climatically available for Kazdagi fir. There are several areas which are not habituated by the species, yet the model predicts them as available habitats. This is the case for most of the modeling studies and the need for revisit Hutchinson’s Fundamental and Realized niche theorem gains more importance.

The modeling results shows the fundamental niche of the species. This means that it is not necessary for all the “red” areas in the model are habituated by Kazdagi fir. There might be several reasons for fundamental niche is not realized by the species as they mentioned before; such as, unavailable habitats patches between two available habitats.

In case of Kazdagi fir, Mt. Simav is included in the fundamental niche, yet it is not included in realized niche. The area is not habituated by Kazdagi fir or another subspecies of firs in Turkey.

In the model result which are projected in 2050 climatic variables, the available habitats show drastic decrease compared to current model. Yet, the core habitats of the species, Mt. Kazdağı and Mt. Uludağ remain the same in the future. Also Mt.

Simav, have still availability in the future. But to be able to make further interpretations a Binomial Distribution Change Analysis was made by using 0.85 threshold which shows that even though the core habitats of the species remains same in the future model, the size of each will tend to decrease (Figure 11 & Figure 12).

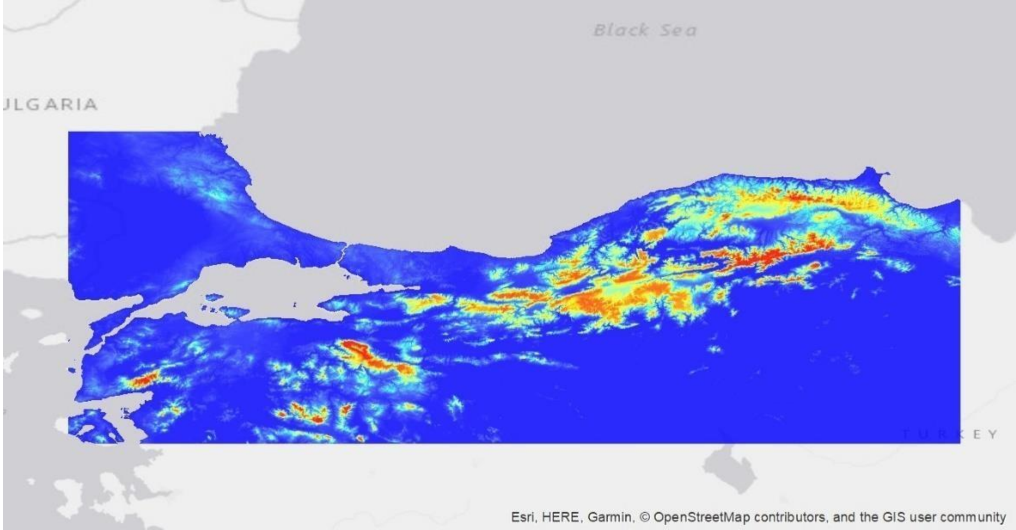

Figure 6: Current SDM map of Kazdagi fir. Probability distribution decreases from red colors to blue colors.

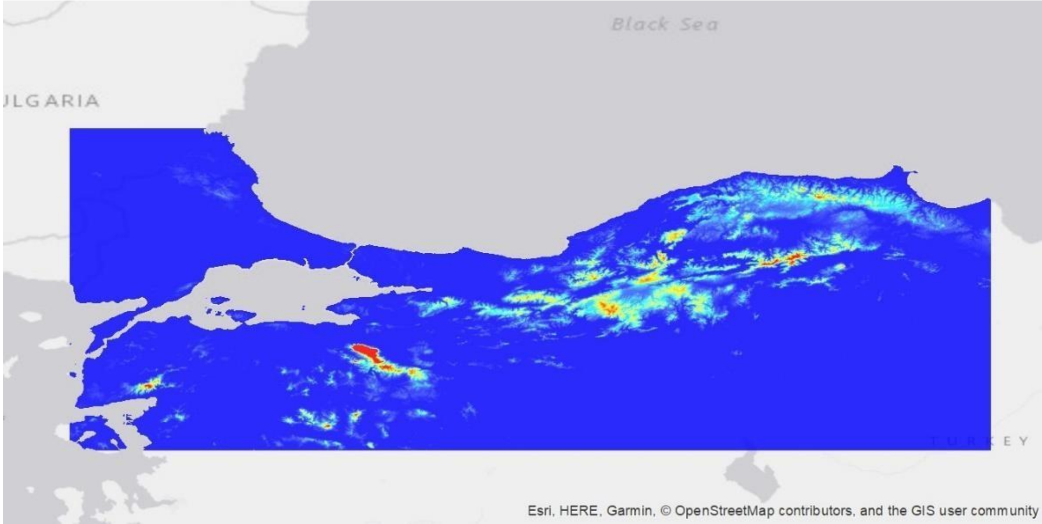

Figure 7: 2050 SDM map for Kazdagi fir. Probability distribution decreases from red colors to blue colors.

Anatolian Black pine has wider distribution compared to Kazdagi fir. The model result also shows the same trend. Additionally, the species has which have medium availability than Kazdagi fir (yellow-green areas on the map). Also, it can be seen by comparison of both species' current distribution maps, Anatolian Black pine have more suitable habitats in inner regions of Anatolia.

The SDM result map of current climatic variables reveals best fit habitat areas for Anatolian Black pine (red areas on the map). There is an unpatched, continuous suitable habitat line from Düzce to Ankara which is a plausible result considering the realized niche of the species. The natural and healthiest populations of the species are currently occupying unconnected patches in the area.

The future SDM results of both Anatolian Black pine and Kazdagi fir, shows decrease in suitable areas compared to current distribution models. Yet, to be able to determine the overlapping suitable habitats of both species requires a series of overlay analyses.

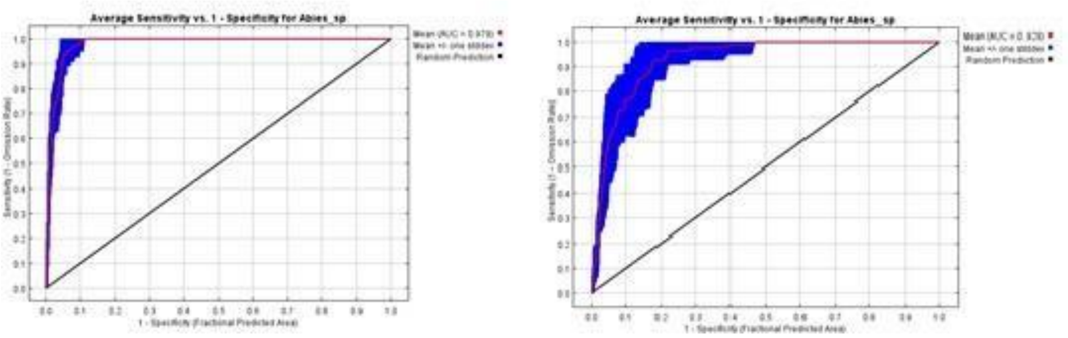

Figure 8: The AUC values for Kazdagi fir (left) and Anatolian Black Pine (right)

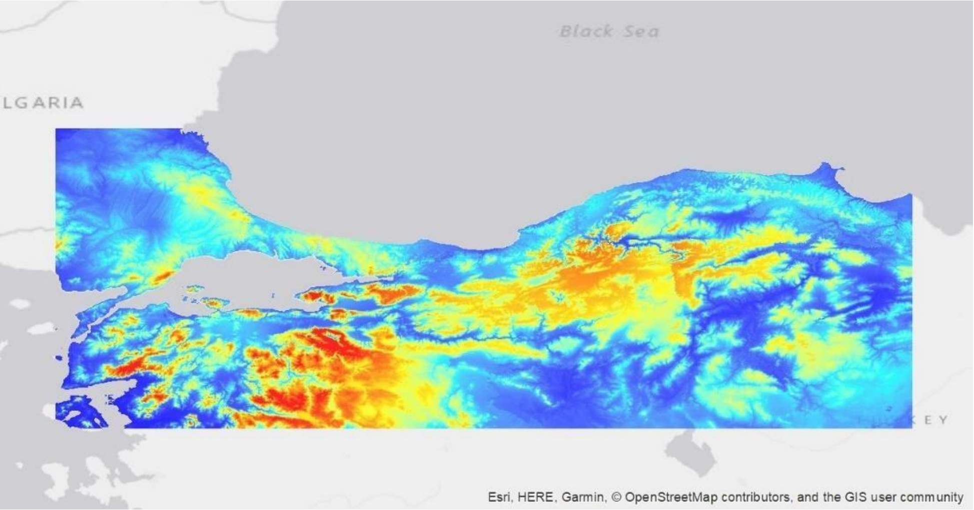

Figure 9: Current SDM map for Anatolian Black Pine. Probability distribution decreases from red colors to blue colors.

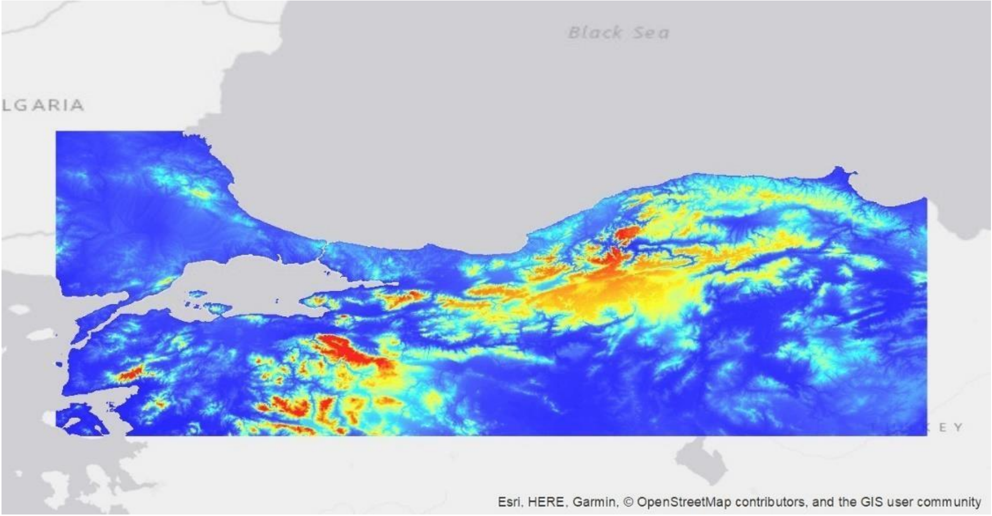

Figure 10**:** 2050 SDM map for Anatolian Black Pine. Probability distribution decreases from red colors to blue colors.

3.2. Overlay Analyses

Overlay analyses are series of methods to detect overlapping features of different data sets to be able to hypothesize the ecological, geographical or anthropogenic reason of the current case.

The aims of overlay analyses in this study are;

1. Determining habitat overlap regions between both species
2. Determining the species which have higher suitability than the other species in the overlapping habitats.
3. Determining distribution change in the future

The modeling process assigns a habitat suitability coefficient in each cell, 30 Arc-sec in this case since the resolution of climatic variables are 30 Arc-sec, and the coefficient varies from 0 to 1. To be able to conduct further analysis on modeling results, a threshold must be determined since the cumulative results include both high, low and medium suitability areas.

***Figure 11**:* Distribution change for Kazdagi fir. Green areas represent the areas which have habitat suitability coefficient greater than zero, while red habitats represent 2050 model

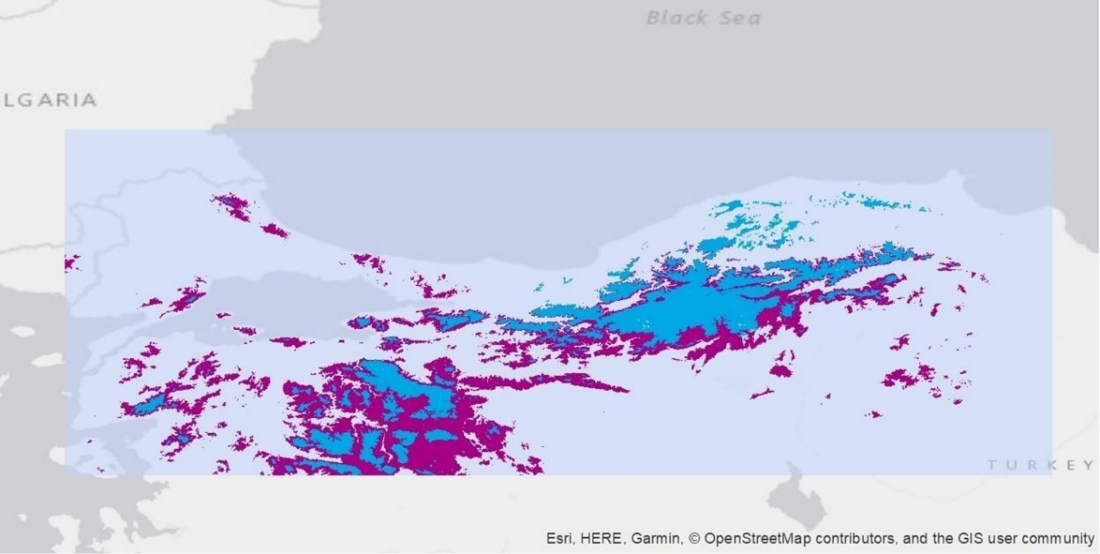

Figure 12: Distribution change for Anatolian Black Pine. Purple areas represent the areas which have habitat suitability coefficient greater than zero, while blue habitats represent 2050 model

3.2.1. The Logic Behind the Intersection Map

In this study, the aim of overlay analyses is to detect overlapping suitable habitats in their future models for both species. The green areas in Figure 10 represents the potential future overlaps between hypothetical two species. Yellow areas are the regions which the first species have habitat suitability coefficient greater than 0.85 in its 2050 model, and blue areas shows the regions which the second species have habitat suitability coefficient greater than 0.85 in its 2050 model. Following the yellow and blue colors, the areas where two colors overlap represented as green. Thus, green areas show the potential future overlapping habitats between two species.

Figure 13: The logic of intersection map

The red areas in Figure 13, shows the results of intersection analysis of high suitability areas of Kazdagi fir and Anatolian black pine. There are several important habitats on the intersection map. Firstly, Kazdağı (Mt. Ida) resulted as an important habitat for both species in the future. Uludağ is another important overlapping habitat for both species. Importance of these areas comes from the current distribution of both species. There are several mixed stands of Kazdagi fir and Anatolian Black pine on Kazdağı and Uludağ. They also declared as national parks several years ago.

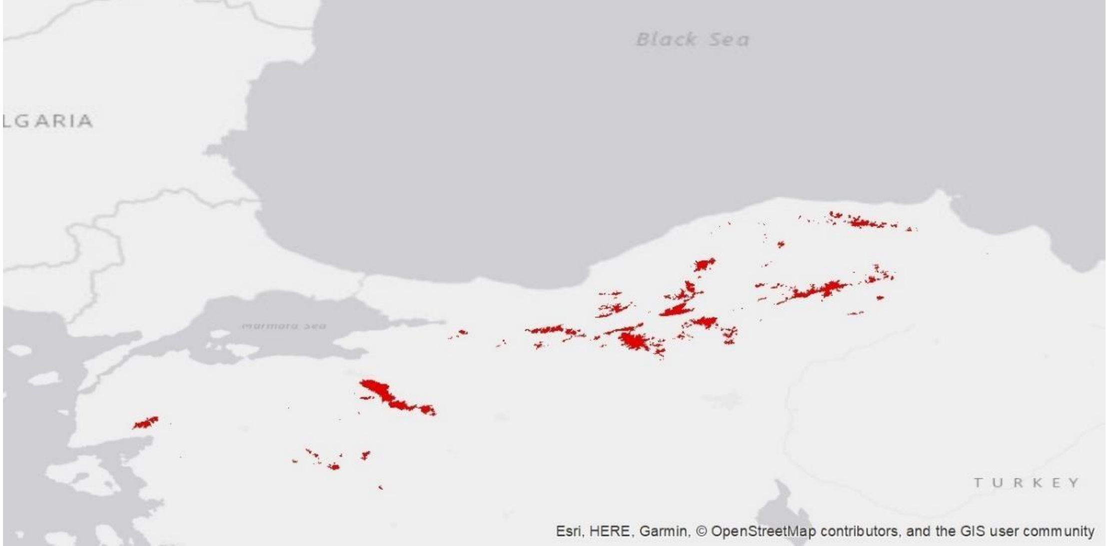

Figure 14: Intersection of high probability distribution areas for Anatolian Black pine and Kazdagi fir.

Intersection analysis was made to determine to overlapping regions of both species which have greater habitat suitability coefficient than 0,85. The red areas on Figure 14 shows the overlapping suitable habitats for both species by using their 2050 model results. This means that the red areas on the map, are potential niche competition regions for Kazdagi fir and Anatolian Black pine. It is also important to emphasize that almost all potential areas of intersection for both species' also covers the all future distribution of Kazdagi fir, which means that other than the intersection areas, there are none or indistinguishably small habitat patches are available for Kazdagi fir.

The potential niche competition regions showed in Figure 14 are definition of Hutchinson's fundamental niche. It does not mean that the red areas will definitely be occupied by both species, it only means that climatic conditions of the areas based on

2050 model results are suitable for both species. Considering the potential niche competition regions in Mediterranean and East Black Sea Costs, the fundamental niche concept becomes more plausible, since the areas are not populated by both species but different species in the same genus.

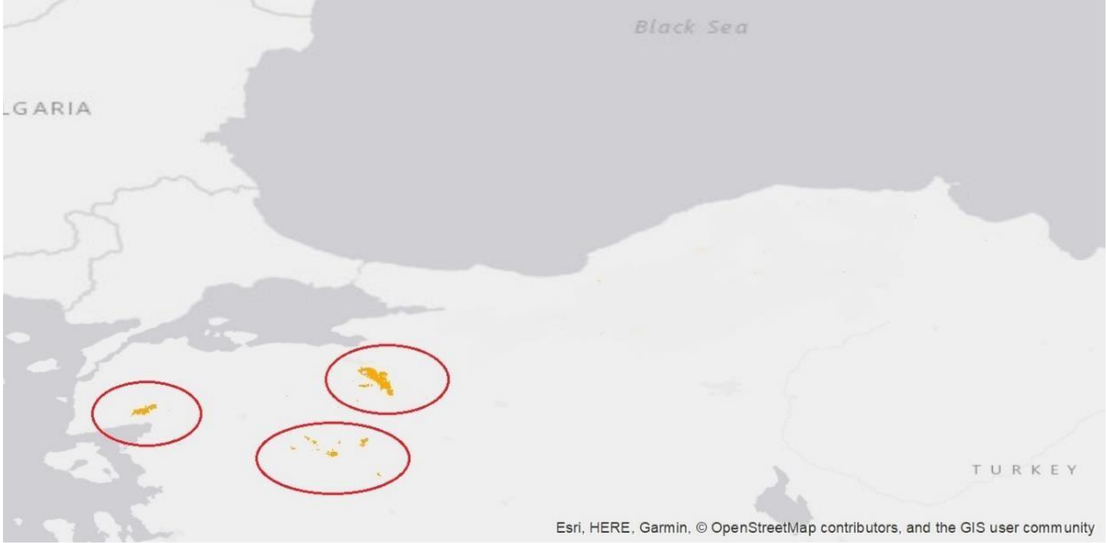

Figure 15: The areas which Kazdagi fir have higher probability distribution than Anatolian Black pine

After the determination of potential niche competition regions in future models, instead of subjective decision making to assess conservation priority areas an objective overlay analysis was made.

For determination of conservation priority areas, the 2050 model results of species were used. First, both models were filtered with the potential niche competition regions map to get the habitat suitability coefficients of species in the overlapping regions since after the selection of the cells which have a value greater than 0,85 the results stored as shapefiles (the coefficient information of cells were lost). Then, a Higher Than Frequency filter was applied for both species to detect which species has higher habitat suitability coefficient within the potential niche competition regions.

The yellow areas in Figure 15 shows the areas which have higher habitat suitability coefficient for Kazdagi fir than Anatolian Black pine. Mt. Kazdağı, Mt. Uludağ and very small unconnected habitat patches on Mt. Simav are the areas which have better habitat suitability for Kazdagi fir than Anatolian Black pine. Areas for Anatolian Black pine are wider than Kazdagi fir, which might be considered as a reason to give conservation priority for Kazdagi fir, in future studies. Almost all the Black Sea costs are better habitats for Anatolian Black pine than Kazdagi fir based on the 2050 model results which might indicate that the effects of global climate change have the tendency to be less severe for Anatolian Black pine (Threat level 3), than Kazdagi fir. Hutchinson's fundamental niche definition also applies for Anatolian Black pine according to results because it also reveals suitable habitats for the species which are not currently populated by the species. Regions near to Mt. Uludağ, and Mt. Kazdağı also shows better habitat suitability for Anatolian Black pine, but the higher elevations of the both mountains have better habitat suitability for Kazdagi fir.

These results gave the ability to assess conservation priority areas for the species, without considering one of them being endemic, and endangered. Both species considered in equal conditions, the only measurement is the higher habitat suitability coefficients which means higher probability for their future distributions.

The yellow areas on Figure 15, shows the assessed conservation priority areas for Kazdagi fir. The selection made by based on the future distribution, to be able to resolve future potential niche competitions between two species. Mt. Kazdağı and Mt. Uludağ are already populated by the species. According to the GDF's e-Harita, Mt. Simav has large and very degraded stands of Anatolian Black pine. Future forestation practices might be done in this area in favor of Kazdagi fir.

The analyses were done here, reveals an unbiased conservation priority areas assessment for the species yet the results follow the same trend if the conservation priority was given to Kazdagi fir since it has EN status by IUCN while Anatolian Black pine has LC status. The results also parallel in conservation priority assesment considering the potential recent speciation events on the *Abies* genus in Turkey. In that case, Kazdağı would also be assessed for priority area for Kazdagi fir rather than Anatolian black pine.

CHAPTER 4

DISCUSSION

In this study, species distribution modeling approach was used to analyze the conservation priority areas for Kazdagi fir, in order to resolve the habitat conflict favoring Kazdagi fir in certain habitat patches the species is endemic and endangered. After the careful modeling studies, it is shown that Kazdağı (Mt. Ida) and Uludağ will still be the most important habitats for the species. Unexpectedly, Simav Mountain and its surrounding mountains shows high probability of presence, yet on the stand maps it does not show occurrence. In contrary, the area around Simav Mountain, defined as mostly degraded stands. There are two possibilities in this case; first the area might be available for the species yet due to dispersal limits or the unavailable habitats between its current populations and Simav Mountain, the area is not currently populated by the species. Second possibility is that the high probability around Simav Mountains is a model error but considering all the other high probability areas are currently populated by the closest relatives of the species, the former possibility seems more prone to be the case. Yet it is almost impossible to know without further field research in the area.

Both Uludağ and Kazdağı are defined as Key Biodiversity area by Doğa Derneği – the BirdLife partner in Turkey. There are national parks in the area, several conservation studies were conducted and currently conducting. It is not surprising, yet so important to prove these two habitats are very important for an endemic species by only modeling works. It proves both the power of unbiased, statistical analysis and the validity of modeling works as conservation evidence.

The reason this study only focus on 2050 climate scenario is to promote immediate action to conserve Kazdagi fir. 30 years is both long enough time to help the species to form healthy populations in their most adapted habitat and short enough time to make a species destined to extinction.

One interesting point of this study to take into consideration in further studies, is that Kazdagi fir have high probability areas in its closest relatives. It might be a hint of recent speciation events when we consider the recent genetic studies shows insignificant difference between all species distributed in Turkey.

There are several advantages and disadvantages for the data collection method used in this study. First advantage is that it does not require fieldwork. Both species have relatively wide distribution around the country, especially Black pine. Collecting occurrence data by fieldwork observations would be both time and money consuming. Second is that the forest stand map has the forestation area information hence the distinguish between natural and artificial populations can be made easily. In case of fieldworks, to detect natural and forestated areas would require additional research. Third, most of the divisions are smaller than the resolution of environmental data which means that even if the coordinate information from a stand does not fall onto an individual, it does not cause problem model-wise. As long as the coordinate stays into the same pixel of environmental data, the results will not be affected since the environmental value of the pixel will be the same for the occurrence data. Also, Maxent does not appear to be strongly influenced by moderate spatial error associated with occurrence data, as location errors up to 5 km appear to have no impact on model performance (Graham et al, 2007).

The most important disadvantage of using e-Harita to collect occurrence data is that the loss of the rare occurrences since the map only shows the most dominant 1 to 3 species. If there are few individuals in other stands, the information cannot be collected. Second disadvantage is that the map is not up-to-date. There is a fast population decline on Kazdagi fir, so several occurrence data might not be correct. Third, GDF does not share the map which could be analyzed using GIS software. The only way to use all the information that they share is to use the map online and there are very limited tools on the web-site comparing to any GIS software. For example; selecting all the stands while on the web-site it requires manual search, selection and coordinate format convert. If the database were shared with an appropriate format for to analyze on GIS software, the data selection process would be more sufficient in timely manners. On the other hand, considering all the disadvantages of the data collection method and comparing the disadvantages of data collection by fieldwork observations it is more favorable in terms of time and budget.

In this study, final model of 2050 distributions of species were set by averaging all 15 different results of different GCMs available in RCP2.6. The reason to do so is uncertainty of representation capability of GCMs for Anatolia. There are several studies have been conducted for several geographical regions to detect the best GCM in the area (e.g. Fand & Kumar, 2012). At the same time, averaging different GCMs and different RCP models also have been used widely (Ahmadi et. al, 2019).

At this point, it is crucial to emphasize the fact that the proposed conservation priority areas are the only regions which Kazdagi fir has a better climatic adaptation than Anatolian black pine. All the other regions in the extent of the study area are more habitable for Anatolian black pine. It is also important to emphasize that the aim of this study is to only release competition stress for both of species in certain habitats to form healthier populations. In this matter reforestation and forestation works have the most important role. Uludağ and Kazdağı should be reconsidered in terms of reducing Anatolian black pine forestation and increasing Kazdagi fir population restoration. The results are not proof of released competition or does not prove that the two species will not survive in mixed stands in the future. They only emphasize that Kazdağı and Uludağ should be considered as conservation areas for Kazdagi fir.

In case of Anatolian black pine, there are several results which arise further research questions. First, the populations in Istıranca Mountains are under serious treat due to global climate change (Fig. 12). Second, the species is expected to migrate through northern latitudes. There are several areas which are not currently habituated by Anatolian black pine, in the mid Black Sea Region which is promising because it gives the species chance to shift its range to survive. Following these two modeling results, a conservation management in Istıranca Mountains for Anatolian black pine is required, and possible migration routes along the northern latitudes should be studied to understand if there are any obstacles for migration & if an assisted migration is needed.

Even though, this study provides a new approach to use species distribution models in conservation planning, there are several aspects of the study needs to be improved. First, the taxonomic position of Kazdagi fir needs to be clarified. All current and previous studies which focused on the phylogeny of *Abies* species in Turkey, did not give significant results for populations of Kazdagi fir in Kazdağı as a distinct taxonomic group. Yet, as IUCN report of the species mentioned, there is a tendency to consider Kazdagi fir as a distinct species *(Abies equi-tojani).* Regional genomic comparisons, morphological comparisons do not support this idea so far. For example; Scaltsoyianes (1997) applied an allozyme differentiation analysis for 19 Mediterranean firs and found highest frequency of a rare allele (ACP-A1) in Kazdagi fir populations on Kazdağı. Such studies implicate that Kazdagi fir populations in Kazdağı might have a different evolutionary history than currently thought. Thus, a detailed whole genome analysis of at least 5 closely related *Abies* species is necessary to enlighten the tangled phylogeny of *Abies* species in Turkey. Also, the relatedness of Kazdagi fir to Greek fir must be studied to enlighten the evolutionary history of Kazdagi fir. To sum up, the uncertainty of the phylogeny of the species might cause an incorrect distribution map, hence an overpredicted potential distribution areas for Kazdagi fir.

Secondly, the proposed conservation priority areas for both species are the regions based on only climatic availability. Land use or land cover status of the areas were not examined in this study. There are several variables which can be further applied on the proposed conservation priority areas besides than land cover and land use such as; road maps and water bodies. Using additional variables give the chance to assess more precise locations for species. Yet, in this study proposing precise locations would be inconvenient since the resolution of the distribution maps are relatively low and the occurrence data does not have the maximum certainty. The aim of this thesis is to provide a new approach to use species distribution models, but it is insufficient to increase the resolution and certainty model wise.

CHAPTER 5

CONCLUSIONS

In this study, an unbiased methodology was used to assess conservation priority areas for Anatolian Black pine and Kazdagi fir. MAXENT approach was used to model both current and 2050 distributions of the species. Then, the potential niche competition regions were selected by applying an intersection analysis, using the areas which have habitat suitability coefficient higher than 0,85. On the intersection areas, which are defined as the potential niche competition regions, the areas which have higher habitat suitability for Kazdagi fir, and Anatolian Black pine were selected, respectively. Among the areas which are better fit for Kazdagi fir than Anatolian Black pine, Mt. Kazdağı, Mt. Uludağ and Mt. Simav were selected as conservation priority areas for Kazdagi fir considering the current realized niche of the species.

There are two main conclusions of this study. Firstly, the species distribution models which are built even only using climatic variables have certain guidance ability to review the situation of the species both current and future and they can be used to get new insights and management approaches in terms of conservation. Secondly, the assessed conservation priority areas propose suggestions for further forestation practices in certain important habitats in Turkey such as Kazdağı & Uludağ. The results do not promote the only Kazdagi fir restricted conservation planning in assessed conservation priority areas for them, it only suggests that it should be considered it has higher probability to habituate in certain areas.

Uncertainty of the taxonomy of Kazdagi fir must be revealed with a comprehensive genetic analysis including all *Abies* species in Turkey, Bulgaria, Greece and Georgia. The results have the possibility to chance the conservation actions and might reveal higher importance than currently assessed to Kazdagi fir.

This study also indirectly shows that there is an urgent need to produce high resolution spatial (such as land cover) & distributional (especially for endemic species) and climatic datasets for stronger modeling studies and for conservation practices. All global datasets were used in this study have relatively low resolution. Even though the models built by using global datasets gives a rough picture of the actual situation and the chance to get new insights from the models, for narrowly distributed endemic species they become inadequate. To be able to carry the conservation studies further in such biodiversity rich country, the effort of ecologists should be invested more into the development of new datasets.

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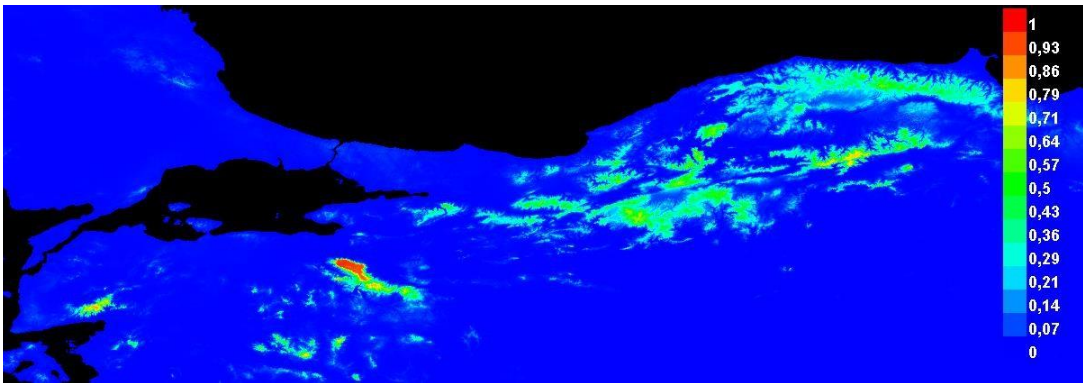
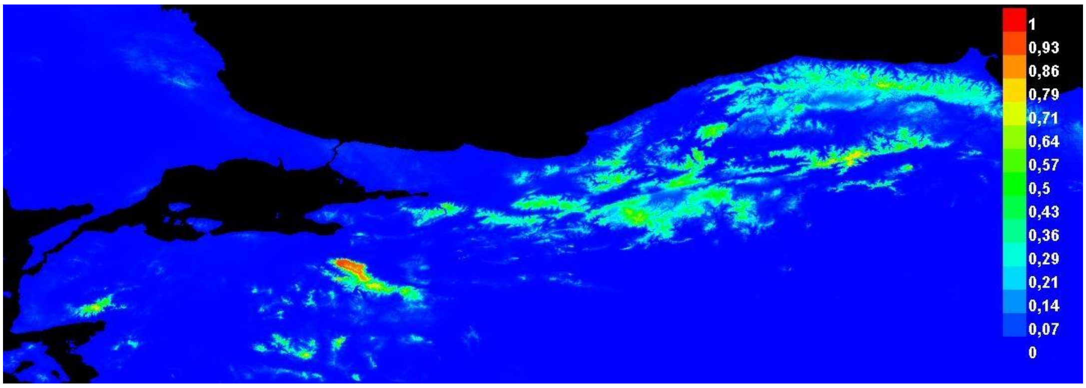
APPENDICES

APPENDIX A: GCM results of Kazdagi fir

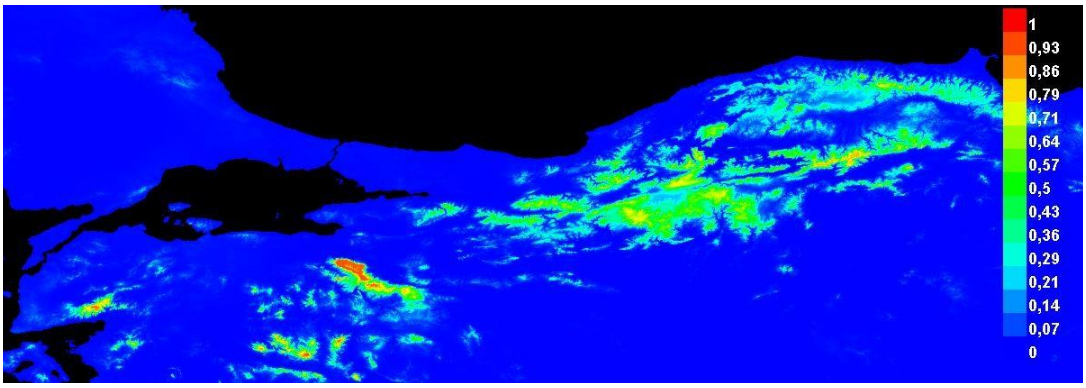
1. BCC-CSM1-1



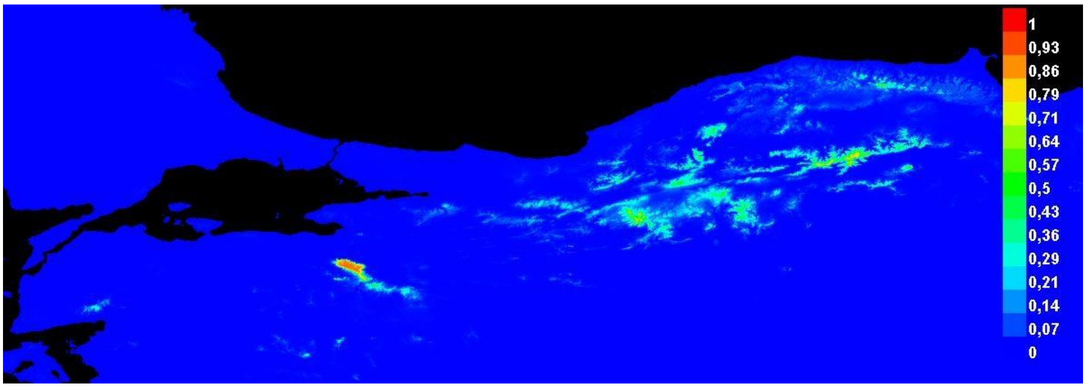
2. CCSM4



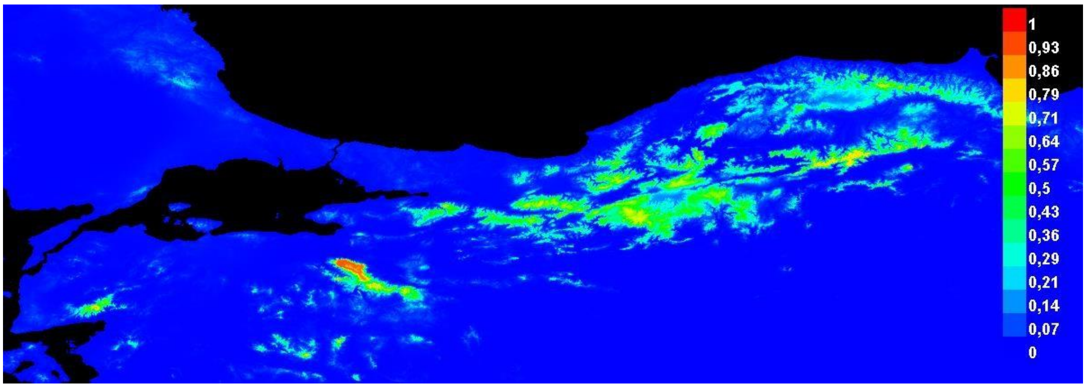
3. CNRM-CM5



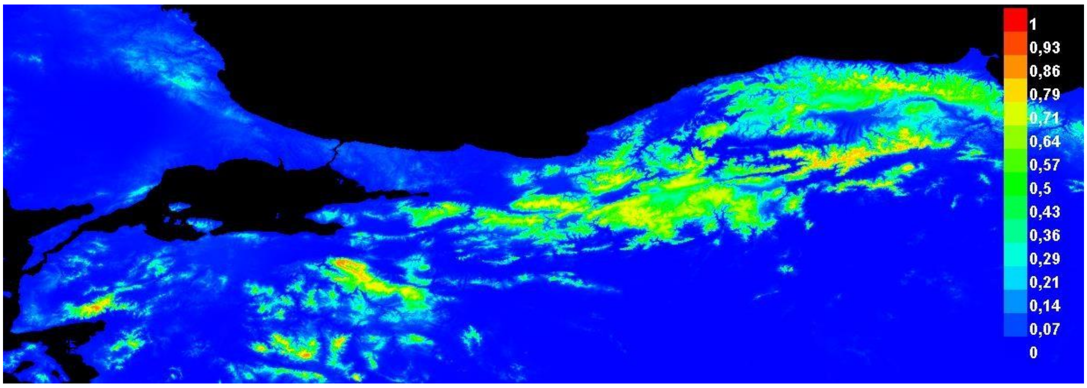
4. GFDL-CM3



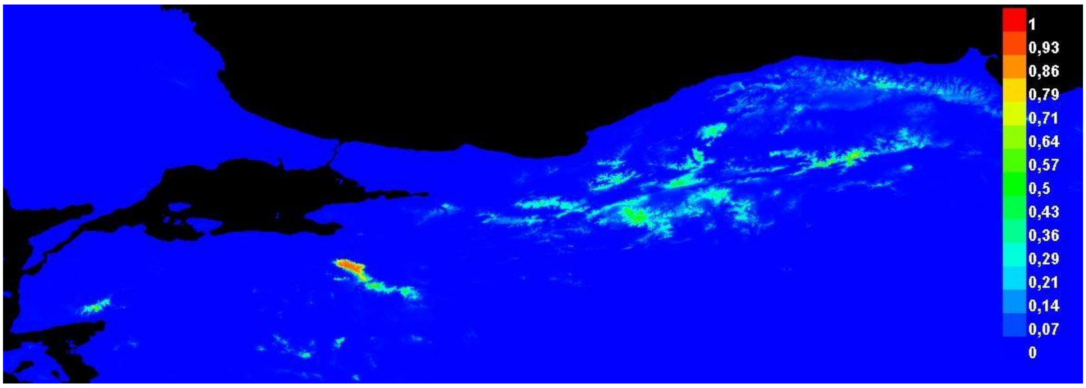
5. GFDL-ESM2G



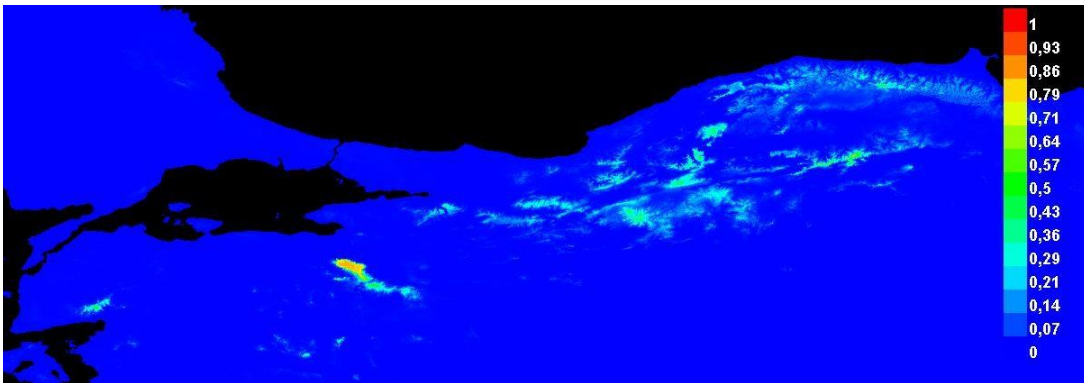
6. GISS-E2-R



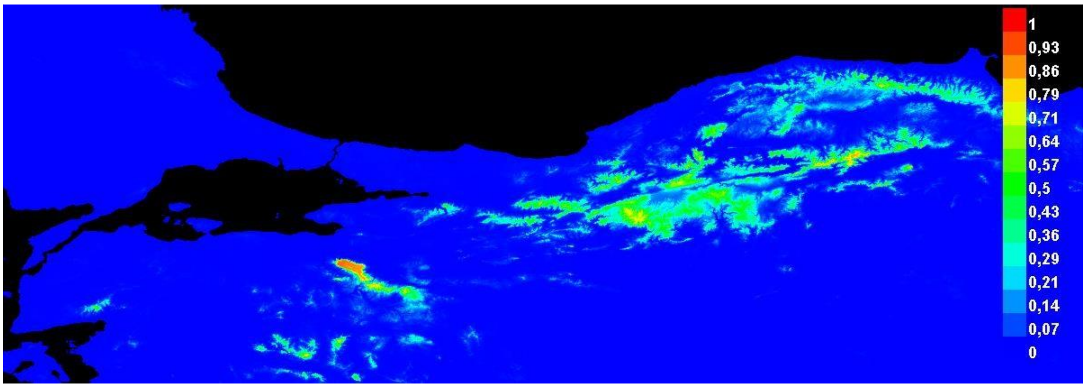
7. HadGEM2-AO



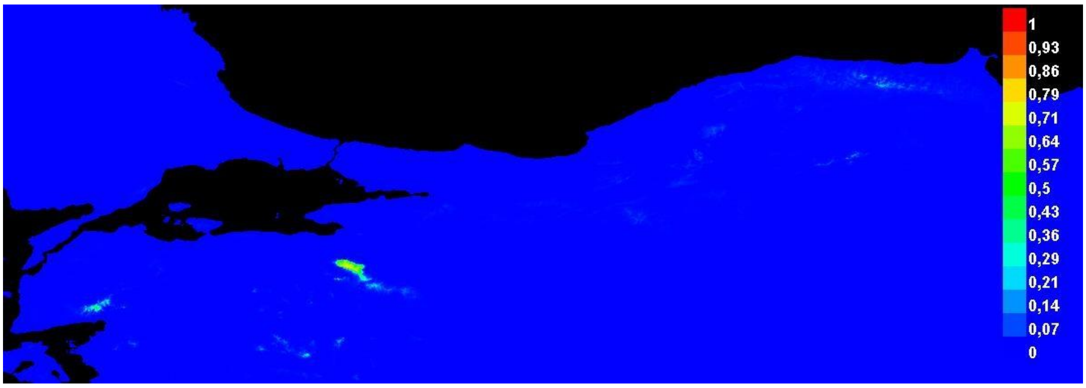
8. HadGEM2-ES



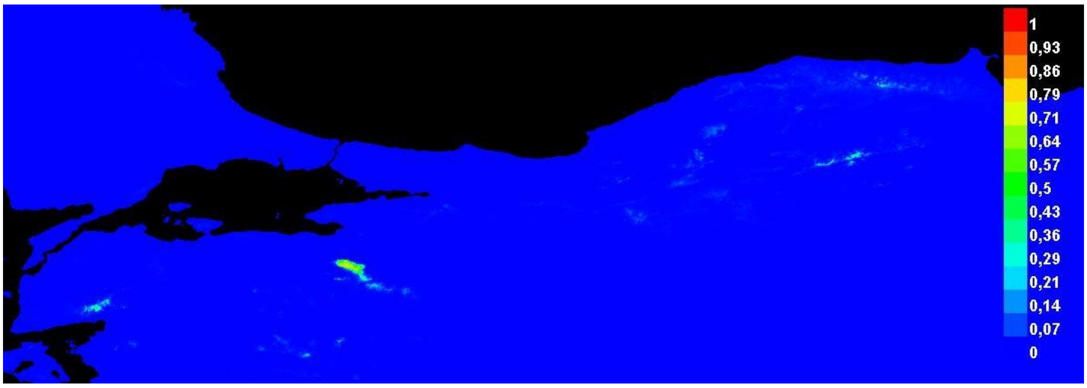
9. IPSL-CM5A-LR



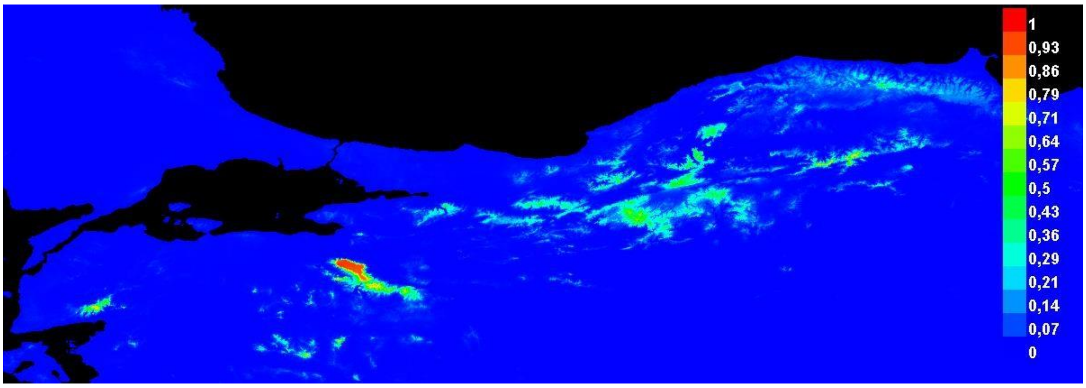
10. MIROC-ESM-CHEM



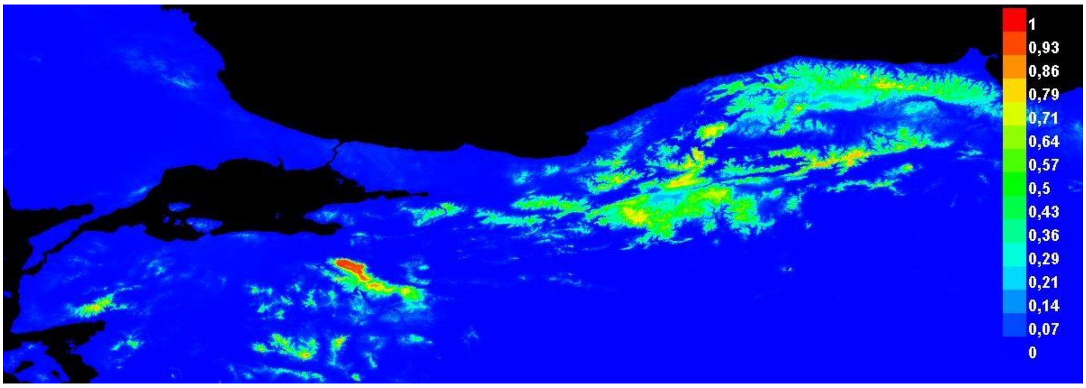
11. MIROC-ESM



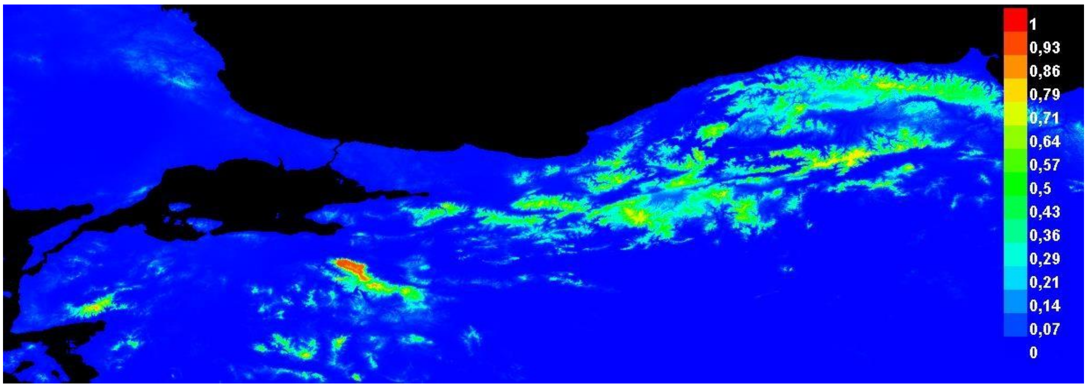
12. MIROC5



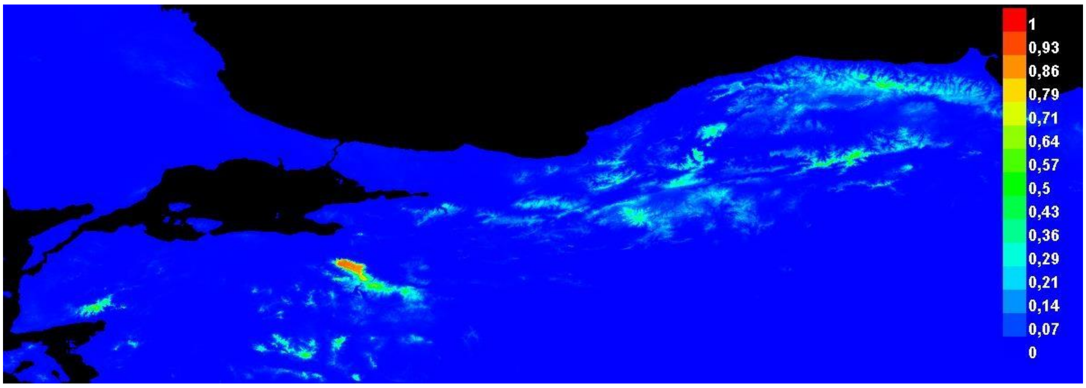
13. MPI-ESM-LR



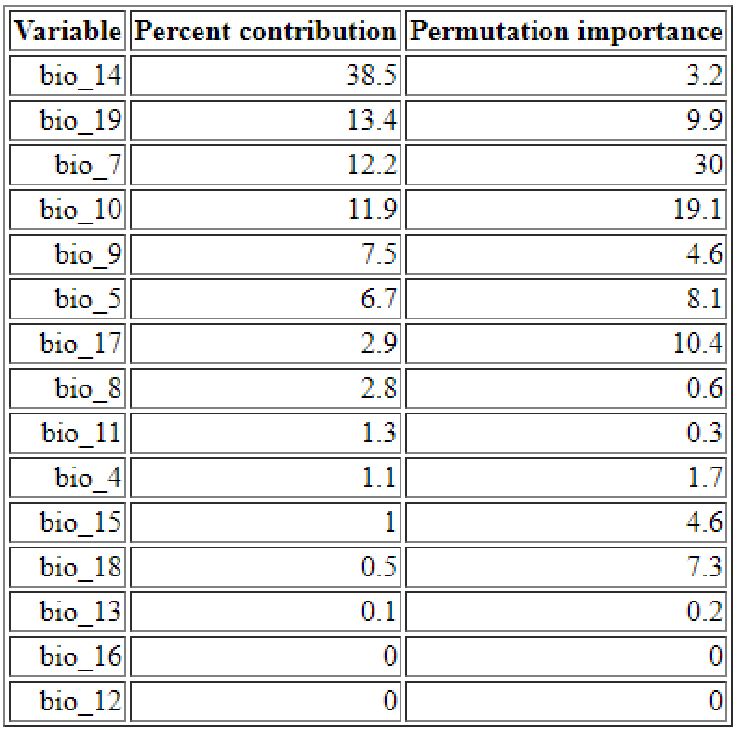
14. MRI-CGCM3



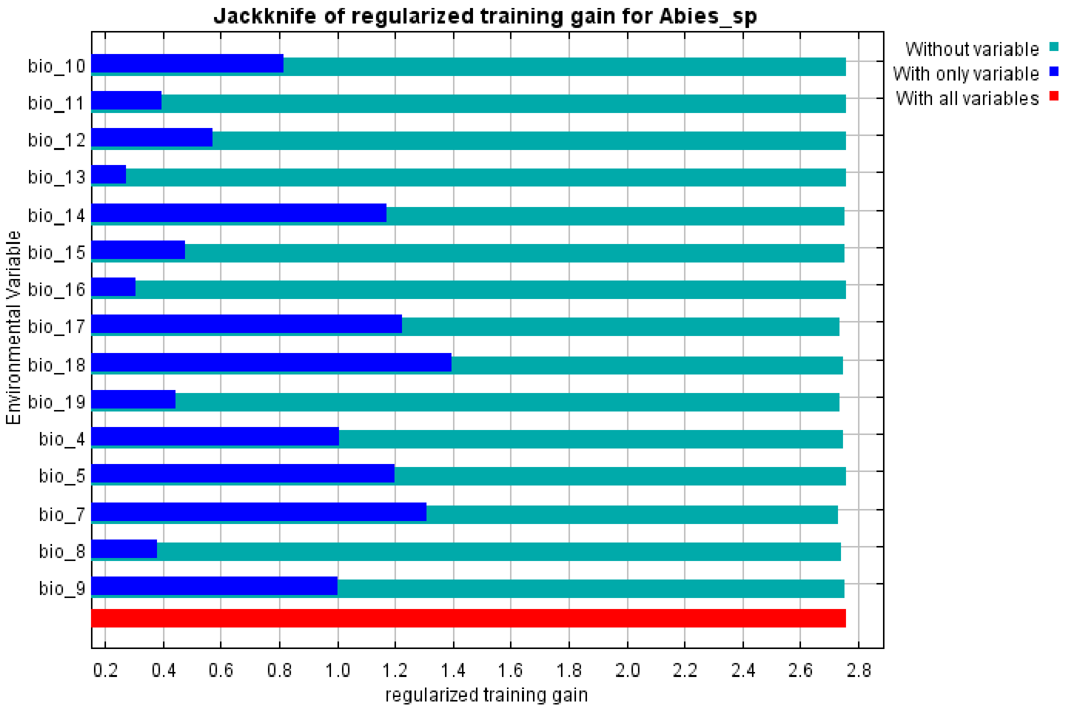
15. NorESM1-M



APPENDIX B: Spatial Jacknifing Results for Kazdagi Fir

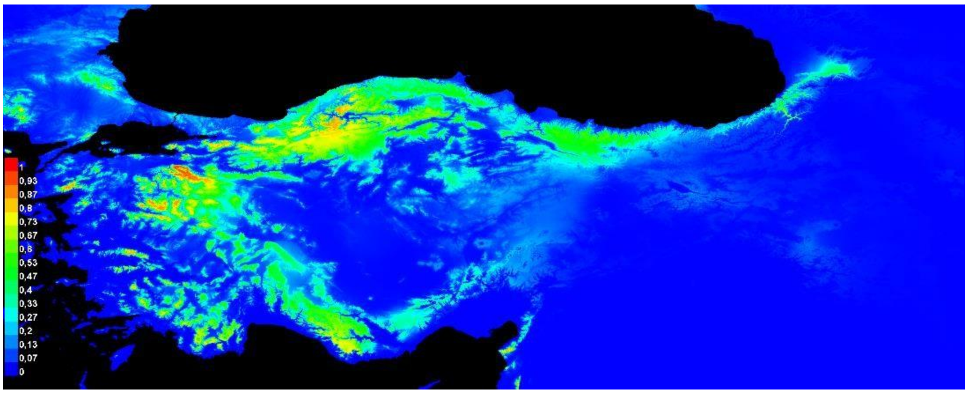


Variable	Percent contribution	Permutation importance
bio_14	38.5	3.2
bio_19	13.4	9.9
bio_7	12.2	30
bio_10	11.9	19.1
bio_9	7.5	4.6
bio_5	6.7	8.1
bio_17	2.9	10.4
bio_8	2.8	0.6
bio_11	1.3	0.3
bio_4	1.1	1.7
bio_15	1	4.6
bio_18	0.5	7.3
bio_13	0.1	0.2
bio_16	0	0
bio_12	0	0

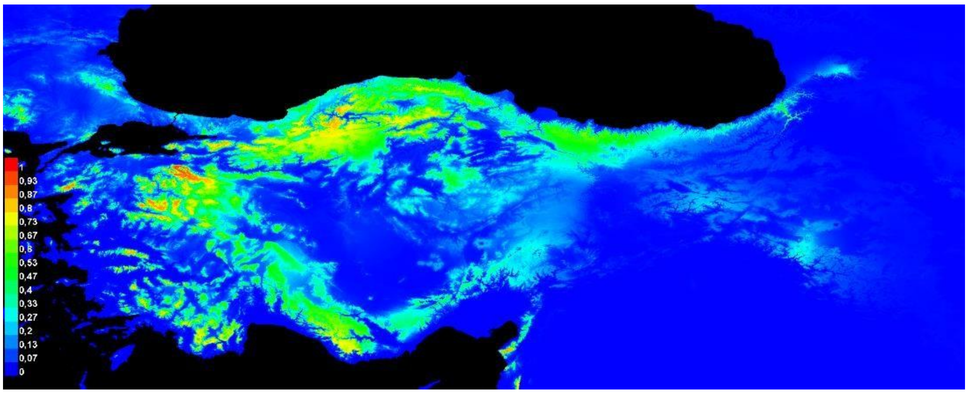


APPENDIX C: GCM Results for Anatolian Black Pine

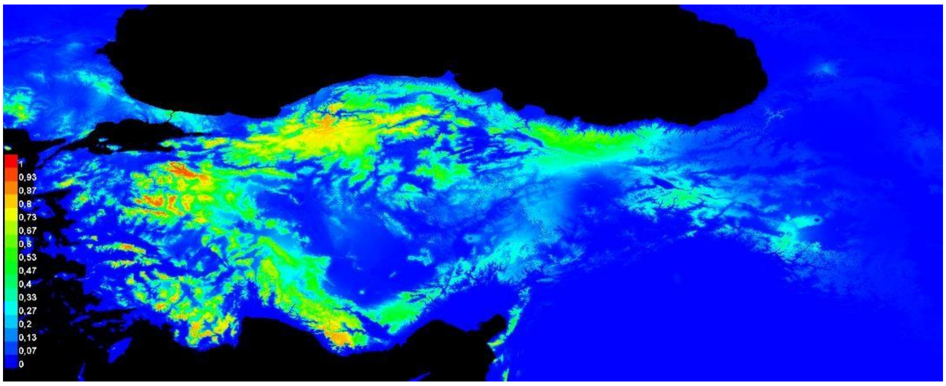
1. BCC-CSM1-1



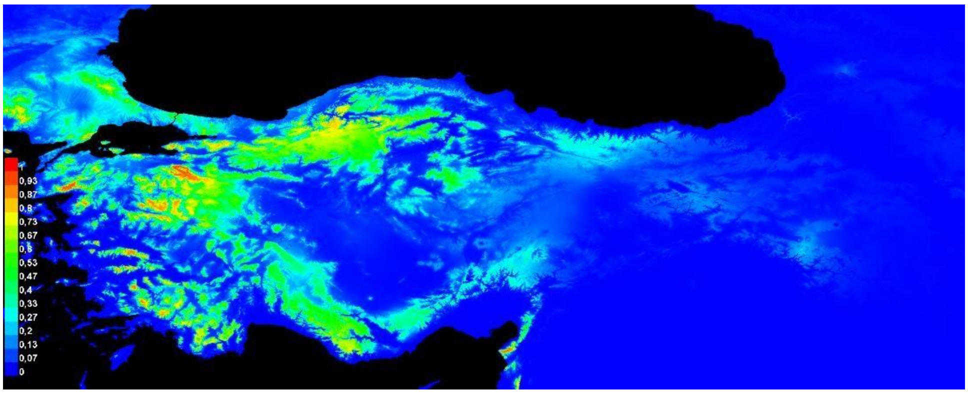
2. CCSM4



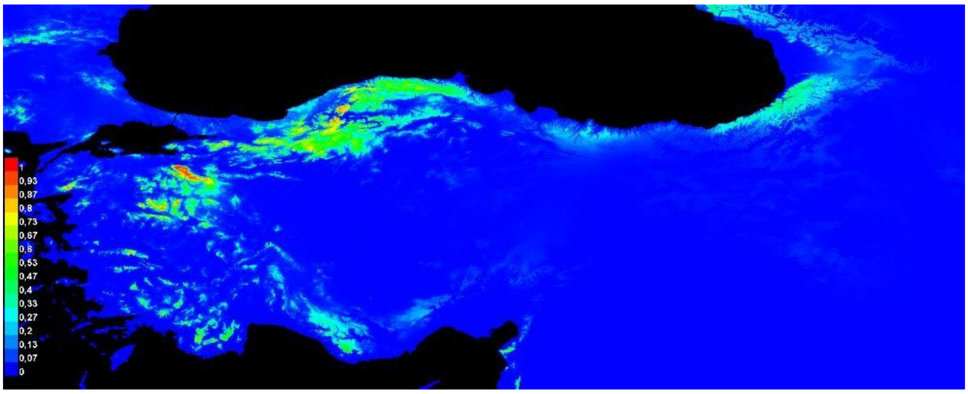
3. CNRM-CM5



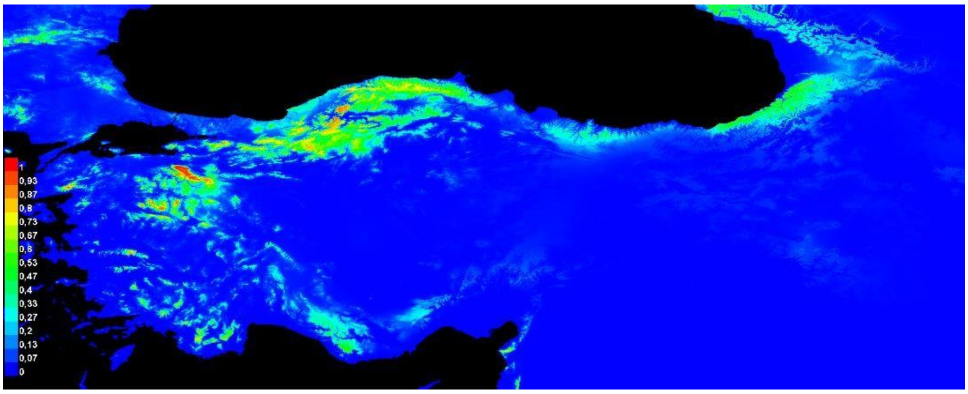
4. GFDL-CM3



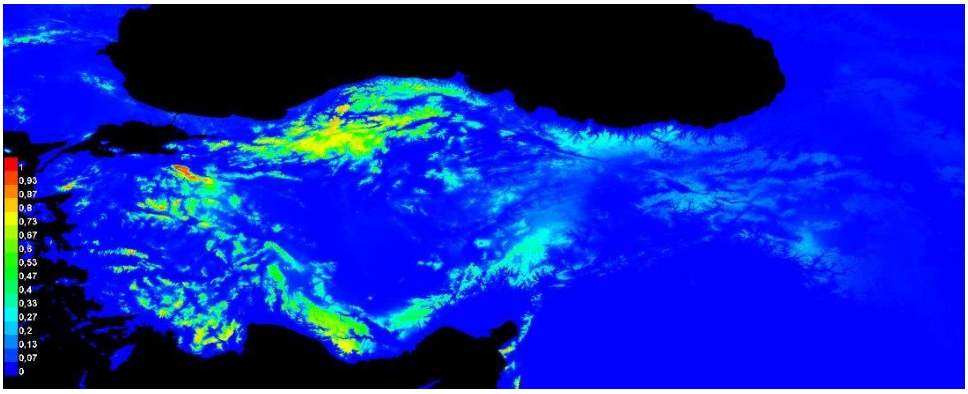
5. GFDL-ESM2G



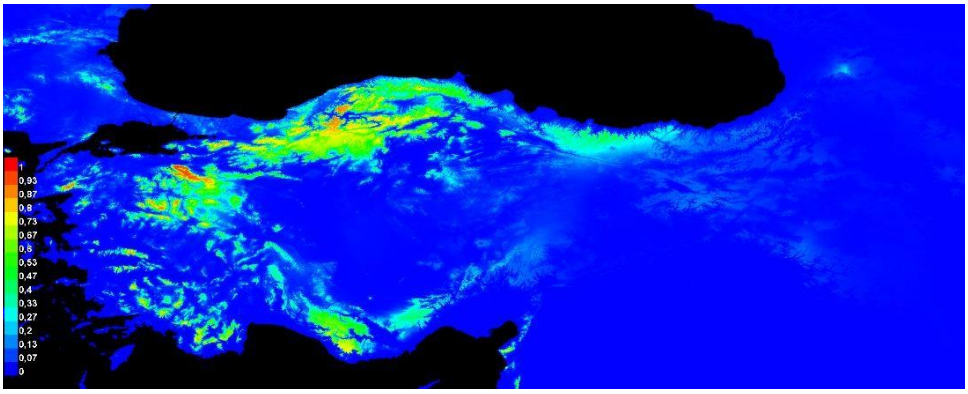
6. GISS-E2-R



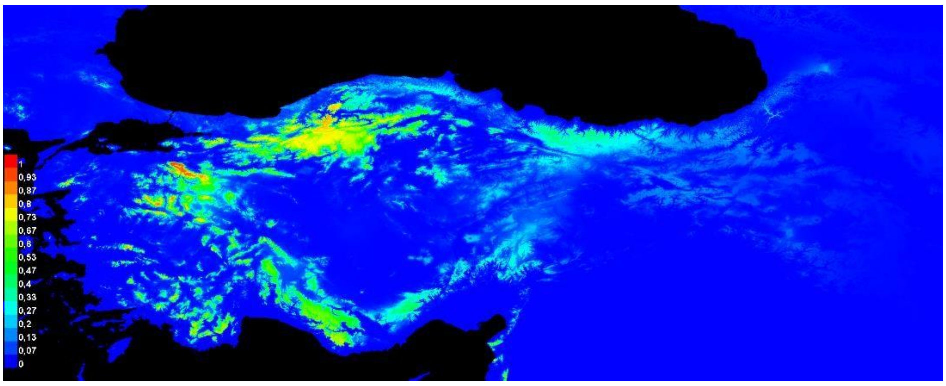
7. HadGEM2-AO



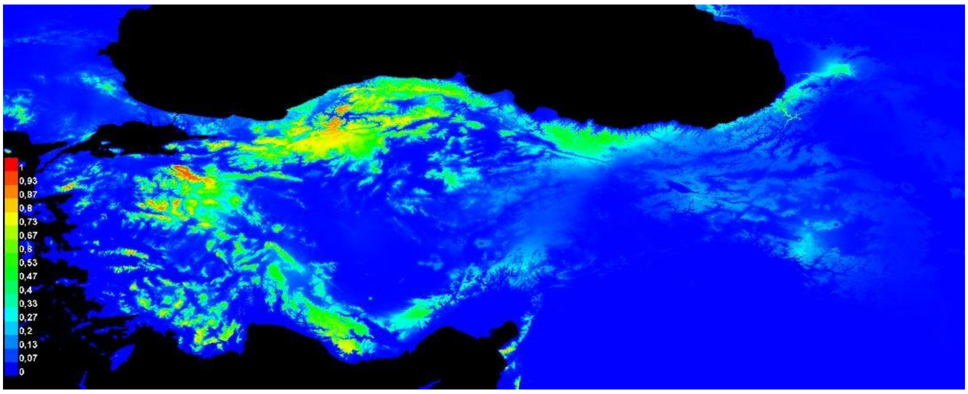
8. HadGEM2-ES



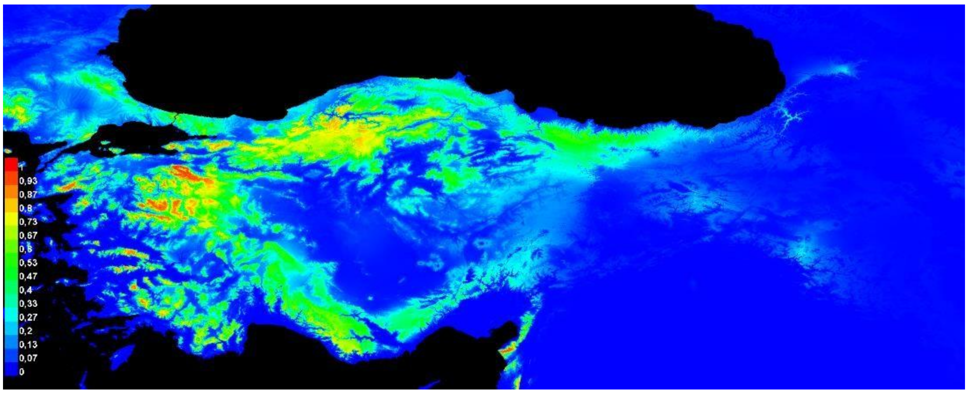
9. IPSL-CM5A-LR



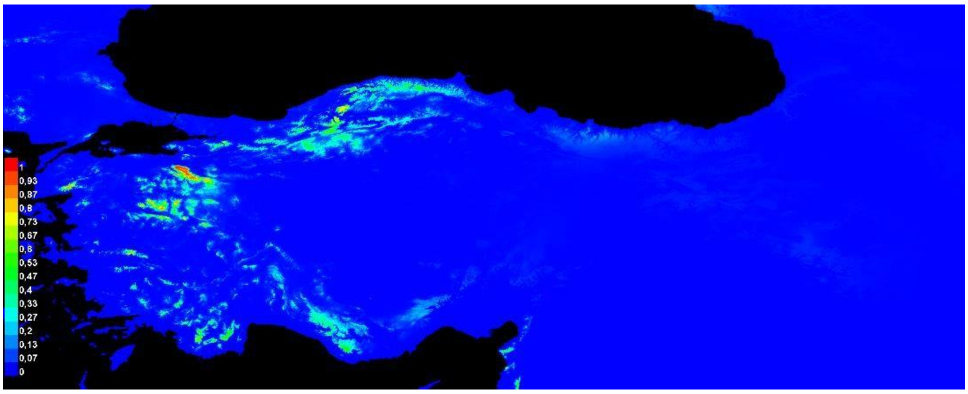
10. MIROC-ESM-CHEM



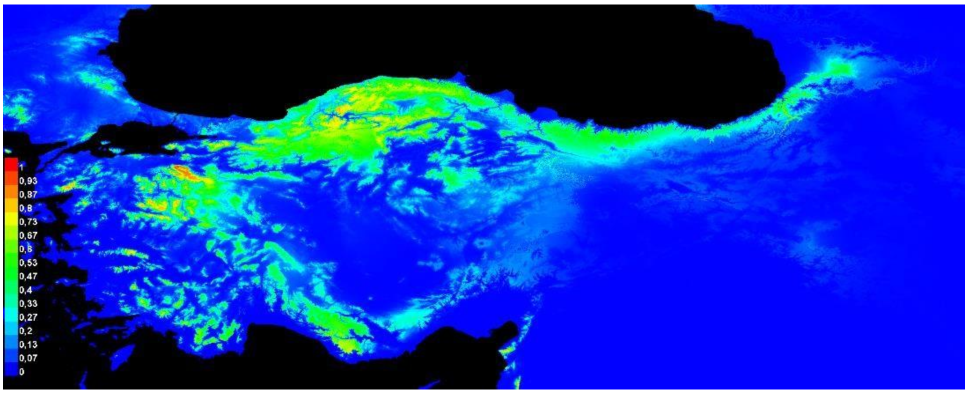
11. MIROC-ESM



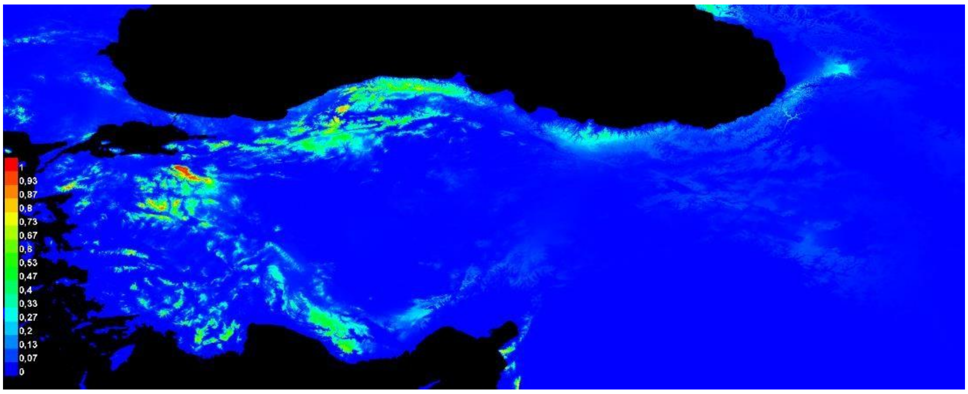
12. MIROC5



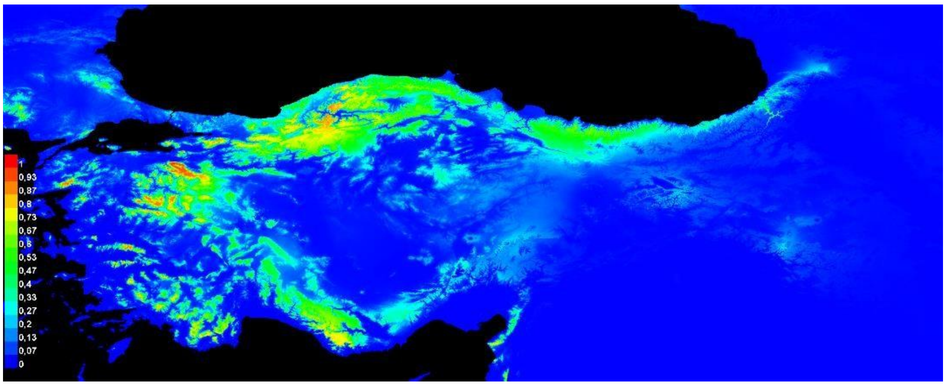
13. MPI-ESM-LR



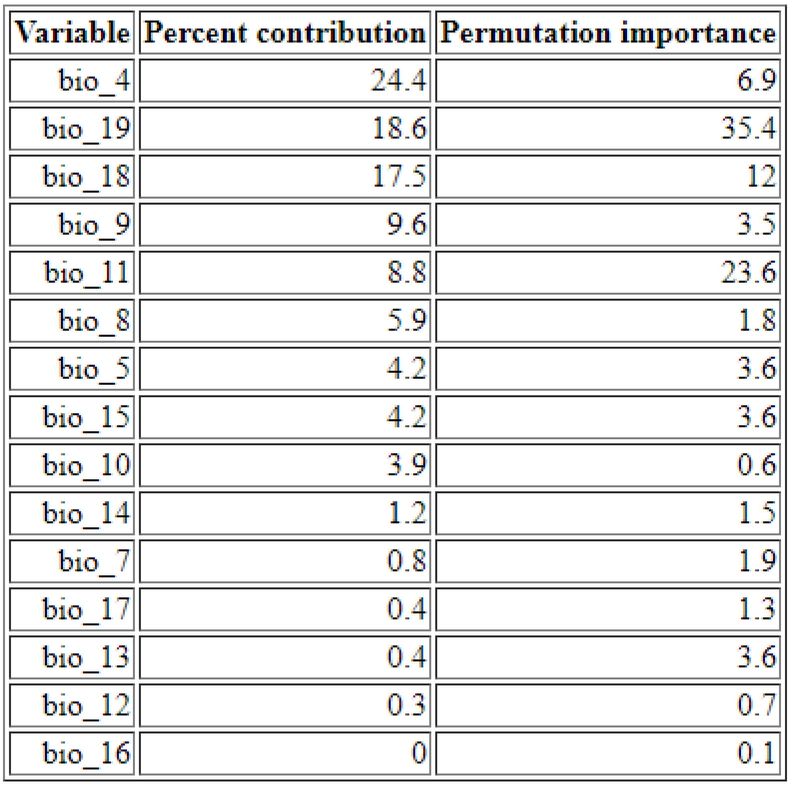
14. MRI-CGCM3



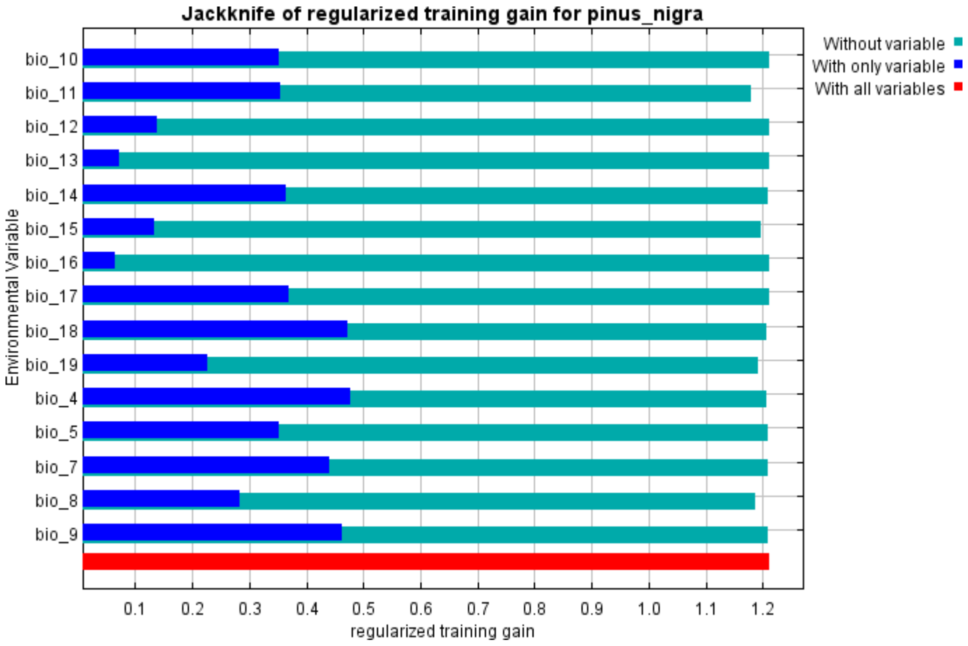
15. NorESM1-M



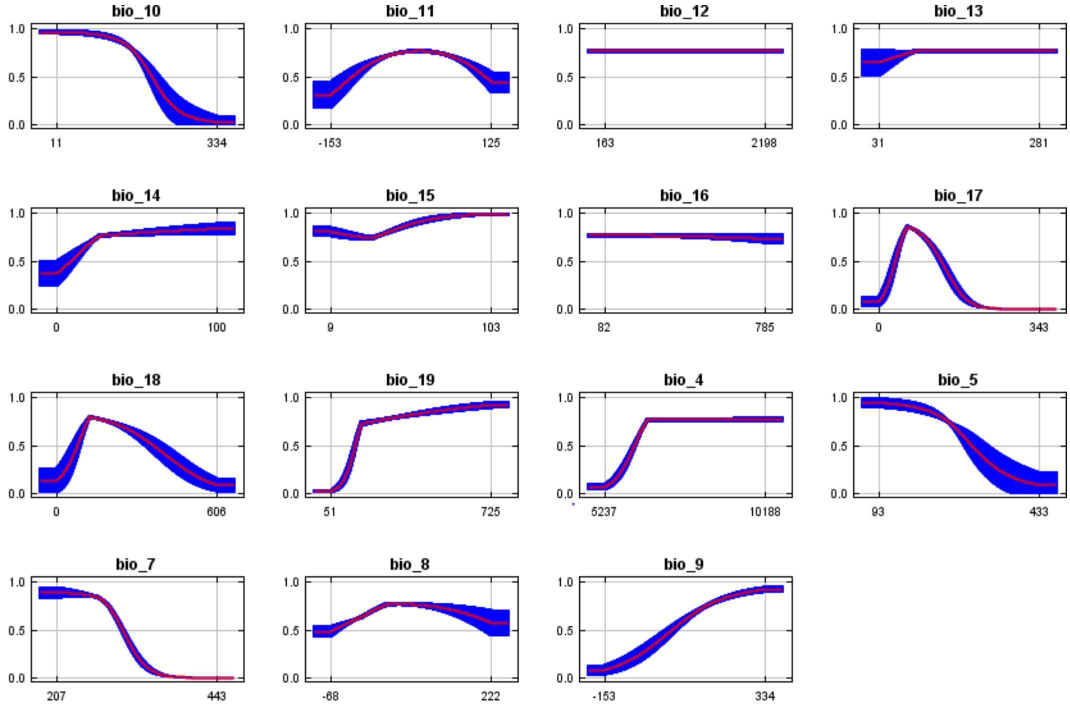
APPENDIX D: Spatial Jacknifing Results for Anatolian Black Pine



Variable	Percent contribution	Permutation importance
bio_4	24.4	6.9
bio_19	18.6	35.4
bio_18	17.5	12
bio_9	9.6	3.5
bio_11	8.8	23.6
bio_8	5.9	1.8
bio_5	4.2	3.6
bio_15	4.2	3.6
bio_10	3.9	0.6
bio_14	1.2	1.5
bio_7	0.8	1.9
bio_17	0.4	1.3
bio_13	0.4	3.6
bio_12	0.3	0.7
bio_16	0	0.1



APPENDIX E: Response Curves for Kazdagi Fir



APPENDIX F: Response Curves for Anatolian Black Pine