KARADENİZ TECHNICAL UNIVERSITY
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF FOREST ENGINEERING

INTEGRATION OF CLIMATE CHANGE TO FOREST MANAGEMENT PRACTICES. AN ANALYSIS OF FUTURE TREE SPECIES DISTRIBUTION, ECOSYSTEM SERVICES AND PERCEPTION OF FORESTRY PROFESSIONALS

DOCTORATE THESIS

LIONEL CONSTANTIN FOSSO

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FOREWORD

This thesis topic “Integration of climate change to forest management practices: an analysis of future tree species distribution, ecosystem services and perception of forestry professionals” was prepared as a doctorate thesis at Karadeniz Technical University, the graduate school of natural and applied sciences, at the department of forest engineering. It would have not been possible for me to carry out this study without the help of many people. This is why I express my sincere gratitude to all those who have contributed from near or far to the realisation of this thesis.

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Lionel Constantin FOSSO
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THESIS STATEMENT

I, Lionel Constantin FOSSO, pledge on my honor that this work entitle “Integration of climate change to forest management practices: an analysis of future tree species distribution, ecosystem services and perception of forestry professionals” is the result of my own works under the supervision of Assoc. Prof. Uzay KARAHALİL in accordance with scientific research and ethical rules. I personally collected and analyzed data from field investigation and from previous related studies. To the best of my knowledge, it contains no material previously published by another person without citing the source. I also confirm that I have completely recognized and referred to all the material and results that are not originating from this work. In case the opposite arises, I declare that I accept the legal results. 09/ 12 /2021

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In this study, habitat suitability modelling with MaxEnt (Maximum Entropy) software was carried out to analyse current and future distribution of 12 selected tree species in Trabzon and Antalya regional forests in Turkey according to climate change scenarios RCP4.5 and RCP8.5. Then, in order to reveal the future changes in products and service values of four different ecosystem services selected for the Cerle planning unit, a strategic decision-making model was developed over a 50 years planning horizon using linear programming technique and solved with LINGO^{TM} software. In addition, the perceptions of forestry professionals in 3 countries (Germany, Turkey and Cameroon) with very different ecological characteristics were analysed to evaluate the general awareness in each country. As results, it is found that potential suitable areas for *Pinus sylvestris* and *Quercus spp.* will expand in Trabzon region, while in Antalya region there will be a serious decrease for *Pinus brutia*; but the areas of *Quercus spp.* and *Pinus nigra* will be expanded. Four forest functions, namely wood production, carbon storage, soil loss and water production, were associated with different stand parameters in the southern part of the Cerle planning unit in Antalya. Ten alternative planning strategies have been developed to maximize wood production and minimize soil loss. The highest amount of wood and the lowest total amount of soil loss were obtained by Strategies 9 and 10, where adapted species were planted, as 447816.5 m^3 and 17263.5 tons. Within the scope of adaptation, 28 different adapted tree species were cited by 69.2% of the respondents in Germany, 12 species by 23% of those in Turkey and 8 species by 10.8% of those in Cameroon. To conclude, it is very crucial to integrate climate change to forest management practices and it is highly recommended to continuously train forest managers on adaptation strategies.

Key Words: Climate change, forest management, habitat suitability modeling, ecosytem services, risk perception, adaptation, Cerle planning unit.

ÖZET

İKLİM DEĞİŞİKLİĞİNİN ORMAN AMENAJMAN UYGULAMALARINA ENTEGRASYONU: GELECEKTEKİ AĞAÇ TÜRÜ YAYILIŞI, EKOSİSTEM HİZMETLERİ ve UZMAN GÖRÜŞLERİNİN ANALİZİ

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Bu çalışmada, Türkiye'de Trabzon ve Antalya'da seçilen 12 ağaç türü için MaxEnt (Maximum Entropy) yazılımı kullanılarak, mevcut ve gelecekteki tür dağılımı iklim değişikliği senaryoları RCP4.5 ve RCP8.5'e göre habitat uygunluk modellemesi yapılmıştır. Daha sonra, Cerle planlama birimi için seçilen dört farklı ekosistem hizmetinin gelecekteki ürün ve hizmet değerlerini ortaya koymak amacıyla doğrusal programlama tekniği kullanılarak 50 yıllık bir planlama ufku boyunca stratejik karar verme modeli geliştirilmiş ve LINGO^{TM} yazılımı ile çözülmüştür. Ayrıca, çok farklı ekolojik özelliklere sahip 3 ülke (Almanya, Türkiye ve Kamerun) seçilmiş ve orman yöneticilerinin algıları ortaya konmuştur. Elde edilen sonuçlar; Trabzon bölgesinde *Pinus sylvestris* ve *Quercus spp*'nin potansiyel uygun alanlarını genişleteceğini, Antalya bölgesinde *Pinus brutia* için potansiyel uygun alanda ciddi bir düşüş olacağını, ancak *Quercus spp* ve *Pinus nigra*'nın alanlarının genişleyeceğini ortaya koymuştur. Cerle planlama biriminin güney kesiminde; odun üretimi, karbon depolama, toprak kaybı ve su üretimi olmak üzere dört orman fonksiyonu farklı meşcere parametreleri ile ilişkilendirilmiştir. Odun üretimini en üst düzeye çıkarmak ve toprak kaybını en aza indirmek için 10 alternatif planlama stratejisi geliştirilmiştir. En yüksek miktarda odun ve en düşük toplam toprak kaybı miktarı adapte edilmiş türlerin dikildiği 9. ve 10. Stratejiler tarafından 447816.5 m^3 ve 17263.5 ton olarak elde edilmiştir. Daha sonra ormancılık konusunda uzman Almanya'da 221, Türkiye'de 279 ve Kamerun'da 130 kişi ile görüşülmüştür. Uyum stratejileri kapsamında, Almanya'daki katılımcıların %69,2'si 28 farklı uyarlanmış ağaç türü, Türkiye'dekilerin %23'ü tarafından 12 tür ve Kamerun'dakilerin ise %10,8'i tarafından 8 tür belirtilmiştir. Sonuçta, orman amenajmanı uygulamalarında uyum stratejilerinin dikkat alınması çok önemlidir ve orman yöneticilerinin uyum stratejileri konusunda eğitilmesi şiddetle tavsiye edilmektedir.

Anahtar Kelimeler: İklim değişikliği, orman amenajmanı, habitat uygunluğu modellemesi, ekosistem hizmetleri, risk algılaması, adaptasyon, Cerle planlama birimi

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ABREVIATIONS AND SYMBOLS

BEF: Biomass Expansion Factor

BRT: Boosted Regression Tree

CF: Carbon Factor

CTA: Classification Tree Analysis

CPU: Cerle forest Planning Unit

CSC: Climate Service Center

DWD: German Weather Services

FAO: Food and Agriculture Organization

FVA: Federal Forest Administraiton in Germany

GAM: General Additive Models

GBIF: Global Biodiversity Information Facility

GCMs: General Circular Models

GDF: General Directorate of Forestry in Turkey

GHG: Green House Gases

GIS: Geographic Information System

GIZ: Geselschaft für Internationalen Zuzamen Arbeiten

GLM: Generalized Linear Model

GPS: Global Positioning System

GWF: Global Forest Watch

HSM: Habitat Suitability Modelling

IPCC: Intergovernmental Pannel of Experts on Climate Change

IUCN: International Union for the Conservation of Nature

Maxent: Maximum Entropy

MK test: Mann Kandall test

NCMC: National Center of Meteorology and Climatology

NN: Neural Network

NP: National Park

NWFP: Non Wood Forest Product

PPM: Party Per Million

PU: Planning Unit

RCP: Representative Concentration Patways

SDM: Species Distribution Modelling

SPSS: Statistical Package for Social Sciences

TS: Sens slope test

UNEP: United Nations Environmental Program

UNFCCC: United Nation Framework and Convention on Climate Change

Worldclim: World climate plateform

WWF: World Wildlife Fund

1. GENERAL INFORMATION

1.1. Introduction

Forest is defined as a large area of land densely populated by trees (GFW, 2005). The world's total forest area was estimated to cover around 31% of the global land area in 2015 with 40 million km^2 unevenly distributed over the global surface (FAO, 2015). However, deforestation has been destroying about 13 million hectares of forest per year mainly due to human activities such as agriculture, mining and urbanization (WWF, 2020). But forests play an important role in human livelihood by providing a number of goods and services that are essentials for human maintenance. For example, forest is a source of food (fruits, leaves, mushrooms and other NWFP used for medicines and cosmetics), wood (timber and lumber for industries or fuelwood), water and shelter. Furthermore, forests are home to 80% of the world's terrestrial biodiversity (animal and plant species), and also provide jobs to more than 13 million people across the world. In addition, more than 300 million people live in or around forests areas, including 60 million indigenous people (WWF, 2020). Moreover, after oceans, forests are the world's largest climate regulator, by absorbing harmful greenhouse gasses that produce climate change and storing carbon. In tropical forests alone, trillion tons of carbon is stored in above and below ground in forest biomass (WWF, 2017).

Climate change can be defined as the long term modification of meteorologic parameters mainly caused by the increasing temperature over decades causing changes at local, regional or global climate scale, and can also refer to the effects of these changes like recurrent canicules, forests fires, insects, pests and allien species invasions (IPCC, 2014a). In recent decades, burning of fossil fuels and removal of forests for agriculture and mining resulting in a rapid increase in carbon dioxyde concentration in the atmosphere has been mentionned as the factor accelerating climate change (Pachauri and Meyer, 2014). Since industrial revolution, the concentration of carbon dioxyde in the atmosphere has risen from around 280 parts per million (ppm) to 413 ppm in the early 2020, and this will increase up to 600 ppm by 2100 corresponding to an increase of temperature of 3 to 4°C by 2100 (Yale, 2020).

This is unprecedently recorded in human history, and there is an urgent need to reduce fossil fuel energy use and to stop deforestation in order to stabilize global emmissions under 340 ppm to maintain global warming under 1.5°C as stated at the Paris agreement (Hansen et al., 2013; UNEP, 2021). Since vegetation sequesters carbon, it is evident that efficient forest mamanegement is the most appropriated solution to cool the planet (UNEP, 2021).

Nowadays, climate change affects forestry activities in many regions around the world by increasing natural hazards in forest areas. There are two main global and fundamental challenges faced by forestry professionals: climate change impact on forests and biodiversity loss. For instance, forests are likely to experience adverse impacts with the loss of many tree species due to the change or destruction of their natural habitat conditions, of which some are potentially irreversible (Lindsey et al., 2012). The problem is that there are no clearly defined adaptation strategies that could be implemented by forestry professionals in anticipation on the future extreme climatic events. Therefore, it is important to understand the nature of climate change risks, where natural variability and human activities threaten forest ecosystems to be more vulnerable, and what may be achieved as adaptive responses (Blennow and Pearson, 2009). As well, the perception of climate change by forest managers and adaptation strategies elaborated in different areas are very important to characterise to take action to reduce forest ecosystem’s vulnerability (Yousefpour and Hannewinkel, 2015). The management of climate change impacts is not only determined by ecological processes but also influenced by the adaptive capacities of forest managers (Seidl et al., 2016).

Furthermore, perception of climate change by forestry professionals plays an increasingly important role in forest’s climate change risk management (Yousefpour et al., 2013). However, there is a gap between scientist’s knowledge and local forestry stakeholder’s knowledge about climate change (Crona et al., 2013). Lindner et al. (2010) showed that the adaptive capacities of both ecosystem and society have to be taken into account for a successful adaptation strategy. Furthermore, introducing the climate change phenomena into forest management practices is very crutial and the role of forestry professionals in the elaboration and implementation of climate change adaptation strategies is very important (Fosso and Karahalil, 2020). For instance, in Germany there is an urgent need to adapt the forest to the expected future environmental changes (FVA, 2016). It can be assumed that converting the Black forest in South East Germany into less productive mixed forests will negatively influence the ecologic and the economic value of these forests and will lower their capacity to sequester carbon for several decades (Bredahl-Jacobsen and Hanley, 2004). Furthermore, climate change will modify the ecological conditions in forests causing tree migration from Mediterranean to temperate areas, and from temperate to boreal areas (Lindsey et al., 2012). Then, the decrease of forest productivity and the increase of regeneration costs for *Picea abies* in Germany will be largely affected by the changing climatic conditions (Hanewinkel et al., 2012).

Hence, these changes present many potential risks that threaten the sustainability of forest and bring out new challenges for forest managers requiring an understanding of the effects of climate change on forests, a prediction of how these effects might change in the future, and the incorporation of this knowledge in management decisions (Keenan, 2015). As well, climate change adaptation process involves the monitoring and anticipation on future changes by undertaking actions to avoid the negative consequences of climate change, and in order to take advantage of potential benefits provided by those changes (Keenan, 2015). Examining the change in habitat suitability around forest ecosystems provide arguments to evaluate the perception of this phenomenon by local forestry professionals. Therefore, evaluating the level of awareness of climate change issue and action from forestry professionals in different countries is highly needed.

As stated, this thesis focuses on forestry professionals because they are directly involved in the implementation of forest management plan and decision making processes. It is important to analyse their knowledge and perceptions about climate change and associated signs, climate change manifestations and their impacts on forestry activities. As well the reactions of forestry professionals and adaptation strategies elaborated in case of extreme climatic events in their forests depend on their willingness to change forest management practices or activities for future adaptation (Kolström et al., 2011). Similar studies have been carried out in Belgium by Silva et al. (2016), in Germany by Yousefpour and Hannewinkel (2015), in the USA by Soucy et al., (2021), Lenart and Jones (2014) and in Sweden by Blennow et al. (2012). On the other hand, there is only a single conducted study considering solely public awareness and perception of climate change in Turkey, yet there is no recorded study investigating the outputs of a broad range of climate change perception by forestry professionals and adaptation strategies elaborated in order to help the forest to adapt to future climatic conditions in Turkey (Korkmaz, 2018).

It is clear that people will have different perceptions due to the difference in geographic positions, with different social and economic contexts in each country. If forest managers perceive well the changes, they will identify good adaptation strategy in order to help the forest to resist to future changes (Seidl et al., 2016). If they don't perceive well the changes, there is a need to train them to elaborate an efficient strategy to be implemented for future adaptation, in order to enforce the sustainability of their forests (Blennow and Pearson, 2009). As well, there will be significant changes in the habitat suitability of many tree species around the world in the next 50 years as stated by Lindsey et al. (2012) and IPCC (2014b). But all of them are not well known and are still in theoretical speculations in scientific and experts communities. It can be estimated that 20 to 30% of animals and plants species in the world will be at higher risk of extinction due to global warming and that a significant proportion of endemic species may become extinct by 2050 or 2100 according to climate change scenarios (IUCN, 2018). According to IPCC 5th report, the geographic distributions of species will change due to future habitat suitability change generated by climate changes (IPCC, 2014b; Martinez-Meyer, 2005). Much recently, multiple techniques and programs have been developed to predict the impacts of climate change on species distribution through modelling, even for areas where no presence data have been recorded due to biased samplings (Araujo and Guisan, 2006; Elith et al., 2006; Trisurat et al., 2011).

Moreover, habitat suitability modelling or species distribution modelling are numerical tools for predicting potential distribution of species that combine observed data of selected species and environmental variables (e.g. climate, soil) to determine whether the environmental features are suitable for occupancy within the study area (Guisan et al., 2014). This technic has been elaborated bases on real forest conditions simulations, and for many applications, like conservation prioritization and reserve selection (Rodríguez-Soto et al., 2011), predicting the dynamics of invasions of forests by alien species (Loo et al., 2007), re-colonisation of abandoned open land areas by trees species (Mladenoff et al., 1995), the suitability of sites for reintroductions of endangered native species (Thatcher et al. 2006), niche evolution using past, present and future environmental data (Warren et al., 2008), and the response of species to climate change (Araújo et al., 2005).

One of the most efficient and popular species distributions modelling tool is MaxEnt which is the abbreviation of maximum entropy, a machine learning model using a calibrated method to find the potential distribution of species that is the most probable to spread out based on probability density (Elith et al., 2011). These allow us to analyse the change in terms of ecological services related to the change in the structure and composition of the forest affected by climate change.

Therefore the link between future tree species distribution and forest management should be established. The main goal of forest management is to produce forest goods and services sustainably in order to maintain a healthier forest for the future generations. This includes many aspects such as ecological, social, economic and cultural services provided by forests. In order to develop and implement sustainable forest management strategies according to future climate change, the understanding of forest ecosystem services interactions and their dynamics should be taken in account by an accurate representation of all parts of the forest ecosystem. That can be used successfully to implement forest management strategies. Linear programming is one of the technics allowing developed model to help forest managers to identify constraints and provide different management alternatives for decision making (Wainwright and Mulligan, 2004).

Furthermore, forest management optimization is one of the most important issues discussed in recent years when forest resources sustainability is mentioned (Kaya et al., 2016; Bettinger et al., 2017). Numerous studies have demonstrated the ability of linear programming to distinguish between many objectives functions and the efficiency of this technic in solving equations and forestry problems like Gül (1998), Karahalil (2003), Karahalil et al. (2009), Karahalil (2009), Kaya et al. (2016), Bettinger et al. (2017), Değermenci (2018), Hagr (2019). Numerous advantages are provided by linear programming like assessing quantitative analysis of goods and services, minimizing deviations from objective function due to constraints, providing a comparison between a number of goals and thus help to achieve a certain objective by making appropriate decisions.

In that sense, what are climate change’s effects on forests in the world? What are the important parameters to display these effects on forests? What is the perception of climate change by forestry professionals? How can a forestry professional identify the risks and challenges faced by forests according to climate change impacts? Which method can be used to identify adapted and non-adapted tree species? What will be the future outputs of forest ecosystem services if tree distribution changes? Is there any advantage to plant adapted tree species compared to non-adapted species in the production of forest ecosystem services according to climate change predictions? Is it possible to find practical answers to these questions in order to integrate this approach in to forest management plans? There must be an effective forest management planning system that can integrate all these answers.

Within the scope of this thesis, it is aimed to draw up the conceptual framework of climate change integration in forest management planning and activities. In addition, a decision making technic (using linear programming) should be implemented to simulate a case where climate change is a challenge to forest management activities, thus offering options at strategic A model should be implemented in a case study of planning unit as an example that can be replicated in each of the other study areas.

1.2. Hypothesis and Objectives

1.2.1. Hypothesis

The main hypothesis of this thesis is that future tree species distribution will be different compared to current distribution. Due to that, forest ecosystem provisioning and supporting services will change. Therefore the perception of climate change by forestry professionals and strategies elaborated to help their forest to adapt to future changes will have significant impacts on the future forest structure and composition. This may depend on the level of awareness of forestry professionals, access to information and training on climate change adaptation technics in each country.

1.2.2. Objectives

The main objective in this thesis is to estimate future tree species distribution and forest ecosystem services outputs considering different scenarios, in order to contribute to document the knowledge on integration of climate change to forest management practices by forestry professionals in the selected study areas.

More specifically, this thesis aims to:

- Display habitat suitability modelling with (MAXENT) for the prediction of future distribution of some selected tree species by 2050, 2070 or 2100 according to climate change scenario RCP4.5 and RCP8.5 in Trabzon and Antalya selected as sample areas. This helps to identify tree species that will be adapted to future climatic conditions as well as those that will be at higher risk of vulnerability due to future climate change.

- Analyse the change that will occur in about 50 years in Cerle PU, in terms of some selected ecosystem services such as timber production, carbon stock, soil loss and water production using linear programming technics and solved by LINGO^{TM} software.
- Evaluate the different perceptions of climate change and adaptation strategies elaborated by forestry professionals in each selected country, and compare the results within the countries to determine the level of awareness of forestry professionals in the selected countries, adaptation strategies, plan and practices elaborated in each study area.
- Elaborate a simplified model system to help forestry professionals in Turkey and around the world to identify adapted tree species for sustainable forest management.

1.3. Basic Concepts on Climate Change and Forest Management

1.3.1. Climate Change and Reflections on Forest Management in the World

Climate change will influence differently the structure and distribution of forests in the world, and forest managers should elaborate strategies and techniques to adapt to and mitigate these changes. According to the FAO (2013) climate change guidelines for forest managers and policy-makers, there is a need to integrate climate change concerns into new or existing forest policies and national forest programs in order to assist forest managers to better assess and respond to climate change challenges and opportunities at the forest management level. There is no need to wait for the venue of climate change adverse before trying to adapt to them. There is a need to put in place an adaptation system that should monitor the disturbance according to regional and local realities to improve their adaptation capacities (FAO, 2013).

Furthermore, forests managers play a key role in the success of the adaptation strategy in forest ecosystems processes. Even if we try to limit global warming increase at a level of less than 2°C as stated in the latest climate policy during Paris agreements in 2015 or the Bonn challenge in 2017, the frequency of wildfire, drought, pest and pathogens, storm and desertification of forests areas will increase by 2050 (IPCC, 2014c). These impacts of climate change on forest ecosystems vary from one region to another. Forest managers generally try to increase wood production in forest areas managed for ecological values without taking into account the effects of climate change. On the other hand, more efforts should be made especially during the forest management planning, responsible for the determination of forestry activities such as regeneration, thinning or cutting via forest management plans (Karahalil, 2009). Therefore, there is a strong need to integrate the climate change issue to those practices since global climate change is causing an increase in the frequency of forest fires in Mediterranean, temperate and boreal coniferous forest areas (Tautenhan et al., 2016).

Accordingly, the consequences for certain species will differ by geographic region and the extent of climatic change: some species will respond positively with an increased development rate, increased survival and reproductive potentialities; while other species, however, will respond with negative effects like decreased growth rate and reduced fecundity are possible (Tüfekçioğlu et al., 2005). Furthermore, there will be an increasing rate of death wood due to drier climate conditions leading to dought and other factors like the venue of wood decomposers such as fungi (Zhang et al., 2017).

Africa remains one of the most exposed region to the adverse climate change impacts, and presents the highest vulnerability due to its little adaptive capacities. It is estimated that in Africa during the twentieth century, temperature warming was between 0.26 and 0.5°C per decade (Hulme et al., 2001). This trend is expected to continue or even intensify significantly, exerting negative effects on the livelihoods of populations (Tadjuidje, 2012). According to the Intergovernmental Panel on Climate Change (IPCC, 2007), a medium to high emission scenario would imply an increase in the average annual surface air temperature of between 3 and 4 °C by 2100. This means hard times for forestry professionals and local people who are directly dependent on natural resources for their livelihoods, and who have few assets or technical knowledge to adapt to upcoming changes (Malhi and Wright, 2004).

The Congo basin, Africa's largest forest area with nearly 1.8 million km^2, and the second largest forest biodiversity reservoir in the world after the Amazon forest, is suffering from the adverse effects of climate change (CSC, 2013). Forests in the Congo basin are extremely important for the storage of atmospheric carbon released worldwide and for the global water cycle through local recycling of water (Haensler et al., 2013). An assessment of climate change in the Congo basin and the possible scenarios that can occur during the 21st century, led by the Climate Service Center in collaboration with GIZ and Wageningen University, reveals that the projected changes in the rainfall will contribute to a general decrease in the amount of water in the Congo basin region and a relatively high frequency of drought periods in the future (Beyene et al., 2013).

Drought, desertification, reduction of agricultural yields, attacks of plantations by insects or diseases, the aridity of agricultural lands, the change of the rhythm of seasons and the regimes of rivers, reduction of forest cover, deforestation, degradation of forest habitats and ecosystems, are increasing the vulnerability of forest areas and forestry activities in Africa (Gyampoh et al., 2007). But the potential contribution of indigenous people to design and implement sustainable mitigation and adaptation measures is considerable. Having always been able to adapt to the variations of the climate and the evolution of ecosystems, with livelihoods so closely linked to natural environments, forest managers and indigenous people have long been observing the nature and can offer sustainable adaptation models based on their knowledge, innovations and traditional practices (IUCN, 2010). It appears that forestry professionals and indigenous peoples adapt to climate change on the basis of their knowledge of forest ecologycal processes (Gyampoh, et al., 2007).

Reflections to forest management on how to integrate climate change is being carried out all over the world for country specific adaptation strategy in the forest sector. As stated in the agreement of the conference of parties, every country has to elaborate a strategic plan for climate change adaptation of forestry as a country-driven process and prepared by focusing the sustainable management of forest ecosystems (GDF, 2020a). It should be consistent with national sustainable development goals and national circumstances and capabilities, and will be integrated to national strategies and programmes such as forest and climate related legislative documents, strategies and programmes to improve institutional, technical and human capacity, raise awareness and understanding, and consider benefits of climate change adaptation (GDF, 2020b).

1.3.1.1. Climate Change and Forest Management in Germany

In Germany, forest managers are responsible for forest regeneration, and tree species development as for the case of *Picea abies* related to the interest that forest managers put on it. The forest ownership in Germany is 44% private forests, 33% state forests, 20% communal and other forests and 3% federal owned forests. In Germany, forest managers are not responsible to define their management and regeneration plans. This will be carried out every 10 years by inventory specialists leaded by the federal state (Bahuss et al., 2014).

There is an urgent need to develop adaptation strategies to help forests facing environmental changes expected. The Black forest is covered by 172,000 ha of *Picea abies* making up more than 72 million m³ of standing volume (430 m³/ha), and representing highly productive forests that store a large amount of carbon. Converting this forest into less productive mixed forest will negatively influence the economic output generated by this forests for private and public forest owners in South East of Germany. (Bredahl-Jacobsen et al., 2004) and will lower their capacity to sequester carbon for several decades as the beech regeneration requires the standing volume to be decreased in order to establish. Furthermore Norway spruce (*Picea abies)* that is the main species in this forests, will have low favorable conditions to establish and will grow slower compared to oak (*Quercus spp.)* which will have more favorable areas to establish easily and grow faster by 2100 (Bindewald et al., 2021). As well, climate change will cause tree migration, a decrease of forest productivity and increase of regeneration costs for *Picea abies* (Hanewinkel et al., 2012). It can be mentioned that extreme weather conditions leading to drought and increasing storm risk have been identified as future climate conditions around the black forest, resulting from temperature and precipitation change for the periods 1961-1990 to 2071-2100 (Matzarakis and Endler, 2010).

1.3.1.2. Climate Change and Forest Management in Turkey

Turkey is one of the country’s most vulnerable to the effects of climate change. In Turkey, the effects of climate change on forest are represented by an increasing frequency in wildfires, forest diseases, wind storms and the change in forest configuration. Extinction of some species, decrease of some habitats quality or drastic changes in some stand type quality are alarming signals announcing for climate change (Tüfekçioğlu et al., 2005). Although Turkish forests area is increasing over the last decade, the structure and composition is susceptible to the effects of climate change. Therefore, displaying the important parameters of climate change that affect the forest ecosystems is crucially important. If the parameters display bad scenarios for the future, forest management decisions should be reviewed or different actions should be implemented. Accordingly, displaying mentioned parameters expressing climate change are also important for the integration of that phenomenon into forest management plans. Thus, different aims apart from classical management approach can be set or alternative silvicultural prescriptions can be implemented to reduce the negative effects of climate change (NCCAP, 2011).

For example, Turkey’s climate change strategies and action plans include sector-specific goals for key economic sectors representing major greenhouse gas (GHG) emissions contributors. In this context, considering that forests occupy 29% (22.72 Mha) of Turkey’s territory (GDF, 2019), and is a key economic sector with significant impact on climate action due to its mitigation and adaptation potential, the forestry sector is included in the strategies and action plan, highlighting the importance of focused climate change adaptation actions in this sector.

More specifically, Turkey targets to:

a) Identify trees species that are tolerant to drought and plant these species and implement site condition diagnosis, especially in arid and semi-arid areas,
b) Plan and implement forestry activities and land used, which are crucial for the protection and management of water resources within the framework of sustainability principles and based on upper basin management principles (MoEU, 2010),
c) Limit the negative impacts of land use and changes to forests, pastures, agriculture, and settlements to combat climate change,
d) Strengthen legal and institutional structures for combating climate change regarding land use and forestry,
e) Integrate the climate change adaptation approach to ecosystem services, biodiversity and forestry policies,
f) Identify and monitor the impacts of climate change on biodiversity and ecosystem services (MoEU, 2011a; MoEU, 2011b).

In this Strategic Plan, 9 strategies and 51 activities are recommended for the adaptation of forests to climate change in Turkey (GDF, 2020a). The recommended strategies and activities will be the main source for the development and update of the forestry section of the National Adaptation Action Plan to the Ministry of Environment and Urbanization. It is also recommended that the Strategic Plan for Climate Change Adaptation of Forestry will be considered for the development of GDF’s future policies and activities in Turkey to guide and support the implementation of national climate actions in the forestry sector to contribute to the UNFCCC to meet its ultimate objective (GDF, 2018).

1.3.1.3. Climate Change and Forest Management in Cameroon

The region of East Cameroon is very important in terms of high biodiversity and natural resources. As for botanical diversity, there are 8500 angiosperms, 279 pteridophytes, 101 lichens (de Wasseige et al., 2015). It has a large network of protected areas, including the Boumba Bek Forest National Park, which is facing pressure from neighboring populations in buffer zones (community forests, zones of synergetic interest and riparian village's forests) who are increasingly buying supplies of the Non Wood Forest Products from the national park when they are becoming increasingly scarce in their area (Bobo et al., 2014). It appears that forestry professionals and indigenous peoples adapt to climate change on the basis of their traditional knowledge and lessons learned from day to day life (Gyampoh, et al., 2007).

Drought, desertification, reduction of agricultural yields, attacks of plantations by insects, cattles or diseases, the aridity of agricultural lands, the change of the rhythm of seasons and the regimes of rivers, reduction of forest cover, deforestation, degradation of forest habitats and ecosystems, are some effects of climate change increasing the vulnerability of forests and local communities living in and around forest areas in Africa (Gyampoh et al., 2007). But these local communities are struggling to cope with the changes they are observing, by elaborating and implementating indigenous strategies based on traditional knowledge transmitted from generation to generation (Gyampoh et al., 2007). The potential contribution of indigenous people to design and implement sustainable mitigation and adaptation measures is considerable. Having always been able to adapt to the variations of climate and the evolution of ecosystems, with livelihoods so closely linked to natural environments, indigenous people have long been observing the nature and can offer sustainable adaptation models based on their knowledge, innovations and traditional practices (IUCN, 2010).

1.3.1.4. Perceptions of Climate Change by Forestry Professionals in the World

The fifth assessment report of IPCC has precised that human activities have been the main cause of the observed global warming since the beginning of the industrial revolution (IPCC, 2013). However, recent extreme weather conditions and events are enough indicators that can help to require a change in public or environmental policies and political decisions. Moreover, in these few last decades, it can be mentioned a relatively less concern and acceptance of the change in climatic conditions in the public (Capstick and Pidgeon, 2014). One of the factors that hinder public opinion to accept the fact that climate change is a reality and that human activities are the main accelerator of this phenomenon is that, historical natural variabilities have also caused climate to change in the past (Hansen et al., 2013). Given the fact that climate change cannot be directly experienced or observed straightforwardly, it is difficult for individuals to find a link between local weather events variability and climate change. Yet, although climate fluctuations are cyclical, rapid global warming in the past decades is highly unusual now compare to the past (Hansen et al., 2013).

Many previous results of research carried out on climate change have presented that ethical, social, political values, attitudes of respondents and also personal experience influence their perception on this phenomenon (Blennow et al., 2012; Myers et al., 2012). Believing in climate change has been shown to be strongly correlated with the willingness to undertake actions or the capacities to implement adaptation practices. (Blennow et al., 2012; Lenart and Jones, 2014). Furthermore, in order to understand peoples attitudes and capacities to act against climate change, it is necessary evaluate their belief in climate change from a social point of view (Goldman, 1999). Climate change perception by forestry professionals and implications for forest management have been investigated by several studies (Blennow et al., 2012; Yousefpour and Hanewinkel, 2015; Nelson et al., 2016; Seidl et al., 2016), using different approaches, demonstrating a wide general awareness of the issue.

In this context, evaluating the perceptions of forestry professionals can provide informations on their capacities to understand the phenomenon and actions to help the forest to adapt sustainably. The research presented here focuses on data on climate parameters change as well as land use change in the different selected areas. As well data on the opinions of forestry professionals about climate change manifestations, their thinking about the phenomena, their experience of natural hazards due to climate change, their reaction in front of natural hazards in forests, and their willingness to change the forest structure and composition to increase adaptation potentialities and to reduce the vulnerability of their forest. Furthermore, the perceptions of the vulnerability of forests to climate change and the impediments that limits the ability of forestry professionals to prepare and respond to climate change. This approach is in line with the studies of Silva et al. (2016), Blennow et al. (2012) and FAO (2012) who used mailed questionnaires to elicit the perceptions of forest owners and forest managers to prepare and respond to climate change. We thus also test the hypothesis proposed by Blennow et al. (2012) that measurements of belief in local effects of climate change and in having experienced climate change are sufficient for accurately explaining adaptation.

1.3.2. Prediction of Climate Change Impacts on Forests

1.3.2.1. Species Distribution Modelling Definition

Species distribution modelling 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 et al., 2008).

Species distribution models are also known as ecological niche models due to the 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 predict species-climate relationships (Guisan and Zimmermann, 2000; Pearson and Dawson, 2003).

One of the fundamental inputs of species distribution models is the locations of the species on the earth coordinate system. There are algorithms which use presence-absence data, but few of them use only presence data (Maxent). This help to minimize field survey data collection activities, time and increase the reliability of the results. 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.

In table 1, the online databanks for species presence data is presented, covering world-wide geographical range. There are also available regional databanks of different countries, continents and bio geographical data for regions. The most important databank nowadays is the “Global Biodiversity Information Facility”, that provides the more widely and representative presence data in the world under bioclimatic parameters.

Table 1**.** 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 2).

Table 2. 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/

The environmental variables used in species distribution models are depending 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 (Guisan and Zimmermann, 2000). Species distribution modelling has become a very important component of conservation biology. It has been used as a tool to assess both land use and environmental change or climate change effects on the distribution of species (Guisan and Theurillat, 2000).

1.3.2.1.1. Maximum Entropy Approach

Species distribution modelling requires algorithms to properly process species observation and environmental data. There are several software based on different algorithms that can be used to build SDMs (Table 3), among them MAXENT is one of the most widely used algorithms (Philips et al., 2006).

Table 3. Examples of SDM algorithms

Algorithm	**URL**
Bioclim	www.bioclim.org
Domain	www.diva-gis.org
GARP	https://desktop- garp.software.informer.com/
Generalized Additive Model (GAM)	https://www.unine.ch/cscf/grasp
MaxEnt	https://www.cs.princeton.edu/~scha pire/maxent/

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 the largest entropy, in the context of precisely stated prior data. 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 java software named MaxEnt, which takes a set of environmental (e.g., bioclimatic) grids and geo-referenced species occurrence data (e.g. mediated by GBIF) and build a model to express 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 and Dudik, 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 0-100 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 scales thus it is more useful over other output formats (Baldwin, 2009).

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 evaluating the model to determine its relevance. As with any modelling approach, it is important to determine the fit or accuracy of the model. Model evaluation primarily has been done in two ways. The first method is to calculate area under the curve (AUC) of receiver operating characteristic (ROC) generated by Maxent results. 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).

1.3.2.1.2. Presence or Occurrence Data

One of the most favourable features of MAXENT is that it allows building 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) (GBIF, 2019), European Forest Genetic Resources Program (Euforgen) (Euforgen, 2019) and others online database are international network and research infrastructure aimed at providing open access to data about all species presence as coordinate information, but are limited in terms of endemic species presence not recorded in the database. Even if, there are more than 50 records of *Pinus nigra subsp. pallasiana* and 120 records of *Pinus brutia*, the geographical distribution of the data does not cover the actual distribution of the species. As well there is no record of *Pinus pinaster* for example, that is normally distributed in some forest of Turkey.

Therefore forest stand type maps are more appropriated to find accurate presence data for local tree species in different selected study areas; 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, the General Directorate of Forestry published an open access web-tool for forest stand type maps named “e-Harita” (https://www.ogm.gov.tr/Sayfalar/OrmanHaritasi.aspx). The e-Harita online platform has several information about species distribution and forests Turkey.

1.3.2.1.3. Environmental Data or Climate Data

One of the most widely used environmental datasets is WorldClim-Global Climate Change Dataset (worldclim, 2019). WorldClim database offers climatic models which are created with different modelling techniques and in different resolutions. Currently, there are two climate datasets versions offered by WorldClim: the version 1.4 provided by CMIP5 (Intergovernmental Panel on Climate Change Fifth Assessment) climate projections from global circulation models (GCMs). There are both past (PaléoClim), current and future climate data sets; while in version 2.0, only current climate datasets are available. WorldClim offers climate data scenarios in 4 different resolutions; 10 arc-minutes, 5 arc-minutes, 2.5 arc-minutes and 30 arc-seconds (with 1 km^2 spatial resolution) for 2020, 2050 and 2070. In this study, downloaded data have a spatial resolution of approximately 1 km^2 (30 s). Current data (2020) and future projections ranges in 2050s (2041-2060) and in 2070s (2061-2080) were downloaded and used for this study according to RCP4.5 (intermediate emissions scenario for Green House Gases “GHG”) and RCP8.5 (highest emissions scenario for GHG) (Fick and Hijmans, 2017). Furthermore RCP2.6 (minimum emissions scenario for GHG) and RCP6.0 (moderate emissions scenario for GHG) were not used in this study. The most significant factors in identifying environmental niches of species are bioclimatic parameters. WorldClim dataset provide 19 bioclimatic variables resulting from the long term recording of monthly temperature and rainfall values from 1950 to 2000 (Hijmans et al., 2005).

According to IPCC, the index to measure greenhouse gases concentration in the atmosphere is RCP (Representative Concentration Pathway). This has been used to model the future emissions scenarios of climate change describing different possibilities of future climate orientations depending on the volume of greenhouse gases (GHG) emitted in the future years. The RCPs are labelled respectively based on the possible radioactive forcing range values by the year 2050 or 2100 (IPCC, 2013).

RCP1.9 is a pathway that limits global warming below 1.5 °C by 2100, the aspirational goal of the Paris Agreement. RCP 4.5 is described by the IPCC as an intermediate scenario. It is the more likely scenario that will result in global temperature rise between 2 degrees C, and 3 degrees C, by 2100 with a mean sea level rise 35% higher than that of RCP 2.6. Many plant and animal species will be unable to adapt to the effects of RCP 4.5 and higher RCPs. The RCP8.5 is the most unlikely climate change higher emissions scenario that will result in global temperature rise between 3.7 and 4.8 degrees C by 2100, implying many ecological and social desasters. This is "increasingly implausible with each passing year" (IPCC, 2014c).

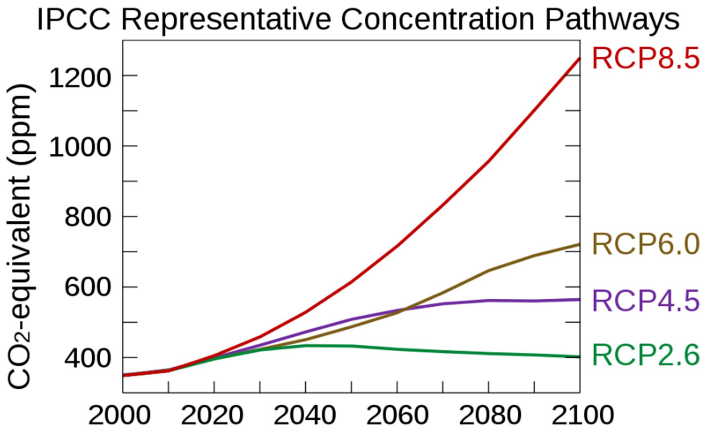


Figure 1. The four most used RCPs in the fifth IPCC assessment report

In this study, RCP4.5 and RCP8.5 have been considered for modelling the habitat suitability of selected tree species in Turkey. Statistical Downscaling (Delta Method) based on thin plate spline spatial interpolation of anomalies (deltas) of original GCM outputs were applied. Anomalies are interpolated between GCM cell centroids and are then applied to a baseline climate given by a high resolution surface (Worldclim, 2019; Hijmans et al. 2005). The spatial resolution of climate data collected from worldclim are 1 km (Fick and Hijmans, 2017).

1.3.2.2. Ecosystem Services

1.3.2.2.1. Definition

Ecosytem services are all the direct or indirect benefits that natural ecosytems provide to human (MEA, 2005). These benefits are grouped into four broad categories:

- Provisioning services which are products obtained from ecosystem such as food, wood and other fibers, fuelwood, fresh water, medecinal plants, and other NWFP.
- Regulating services which are benefits obtained from regulation of ecosystem processes such as climate regulation, desease regulation, flood regulation, water purification, air purification.
- Cultural services which are non material benefits obtained from nature such as spiritual and recreational experiences building knowledge in human societies by drawing nature and disseminating ideas, peace of mind and heart, as well as entertainment are among the unique effects that have driven people's cultural, intellectual and social growth.
- Supporting services which are the basic functions in the ecosystem supporting all other services. Such as photosynthesis leading to oxygen production, polination, water cycle, nutrient cycle, and soil formation. Suporting services are among the fundamental natural processes

To help in informing decision-makers, ecosystem services are being valuated in order to draw equivalent comparisons to human goods and services (Ecomod, 2021).

1.3.2.2.2. Timber Production

One of the major objectives of forest management is to produce wood by exploiting forest in order to regenerate forest ecosystem dynamic through silvicultural operations. Old trees with large volume are removed and young trees are replanted (WWF, 2020). According to FAO's forest product statistics report in 2019, the global production of timber was evaluated as 4000 million m^3 all over the world corresponding to 250 billion USD raw values (FAO, 2019). This timber is used for industries, sawnwood, paper and other wood products. But poor forest management promotes soil erosion by increasing runoff and reducing the protection of soil provided by tree litter. When forest tree cover thins, it leed to deforestation, genetic epurement, ecosystem degradation increasing forest vulnerability to climate change, and other consequences leading to the loss of ecosystem services. Therefore, sustainable forest management must be implemented for sustainable timber production.

1.3.2.2.3. Carbon Sequestration

Carbon sequestration is the process in which forests capture and store atmospheric carbon dioxide (USGS, 2020). This is the most efficient method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change. Carbon cycle move from geologic to atmospheric then from atmospheric to biologic. Carbon is store in oceans, forests, soil and atmosphere. Due to carbon cycle, there are 4 main types of carbon namely: grey carbon (in the atmosphere), blue carbon (in water bodies) and green carbon (in plants and forest) and black carbon (stored in geologic fossil fuel). This carbon cylce is the main source of climate change when more carbon is emited to the atmosphere, and increasing carbon sequestration is the solution to reduce climate change.

1.3.2.2.4. Soil Loss

According to Montgomery (2017), land degradation is mainly caused by soil erosion as a result of abusive and unsustainable land use and many other disturbances such as intensive agriculture, forest fires and mining industries. Continous soil loss may impact seriously the quantity and quality of soil ecosystem services, generating serious economic, social and political implications that will impact human activities and increase soil vulnerability to erosion. The Universal Soil Loss Equation (USLE) that provide the quantity of soil loss per unit of area with the erosive power of rain, the velocity or speed of water runoff, soil erodibility and vegetation cover as a mitigating factor, cultivation methods and soil conservation. The USLE equation is given by an equation where all these factors are combined together as in the formula:

$A = R*K*LS*C*P$ where:

A is the Annual soil loss in t/ha
R is the erosive power of rain or rainfall erosion factor, related to the amount and intensity of rainfall over the year. the rainfall erosion factor is expressed in erosion index units.
K is the soil erodibility factor to account for the soil loss rate in t/ha for each erosion index unit per given soil as measured on a unit plot which is defined as a plot of 22.1 m long on

9% slope under a continous area of forest land. The soil erodibility factor ranges from 0.1 for the least erodible soils to approaching 1.0 in the worst possible case.

LS is a combinated factor taking into account the length and the steepness of the slope. According to this factor, the intensity of erosion is related to the lenght and the speed of the runoff. If the slope is longer, the volume of runoff is greater. And if the slope is steeper, the volocity of runoff is greater. These may cause more damage to the soil through erosion. For example, LS = 1.0 for a 9% slope and 22.1 m long.

C is a combined factor accounting the effects of vegetation cover and management techniques. This factor is very important to reduce the rate of soil loss. İn the worst case when there is no cocer on the soil and there is no management techniques applied, C = 1.0. In the ideal case, there is no soil loss and C would be equal to zero.

P is the physical protection factor taking into account the effects of soil conservation measures. According to previous studies carried out on soil conservation measures, physical protection factor is defined as structures or vegetation barriers spaced at intervals on a slope, as distinct from continous mulching or improved cultural techniques which come under management techniques.

According to this USLE equation the main way to reduce soil loss is to increase vegetation cover (C factor) in the forest. So intensive forest exploitation lead to intensive soil loss.

1.3.2.2.5. Water Production

According to FAO, forested watersheds and wetlands supply 75 percent of the world’s accessible fresh water for domestic, agricultural, industrial and ecological needs (FAO, 2021). About 90% of the world’s largest cities obtain significant proportions of their drinking water directly from forested watersheds. Forests act as natural water filters by minimizing soil erosion on site, reduce sediment in water bodies and trap or filter water pollutants in forest litter. Climate change is altering forests’ role in regulating water flows and influencing the availability of water resources. Climate change impacts will also be the increasing in natural catastrophes like floods, landslides, droughts, and other natural disasters that are controled by forest cover. Moreover, large scale deforestation will influence the precipitation patern in forest areas. The water provision service can be well improved to increase economic gains for the world. It is projected a deficit of 40% of global water by 2030 under RCP4.5. this means 60 billion USD to invest in order to reduce water loss (FAO, 2021). In this aim, forests have the main role in building and strengthening climate change resilience. When sustainable forest management is establish, forests contribute significantly to reduce soil erosion, risk of landslide and avalanches (FAO, 2021).

1.3.2.3. Modelling

Forests are highly complex ecosytems dominated by trees and associated vegetation growing under various physiographic, edaphic and biotic conditions. As an ecosystem, they include all the interacting populations of plants, animals, insects and mico-organisms that occupy the area plus their physical environment. In view of their inherent complexity, the word modelling can be define as the simple representation of a complex system with all it's interactions. Modelling can help to understand the whole ecosystem functioning, as well as to predict future interactions, according to internal or external factors modifications (Botkin, 1993).

1.3.2.3.1. Ecological Modelling

An ecosystem model is an abstract, usualy mathematical, respresentation of an ecological system, which is studied to better understand the real system (Hall et al., 1990). These models are studies in order to make preditions about the dynamics of the real conditions. The study of disfunctioning or inaccuracies in the model (comparing the results of the model to real conditions or empirical observations) will lead to the generation of hypothesis about possible relationship between ecological factors that are not yet known or well understood. Therefore, ecological modelling can enable the researchers to simulate large scale experiments that would be too costly or unethical to perform on real ecosystem. This also enable the researcher to simulate ecological processes over very long periods of time. As illustration, ecological modelling can be used to simulate ecological processes that take decenies or centuries in reality, and can be visualized in some minutes using a computer (Hall and Day, 1990).

1.3.2.3.2. Linear Programming

There are several optimization technics that have been developed to predict future outputs of ecological services. One of them is linear programming that is widely used to determine forest values in forest management planning. It is a powerful tool for generating an optimal solution which can enable further sensitivity analyses (Weintraub and Romero, 2006; Kaya et al., 2016; Bettinger et al., 2017). Linear programming (LP) can be defined as an optimization technics that help to solve the problem of maximizing or minimizing an ecosystem service production that is subject to linear constraints. Those constraints may be the equality or inequality in the provision of that service. Optimization problems may involve the calculation of profit and loss due to the increase or decrease of that service. For this purpose, linear programming is an important optimisation technic that help to find the appropriate solutions in order to have its highest or the lowest value (Analytics, 2017). Linear programming is the method of considering different inequalities relevant to a situation and calculating the best value that is required to be obtained in those conditions. Many assumptions are taken while using this technic: the number of constraints can be expressed in quantitative terms, the objective function and the relationship between the constrainsts should be linear in order to optimise the solution.

Many technics and programs have been developed to solve linear programming problems such as ‘the Simplex Method’ and LINGO^{TM} (Bettinger et al., 2017) and others. For the purposes of this thesis, LINGO^{TM} has been used for its abilities in forest management situation problem solving after the elaboration of mathematical equations. LINGO^{TM} allow to perfom sensitivity analysis and displaying the solution report (Bettinger et al., 2017).

Therefore, linear programming is based on three main pillars elaborated by William (1984) then Joseph and Keith (2003):

- Decision variables
- Objective equation (expressing the contribution of each variable to the desired result)
- Constraint(s)

To be more precise, it can be summarized that linear programming is an optimization technique (aiming at improving the result). It can be used to solve the problem of competition for limited resources in an exemplary manner (Bettinger et al., 2017). The solution provide is the most suitable for forest managers, who the problem of limited resources and the inability to choose an activity without the other and the difficulty to choose to work to achieve certain goal alone (Bettinger et al., 2017). As an example, forest manager may want to increase wood production, but this may increase soil loss. On the other hand, he may want to regenerate the forest, but he face the problem of water production. By using linear programming, the decision to choose between different goals can be achieve with the most efficient solution (William, 1984; Zainal and Isa., 1990; Joseph and Keith, 2003; Bettinger et al., 2017).

2. MATERIAL AND METHODS

2.1. Material

2.1.1. Location of study areas for Future Distribution and Ecosystem Services

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, modelling the distributions of species under climate change scenarios has become one of the most widely used tool to assess conservation status of a species (Margules and Augustin, 1994). Within this context, Habitat Suitability Modelling (HSM) with Maximum Entropy software has been conducted according to both current and future climate prediction under scenario RCP4.5 and RCP8.5, combining MaxEnt Java application software and Arc GIS 10.3^{TM}.

For the purpose of this thesis, Trabzon located at the Black Sea coast of the Northern East side of Turkey and Antalya located at the Mediterranean Sea coast of the South-west side of Turkey have been selected as sample regions to perform habitat suitability, based on their location in highly sensitive areas to climate change in Turkey and the facilities available to collect data for conducting this modelling technic. Since climate change will have serious impacts on forest ecosystems services in these regions as stated by Karahalil and Köse (2015), running HSM is very important in order to help forestry professionals of these regions in their decision making for the sustainable management of forests resources (Philips et al., 2006).

Furthermore, there is a two-way relationship between climate change and forest ecosystems. While the negative effects of climate change damage forest areas, forests also have functions to reduce the effects of climate change like absorbing carbon to store as biomass and cooling the earth system (Allen et al. 2010). The expected impacts of climate change on forests are as follow: more sensitivity and reaction of forests ecosystems leading to forest fires, increasing natural mortality of tree species, changing tendency of forest spreads, decreasing biomass stored in forests, natural changing of tree species composition, etc. (Tüfekçioğlu et al. 2005). This has been accessed through perceptions in 3 different countries.

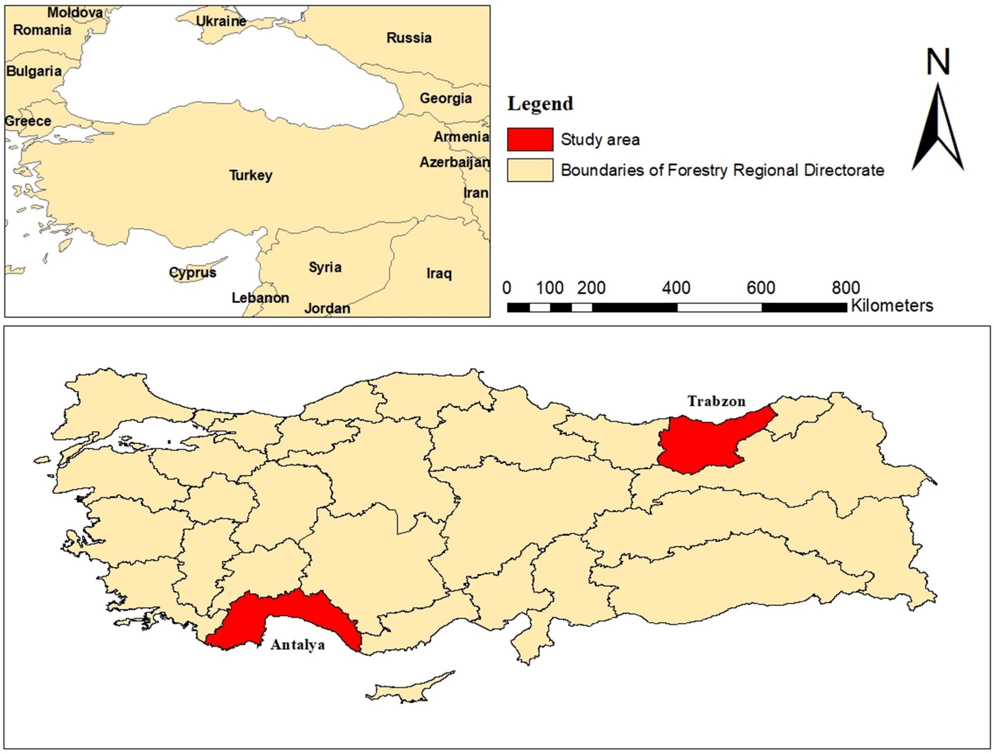


Figure 2. The spatial location of Antalya and Trabzon regional directorate of forestry

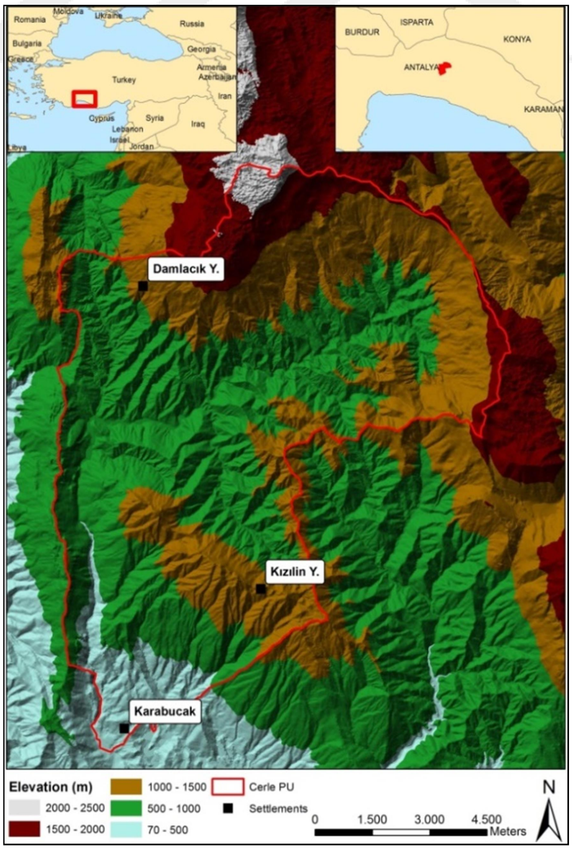


Figure 3. The spatial location of Cerle planning unit (PU)

After analysing data provided by the survey questionnaire in each country, different existing tolerant tree species have been cited by respondents in each study area. This has been the motive for performing habitat suitability modelling to produce maps showing where the suitability will increase, decrease or be stable for the selected tree species.

Trabzon and Antalya regional forests (Figure 2) have been selected to perform habitat suitability modeling, and Cerle Planning Unit (PU) located in Antalya has been selected to perform ecosystem services modeling. Cerle PU administratively works under Taşağıl State Forest Enterprise in Antalya Regional Directorate of Forestry (Figure 3). Cerle PU is 60 km far from the Antalya city. The study area has a 10,254 ha general area of which 9,222 ha is forested. Forests are dominated by pure stands of Calabrian Pine *(Pinus brutia)* and mixed stands of Calabrian Pine, Cremian Pine *(Pinus nigra)*, Juniper *(Juniperus)*, Cedar *(Cedrus libani)*, Fir *(Abies cilicica)* and Plane *(Platanus orientalis)*. According to the current forest management plan designed for the periods between 2011 and 2020, forest allocated to timber production and ecological values (old growth forests, soil conservation, fire prevention zone and forests with poor sites) are 45% and 55% respectively (GDF, 2010a). The population reaches nearly 5080 people within the planning unit. Most of the people support their lives by agriculture or working for the tourism sector. Few people work for the forestry sector's activities. Apart from Antalya and Trabzon regional forest selected to perform habitat suitability modeling, other study areas such as İstanbul has been selected to evaluate the perception of climate change by forestry professionals in Turkey (Figure 5).

2.1.2. Location of Study Areas for Climate Change Perceptions Analysis

In this study, 3 countries (Germany, Turkey and Cameroon) with very different ecological characteristics have been selected to compare the perception of climate change and adaptation strategies elaborated by forestry professionals. These sample areas have been selected based on facilities available to collect data in each country. The Black forest in Germany, Antalya, İstanbul and Trabzon regional directorate of forestry in Turkey, and the Boumba bek forest national park in Cameroon have been selected due to the researcher who is Cameroonian working on his thesis in Turkey and had an exchange program in Germany.

2.1.2.1. Location of the Black Forest in Germany

Germany is located in western and central Europe, between 47-55 °N and 5-16 °E (Figure 4). The German territory covers 357,000 km^2, consisting of 349,000 km^2 of land and 7,800 km^2 of water, with about 1/3 of the national land territory covered by forests. In Germany, the Black Forest was selected as the study area. The Black Forest is the largest contiguous forest area in Southwest Germany, established over an area of approximately 391,000 ha of forest. According to the German's second notional forest inventory, more than 172,000 ha of these forests were originally covered by *Fagus sylvatica* often in mixture with *Abies alba* in the past. But presently they are dominated by *Picea abies* (FVA, 2016).

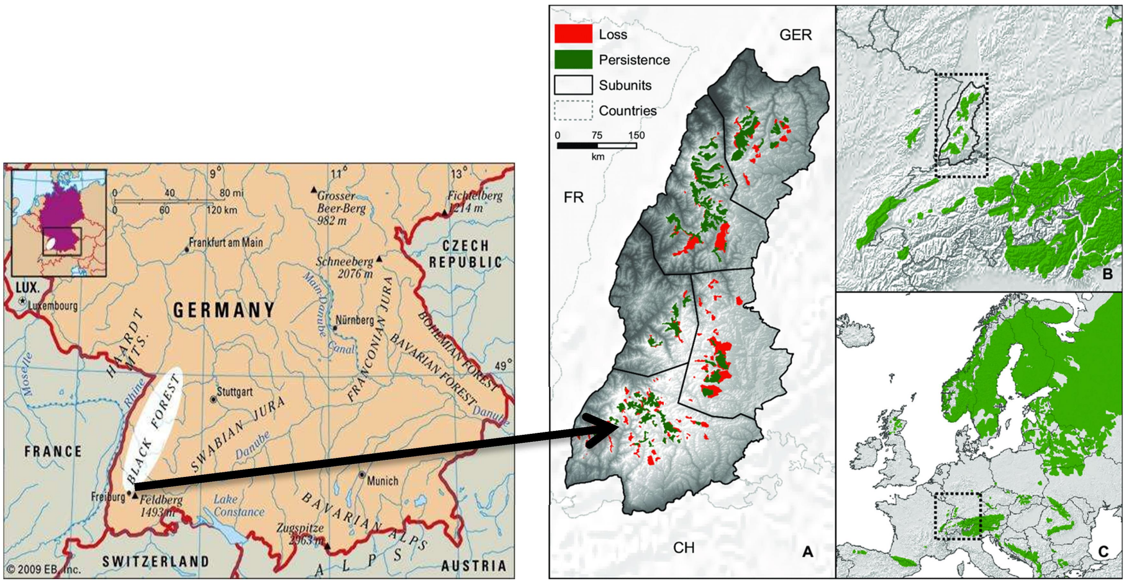


Figure 4. Location of the Black Forest in Germany (FVA, 2016)

More than 1/3 of the Black forest (66,000 ha) are pure stands with less than 10% of other tree species mixed. These are therefore highly susceptible to an expected climate change with increasing temperatures and increasing pressure of biotic and abiotic hazards natural hazards (FVA, 2016).

2.1.2.2. Location of Antalya, İstanbul and Trabzon in Turkey

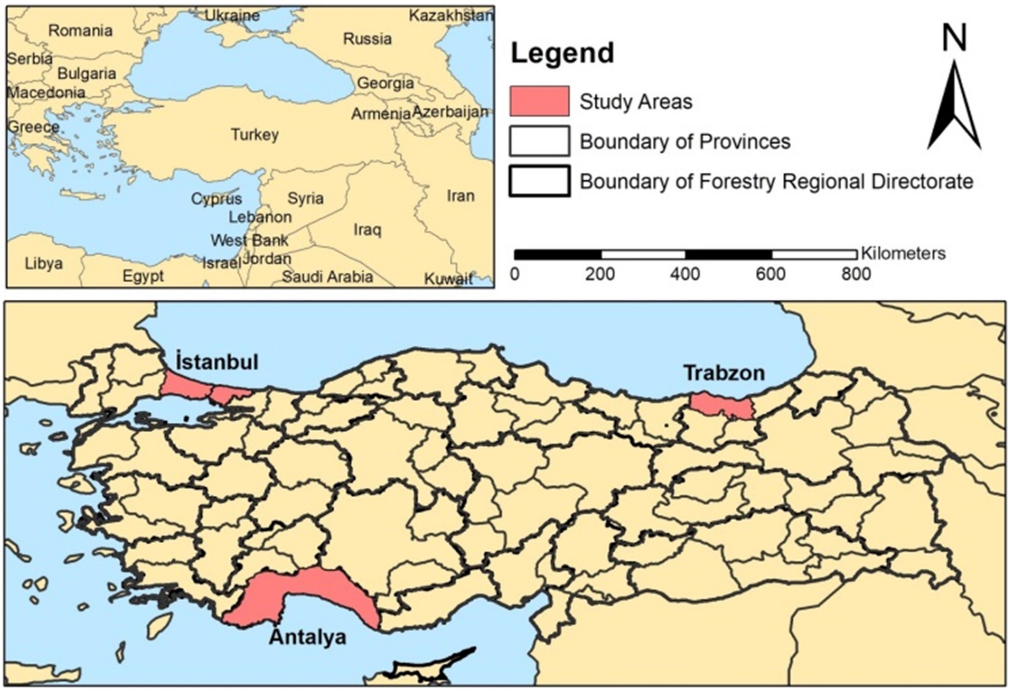


Figure 5. Location of the selected study areas in Turkey (Fosso and Karahalil, 2021)

Antalya is located in the south west side of Turkey with an altitude of 20 m, between 36° 13′–36° 34′ N latitudes and 32° 15′–32° 38′ E longitudes, covering 2,049,865 ha of forest which has general characteristics of Mediterranean climate. It is one of the city’s most vulnerable to the effects of climate change in Turkish forest with the highest frequency of forest fires and drought occurrence (Fosso and Karahalil, 2021). İstanbul is located in the north-west side of Turkey, at 41° 0' 54.4932" N latitude and 28° 58' 46.3080" E longitude, covering 1,614,786 ha of forest exposed to frequent heat waves, drought, and wind storm affecting the forest. Trabzon is located on the north-east side of Turkey at the Black Sea coast at the 41°00'18.00" north latitude and the 39°43'36.98" east longitude, covering 1,854,703 ha of forest (GDF, 2020a). Trabzon is an example of temperate climate in Turkey where climate change effects can also be perceived by the higher frequency of insect’s attacks on forest. The main tree species in Turkish forests are Oak (*Quercus sp.*), Crimean pine (*Pinus nigra* Arnold), Calibrean pine (*Pinus brutia* Ten.), Scotch pine (*Pinus sylvestris*) and Beech (*Fagus orientalis*) (GDF, 2020a). Cerle Forest PU (Figure 5) located at the north of Antalya region was used as sample forest for ecosystem services modelling due to data availability.

2.1.2.3. Location of the Boumba Bek Forest National Park in Cameroon

Cameroon is located at the hearth of the African continent between the 8 and 16°N and the 2 and 13°E. It covers 475,440 km² with 472,710 km² of land and 2,730 km² of water. Forest land cover 1/3 of the national territory, and 20 million ha of forest are protected areas. The Boumba Bek Forest N. P. has been selected as study area in Cameroon (Figure 6).

The Boumba Bek forest National Park is located between latitudes North of 2°08' to 2°58' and longitudes East from 14°43' to 15°16' in the Eastern Region of Cameroon, covering an area of approximately 238,255 ha. The national park of Boumba Bek is part of the Congo Basin forest. It is an area of dense semi-deciduous wet forests (98%) and swampy raphia forests harboring a variety of natural sub-habitats (2%) (Letouzey, 1985).

The flora of Boumba Bek is very diverse. In some places, it has large areas of monospecific forest of *Gilbertodendron dewevrei* (Letouzey, 1985). There are nearly 984 plant species in 94 different families (Ekobo, 1998). A new variety of *Lophira alata* (*Ochnaceae*) has been discovered in the region of Boumba Bek and Ndongo-Adjala. Two endemic species of lianas (*Milletia duchesnei and Milletia sp.*) have also been identified (Ekobo, 1998). Nearly 44 plant species in the area are commercially valuable species. Bark, seeds and dried fruits are exploited and marketed by the local population. These include *Irvingia gabonensis*, *Ricinodendron heudelotii*, *Tetrapleura tetrapteura*, *Gnetum africanum*, *Afromomum dalziellii*, *Cola spp*., *Baillonella toxisperma* (Ekobo, 1998). About 41 out of 131 woody plant species identified in the area are part of the traditional Baka pharmacopoeia (Fimbel et al., 2000). This rich biodiversity of natural habitats associated with an important animal biodiversity (mammals, birds, reptiles, fish and insects) are under threat of global climate change. The Boumba-Bek hydrographic system flows southward to the rivers Dja and Ngoko, two tributaries of the Congo River. It is formed by the rivers Apom and Gbwogbwo in the North, Boumba in the East, Bek in the West and in the South.

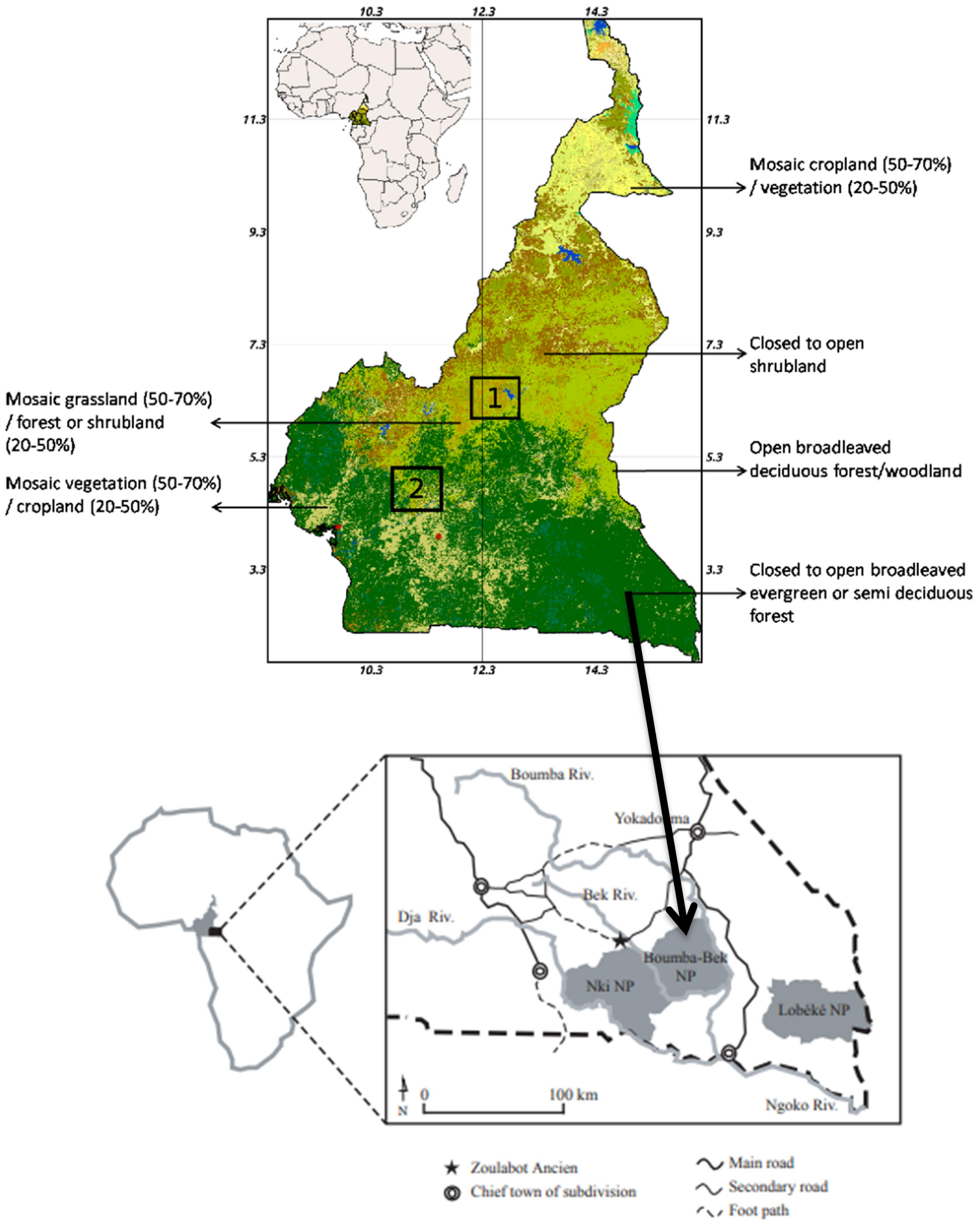


Figure 6. Location of the Boumba Bek Forest National park in Cameroon (adapted from Yasouoka, 2006)

2.2. Method

2.2.1. Habitat Suitability Modelling with MaxEnt in Trabzon and Antalya regions

2.2.1.1. Species Presence or Occurrence Data Collection and Preparation

In this study, presence or occurrence data have been collected from stand type maps of forest management plans provided by the regional directorate of forestry in Trabzon and Antalya in 2019 and 2020. The latitude and longitude giving the exact coordinates on the global positioning system of each presence points have been generated for each selected species from geo-processing, coordinate then features to points in ArcGIS 10.3^{TM}. Attribute tables of feature points generated for each selected species have been exported as table data base, then cleansed in Microsoft Excel and saved as a “CSV” file as required by MaxEnt software. A total of 7 species in Trabzon, namely: *Picea orientalis* (Oriental spruce), *Fagus orientalis* (Oriental beech), *Quercus sp.* (Oak), *Alnus glutinosa* (Alder), *Pinus sylvestris* (Scots pine), *Carpinus betulus* (Hornbeam), and *Abies nordmanniana* (Fir), then 5 species in Antalya, namely: *Pinus brutia* (Turkish red pine or Calibrean pine), *Pinus nigra* (Black pine), *Quercus sp.* (Oak), *Cedrus libanii* (Cedar), and *Abies cilicica* (Fir) were modelled to predict their potential habitat suitability using current and future predictions of environmental data.

2.2.1.2. Environmental Data Collection and Preparation

In total, 19 bioclimatic variables (Table 4) were used to identify factors with the highest influences on the distribution of selected tree species for Trabzon regional forest and for Antalya regional forest. Data downloaded from WorldClim have been clipped to the study areas using ArcGIS 10.3 software and saved under ASCII file format as required by MaxEnt. Then both presence and environmental data have been uploaded to Maxent Java application software and ran. All the environmental parameters must have the same geographical extent and projections must match with presence data coordinates.

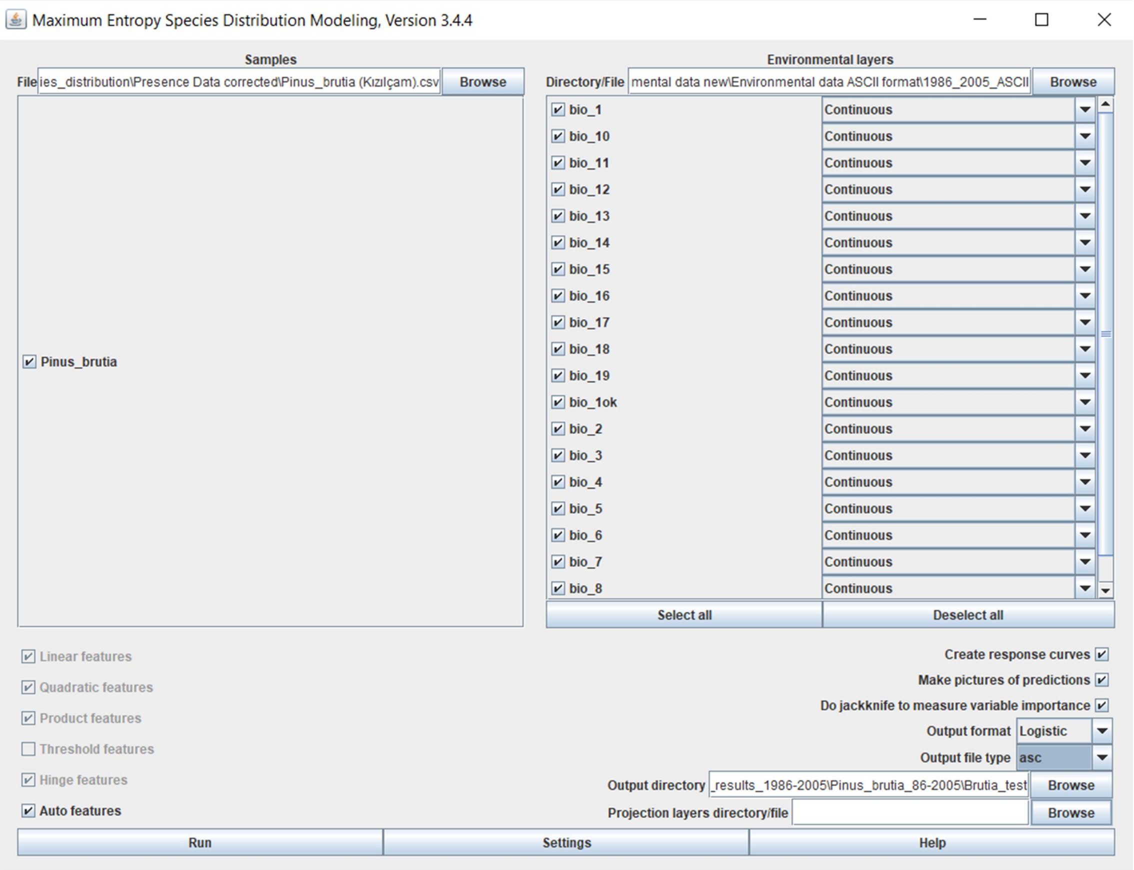
Table 4. Environmental variable downloaded from Worldclim

Bioclimatic Variables	Definitions	Unit
Bio_1	Annual Mean Temperature	°C
Bio_2	Mean Diurnal Range	°C
Bio_3	Isothermality (BIO2/BIO7) (* 100)	°C
Bio_4	Temperature Seasonality (standard deviation *100)	°C
Bio_5	Max Temperature of Warmest Month	°C
Bio_6	Min Temperature of Coldest Month	°C
Bio_7	Temperature Annual Range (BIO5-BIO6)	°C
Bio_8	Mean Temperature of Wettest Quarter	°C
Bio_9	Mean Temperature of Driest Quarter	°C
Bio_10	Mean Temperature of Warmest Quarter	°C
Bio_11	Mean Temperature of Coldest Quarter	°C
Bio_12	Annual Precipitation	mm
Bio_13	Precipitation of Wettest Month	mm
Bio_14	Precipitation of Driest Month	mm
Bio_15	Precipitation Seasonality (Coefficient of Variation)	mm
Bio_16	Precipitation of Wettest Quarter	mm
Bio_17	Precipitation of Driest Quarter	mm
Bio_18	Precipitation of Warmest Quarter	mm
Bio_19	Precipitation of Coldest Quarter	mm

2.2.1.3. Maxent Model Setting, Running, Analysis and Interpretation of Results

For many years, researchers have compared different HSMs such as generalized linear models (GLMs), classification tree analysis (CTA), artificial neural networks (ANN), genetic algorithms (GA), and maximum entropy (MAXENT) without reaching a consensus on which model(s) performs better under different conditions (Elith et al., 2006). The different approaches to model habitat suitability differ in their underlying hypotheses and how they build the multi-dimensional environmental niche of the species. Some models assume linear relationships and/or parametric stochastic distributions of the errors they make (e.g. GLM) while others can fit more complex and non-parametric relationships (e.g. general additive models (GAM), MAXENT, boosted regression trees (BRT). In general, there is no universal best model and most of the models have advantages and disadvantages. In comparative studies more flexible models like GAMs and BRTs frequently outperform other HSMs. HSMs using presence-absence data are more seriously influenced by false negatives data (Hirzel et al., 2002). Habitat suitability can be classified as: (1) habitat is unsuitable, (2) habitat is suitable but species has not colonized it yet (due to limited dispersal), (3) habitat is suitable (species is present but is not detected), and (4) habitat is highly suitable (species is present and well detected) (Hirzel et al., 2002).

Using MaxEnt requires a basic proficiency in ecology and the use of Geographic Information Systems (GIS), with an emphasis on ESRI products (i.e. ArcGIS). It is open source software downloadable. To perform a run, we need to supply a file containing presence data ("samples"), a directory with environmental variables, and an output directory (Figure 7).



Maximum Entropy Species Distribution Modeling, Version 3.4.4

Samples

File: ies_distribution\Presence Data corrected\Pinus_brutia (Kızılçam).csv

☑ Pinus_brutia

Environmental layers

Directory/File: mental data new\Environmental data ASCII format\1986_2005_ASCII

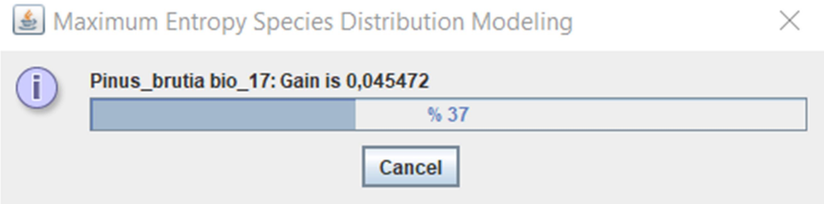
☑ bio_1	Continuous
☑ bio_10	Continuous
☑ bio_11	Continuous
☑ bio_12	Continuous
☑ bio_13	Continuous
☑ bio_14	Continuous
☑ bio_15	Continuous
☑ bio_16	Continuous
☑ bio_17	Continuous
☑ bio_18	Continuous
☑ bio_19	Continuous
☑ bio_1ok	Continuous
☑ bio_2	Continuous
☑ bio_3	Continuous
☑ bio_4	Continuous
☑ bio_5	Continuous
☑ bio_6	Continuous
☑ bio_7	Continuous
☑ bio_8	Continuous

☑ Linear features
☑ Quadratic features
☑ Product features
☐ Threshold features
☑ Hinge features
☑ Auto features

Create response curves ☑
Make pictures of predictions ☑
Do jackknife to measure variable importance ☑
Output format: Logistic
Output file type: asc
Output directory: _results_1986-2005\Pinus_brutia_86-2005\Brutia_test
Projection layers directory/file:

Figure 7. General outlook for the Maxent software

There is one species in the sample file, which is why one species appears in the panel. There can be multiple species in the same samples file, in which case more species would appear in the panel, along with one species. Coordinate systems other than latitude and longitude can be used provided that the samples file and environmental layers use the same coordinate system. All of our variables are continous variable describing potential climatic classes. The categorical variables are not presented in our table. After the environmental layers are loaded and some initialization is done, progress towards training of the MaxEnt model is shown like in Figure 8. The software runs species and analyse environmental parameters one after one.



Pinus_brutia bio_17: Gain is 0,045472

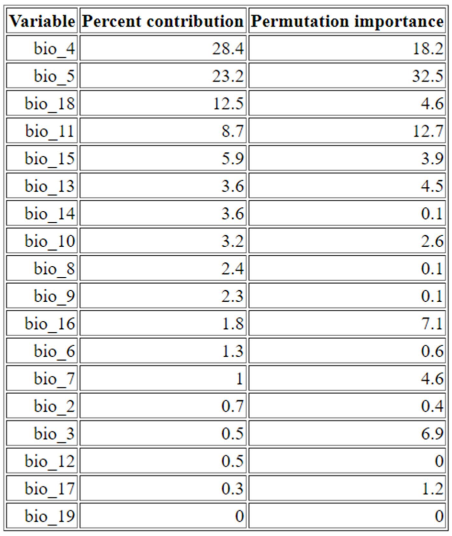
Figure 8. Progress over MaxEnt running

The run produces multiple output files. To see what other (more interesting) output there can be in an "html" file, we will turn on a couple of options and rerun the model (Elith et al., 2006).

Prediction: The file pointed to is an image file (.png) that we can just click on or open in most image processing software. If you want to copy these images, or want to open them with other software, you will find the .png files in the directory called "plots" that has been created as an output during the run.

Output: MaxEnt supports four output formats for model values: raw, cumulative, logistic and cloglog. First, the raw output is just the MaxEnt exponential model itself. Second, the cumulative value corresponding to a raw value of r (coefficient of correlation) with the percentage of the Maxent distribution where raw value is at maximum r value. Cumulative output is best interpreted in terms of predicted omission rate. Third, if c is the exponential of the entropy for Maxent distribution, then the logistic value corresponding to a raw value of r is c*r/ (1+c*r). This is a logistic function, because the raw value is an exponential function of the environmental variables. The cloglog value correspond to a raw value of r = 1-exp (-c*r).

The four output formats are all monotonically related, but they are scaled differently, and have different interpretations. Then it is necessary to run statistical analysis to find the predictions of each species distribution or habitat suitability. We can keep track of which environmental variables are making the greatest contribution to the model (Figure 9).



Variable	Percent contribution	Permutation importance
bio_4	28.4	18.2
bio_5	23.2	32.5
bio_18	12.5	4.6
bio_11	8.7	12.7
bio_15	5.9	3.9
bio_13	3.6	4.5
bio_14	3.6	0.1
bio_10	3.2	2.6
bio_8	2.4	0.1
bio_9	2.3	0.1
bio_16	1.8	7.1
bio_6	1.3	0.6
bio_7	1	4.6
bio_2	0.7	0.4
bio_3	0.5	6.9
bio_12	0.5	0
bio_17	0.3	1.2
bio_19	0	0

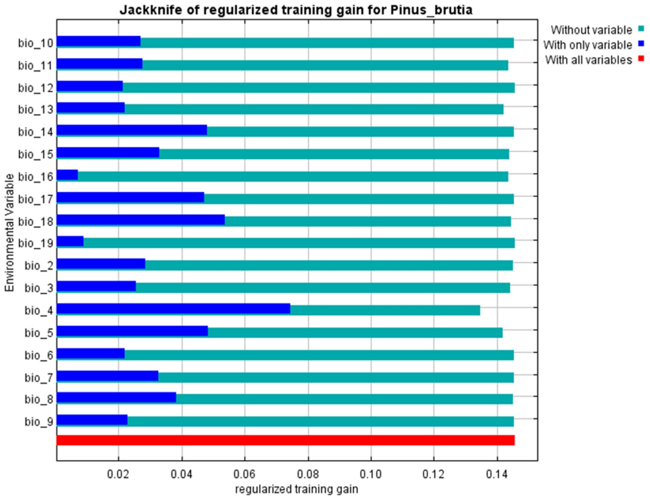


Figure 9**.** Analysis of variable contributions

Within this context, some appropriated tree species have been modelled using MaxEnt to find their habitat suitability. MaxEnt also help in tracking which environmental variables are making the greatest contribution to the model. HSM aim at defining, for any chosen species, the 'envelope' that best describes its spatial range limits by identifying those environmental variables that limit its distribution. They are built by relating current species' distributions to current environments. Future species' biogeographical ranges are modelled by projecting these relationships to selected environmental change scenarios. Note that these environmental variables can be anything important for the species of interest. Environmental variables can exert direct or indirect effects on species and are optimally chosen to reflect the three main types of influences on the species: limiting factors, defined as factors controlling species' eco-physiology (e.g. minimum winter temperature) or appearance (e.g. competition and facilitation), disturbances, defined as all types of perturbations affecting environmental systems (e.g. fire frequency), and resources, defined as all materials that can be assimilated by organisms (e.g. availability of food, seeds or insects).

The software will be run for several tree species one by one and the obtained output maps will be overlaid to see the future mixture options. Predictive performance of the model is provided by species response curves produced from model output. Therefore model calibration was divided into a training set (90% of the total occurrence data) and test (10% of the total occurrence data) for design assessment.

The Area under the Curve of Receiver Operating Characteristic (AUC of ROC) is a measure of model performance that range between 0 to 1 (Phillips, 2006). The AUC is an autonomous threshold index capable of evaluating the ability of the model to discriminate presence from absence efficiently. AUC < 0.5 describes models that have less than chance and rarely occur in reality. An AUC of 0.5 is a pure guess. Model performance is classified as failing (0.5 to 0.6), bad (0.6 to 0.7), reasonable (0.7 to 0.8), good (0.8 to 0.9), or great (0.9 to 1) (Swet, 1988).

The jackknife test was used to assess the dominant environmental variables that determined the species potential distribution (Yang et al., 2013). Species response curves were generated to investigate the relationship between target species habitat suitability and environmental factors. The prospective species distribution chart generated had values ranging from 0 to 1. These values have been grouped into four groups: high potential (> 0.6), good potential (0.4 to 0.6), moderate potential (0.2 to 0.4), and low potential (< 0.2) (Yang et al., 2013).

Maxent provides results in a folder containing a raster dataset JPEG image corresponding to the picture of prediction for each species, an ASCII file that has been converted into raster and used in ArcGIS for further analysis, Response curves and Jackknife variable importance picture as well as html extension file presenting the summary of the analysis and providing more details on all results.

2.2.1.4. Determining Future Stand Type

The ASCII file of each maxent results have been transferred to ArcGIS 10.3^{TM} and converted to raster, multiply times 100, round down, copy raster dataset, build raster attribute table, convert raster to polygon vector, dissolve by grid code, clip the boundaries, then classify the pixel value generated automatically into a gradient of habitat suitability (0 to 25 = not suitable), (25 to 50 = moderately suitable), (50 to 75 = suitable) and (75 to 100= highly suitable). Then corresponding number have been attributed to each habitat suitability gradient level: (1 = not suitable), (2 = moderately suitable), (3 = suitable) and (4= highly suitable).

In order to generate the real situation of the forest, the attribute table generated from each species' results have been intersected to determine the composition of the stand type in terms of habitat suitability. Species having the highest gradient of suitability have been considered to be dominant on each stand, and in case where two species have the same highest gradient of suitability, they are considered as co-dominants. There are stand types where 3 or 4 species were co-dominants. These have been named mixed forest in the suitability maps. The stands having the lowest gradient of suitability have been considered as not suitable areas. The consequences for certain species will differ by region and the extent of climatic change: some species will respond positively with increased development rates, an increased chance of survival and reproductive potential; for other species, however, negative effects like decreased growth rate and reduced fecundity will be possible. We have been able to successfully predict the distribution of different tree species in the selected study areas in Trabzon and Antalya based on the relative likelihood of all environmental variables in the model over the range of those regions (Guillera-Arroita et al., 2014).

2.2.2. Estimating Future Ecosystem Services in Cerle Forest Planning Unit

In order to evaluate the changes in terms of forest ecological services related to the predicted changes of habitat suitability for the selected tree species, Cerle PU has been selected as a sample in the Antalya Regional Directorate of Forestry. A total of 109 stand types selected in the south part of Cerle PU have been identified for the development of equations using linear programing modelling method. Climate change adapted tree species as well as non-adapted species have been used for forest ecosystem services change analysis, performed with LINGO^{TM}. The change maps based on habitat suitability predictions provided the sides of the regional forest where the change will happen and those where there will be no change related to climate change scenarios.

To achieve the desired objectives of the use of linear programming technique, forest values were tried to associate with stand structure. Several equations generated by previously conducted studies were used (Karahalil, 2003; Karahalil, 2009). The equations used were based on the following information provided by the forest management plan's tables of each stand type. They provided information on the age of the stand, site quality, volume and increment. These information were collected and filled in Excel matrixes for each stand type. As well a simulation of the objective function in each stand type was operated.

For this case study, 2725 (25*109) coefficients for each ecosystem service and 13625 total coefficients for the 4 ecosystem services were generated for each scenario. Carbon storage formulation necessitates five other coefficients namely; the above ground, below ground, dead wood, soil and litter carbon, to calculate the stand type carbon, meaning that another 13625 coefficients calculated for carbon storage. The scenario where there is no effect of climate change was considered over 50 years planning horizon (5 periods of 10 years). This scenario has been considered as the normal scenario. Two other scenarios where climate change impact will affect the forest and forestry professionals' plant same species as in normal scenario were also considered under RCP4.5 and RCP8.5. Then two other scenarios where adapted tree species were planted under climate change impacts for RCP4.5 and RCP8.5 were also considered. This help to see the change in terms of forest ecosystem services in a situation where forest managers will take no action for adaptation compare to a situation where they will take action for adaptation.

2.2.2.1. Determining Timber Production

The minimum age for harvesting was fixed at 50 years old for each stand since almost all of the stands are *Calibrian pine* stands. Regeneration was operated directly after final harvesting and the yield table of each specie was used to record the volume corresponding to each age class, and then maintenance cutting was considered to be 10% of the volume harvested for each period. The yield table of *Pinus brutia* was collected from Alemdag, (1962); yield table of *Pinus nigra* was collected from Kalıpsız, (1963); yield table of *Quercus spp* was collected from Eraslan, (1954); and the yield table of *Cedrus libani* was collected from Evcimen, (1963). All of them were professors at universities.

According to the Table 5 and table 6 below, the possibility to harvest at the first period is 200 m^3. After harvesting at the first period, immediately the regeneration takes place and the yield table is used to provide the volume at each age class. The standing volume at the second period is equal to the volume at the first period + increment – maintenance that is 10% of the harvested volume of the precedent period. We assume that the increment would not change in different periods in order to avoid trouble in our simulation since degraded stands have no age class and sometimes growing stocks decline and they are not proportional to the yield table. Then using coefficients generated in Table 5, Equations were generated with X_i as the stand number and P_j as the period (Table 6).

Table 5. Example of harvest coefficient matrix in the stand Id45

Id45	Age=70	Site index=III	Stand type Çzcd2	Volume=199.20 Increment=4.64	Area=8.0
45	1	2	3	4	5
1	200	20	20	20	20
2	1.0	226	23	23	23
3	6.0	1.0	249	25	25
4	10.0	6.0	1.0	270	27
5	12.0	10.0	6.0	1.0	289

Table 6. Example of timber production matrix in stand Id45

200X45P1+	20X45P2+	20X45P3+	20X45P4+	20X45P5+
1X45P1+	226X45P2+	23X45P3+	23X45P4+	23X45P5+
6X45P1+	1X45P2+	249X45P3+	25X45P4+	25X45P5+
10X45P1+	6X45P2+	1X45P3+	270X45P4+	27X45P5+
12X45P1+	10X45P2+	6X45P3+	1X45P4+	289X45P5+

Based on those coefficients, equations were elaborated for the 109 selected stand types. Stand types which age was less than 50 records a 0 coefficient accordingly up to the minimum harvesting age. As well, site quality affected the coefficients. Degraded stand types (BÇz) have been regenerated and open land (OT) stand type areas have been afforested thus recorded the coefficient of the growing stock for each species.

2.2.2.2. Determining Standing Volume

For standing volume coefficients, the same yield tables of each specie provided by the General Directorate of Forestry in Turkey were used to produce informations. For each stand type, the corresponding volume and increment was provided by forest management plan’s stand type tables. Growing stock coefficients after regeneration for each age class were provided by yield tables, while maintance was considered as the same as standing volume for each period (Table 7) and equations (Table 8).

Table 7. Example of standing volume coefficients for stand Id45

Id45	Age=70	Site index=III	Stand type Çzcd2	Volume=199.20 Increment=4.64	Area=8.0
45	1	2	3	4	5
1	0	200	200	200	200
2	5.0	0	226	226	226
3	60.0	5.0	0	249	249
4	97.0	60.0	5.0	0	270
5	121.0	97.0	60.0	5.0	0

Table 8. Example of linear matrixes for standing volume equation in stand Id45

0X45P1+	200X45P2+	200X45P3+	200X45P4+	200X45P5+
5X45P1+	0X45P2+	226X45P3+	226X45P4+	226X45P5+
60X45P1+	5X45P2+	0X45P3+	249X45P4+	249X45P5+
97X45P1+	60X45P2+	5X45P3+	0X45P4+	270X45P5+
121X45P1+	97X45P2+	60X45P3+	5X45P4+	0X45P5+

2.2.2.3. Determining Carbon Stock

Carbon stock coefficients were calculated based on previous studies carried out by Tolunay, (2011). The coefficient of carbon factor for each species provided was used as presented in Table 9.

Table 9. Example of carbon stock calculation based on Tolunay, (2011) formulation

Id45	Age=70	Site index=III	Stand type Çzcd2	Volume=199.20 Increment=4.64	Area=8.0
45	1	2	3	4	5
1	84.0	156.2	156.2	156.2	156.2
2	85.8	84.0	165.6	165.6	165.6
3	105.7	85.8	84.0	173.9	173.9
4	119.0	105.7	85.8	84.0	181.4
5	127.7	119.0	105.7	85.8	84.0

Total Carbon stock = above ground biomass + below ground biomass + dead wood + litter + soil carbon (Tolunay, 2011).

The equations provided by Tolunay, 2011 have been used as follow:

Above ground biomass = V*WD*BEF*CF (Eq. 1)

Where:

V is the growing stock volume (m^3/ha),
WD is the wood density,
BEF is the biomass extension factor and
CF is the carbon factor.
Below ground biomass = above ground biomass * root to shoot factor
Dead wood is 1% of the growing stock calculated with the formula:

Dead wood = V*WD*CF* 0,01 (Eq. 2)

Litter and soil coefficients have been collected from Tolunay, 2011.
For the stand type Id45; litter coefficient = 7.46 and soil coefficient = 76.56.

2.2.2.4. Determining Soil Loss

To calculate the amount of soil loss for the stands, the formula developed by Karahalil (2003) based on Universal Soil Loss Equation (USLE) was used:

$$\ln SL = 2.553079 - 0.065*BA \quad \text{with } (R^2 = 0.67) \qquad \text{(Eq. 3)}$$

Where;

ln = Natural logarithm
SL = Approximate soil loss (tonnes/ha/year)
BA = Basal area (m^2/ha)
Due to the absence of direct values of the basal area, the (dbh) to obtain (BA) was used.
To calculate basal area (Equation 4) was used:

BA= (Pi/4)*dbh^2 (Eq. 4)

Where;
BA= Basal area (m^2/ha)
Pi= returns the value of Pi = 3.14
dbh= diameter at breast height (m)
The soil loss matrix for stand 45 is given in Table 10 bellow:

Table 10. Example of soil loss coefficients for the stand Id45

Id45	Age=70	Site index=III	Stand type Çzcd2	Volume=199.20 Increment=4.64	Area=8.0
45	1	2	3	4	5
1	12,8	4,6	4,6	4,6	4,6
2	8,4	12,8	4,2	4,2	4,2
3	3,8	8,4	12,8	3,8	3,8
4	2,9	3,8	8,4	12,8	3,4
5	2,6	2,9	3,8	8,4	12,8

Here in Table 10, for example, when the stand was harvested specifically in the period 1, the amount of soil loss was 12.836 tonnes/ha/year, and when the final harvest was done in period 5, the amount of soil loss was 12.843 tonnes/ha/year.

2.2.2.5. Determining Water Production

In order to estimate the amount of water production, Equation (5) developed by Karahalil (2009) was used:

$$\ln WP = 8.7493 - 0.0151 * dg \quad (R^2 = 0.22) \qquad \text{(Eq. 5)}$$

Where; WP = Water production value (m^3/ha/year)
dg = dbh (mean diameter at breast height) (cm)

The water production matrix for stand type Id45 is given in the table below. Water production values were determined in the same way as soil loss values, but using water production equation (Table 11).

Table 11**.** Example of water production coefficient for stand Id45

Id45	Age=70	Site index=III	Stand type Çzcd2	Volume=199.20 Increment=4.64	Area=8.0
45	1	2	3	4	5
1	6305,3	4362,8	4362,8	4362,8	4362,8
2	5892,0	6305,3	4157,0	4157,0	4157,0
3	5430,6	5892,0	6305,3	3984,9	3984,9
4	5414,3	5430,6	5892,0	6305,3	3848,9
5	5127,8	5414,3	5430,6	5892,0	6305,3

In Table 11, for example, when the stand was harvested in the period 1, the amount of water production was 6303,4 m^3/ha/year, and when the final harvest was done in period 5, the amount of water production was 6305,3 m^3/ha/year.

2.2.2.6. General Structure of the Linear Model

To develop linear programming, ‘‘Model I’’ approach was used (Keleş et al., 2005; Karahalil et al., 2009; Bettinger et al., 2017, Hagr, 2019). Based on previous assumptions, subsequent equations were used to elaborate model objective functions:

2.2.2.7. Objectives Fonctions and Constraints

The objective functions of two different forest values was selected. Zmax = TH on one side and Zmin = TSL on the other side with TH >=300000 m^3 fixed for Zmin.

Total Harvest (TH)

$$\sum_{i=1}^{m}\sum_{j=1}^{p} Hij * Xij - TH = 0 \qquad (Eq.\ 6)$$

m = 109 (standtype No.)
p = 5 (period No.)

Total Standing Volume (TSV)

$$\sum_{i=1}^{m}\sum_{j=1}^{p} SVij * Xij - TSV = 0 \qquad (Eq.\ 7)$$

m = 109 (standtype No.)
p = 5 (period No.)

Total Carbon Storage (TCD)

$$\sum_{i=1}^{m}\sum_{j=1}^{p} CDij * Xij - TCD = 0 \qquad (Eq.\ 8)$$

m = 109 (standtype No.)
p = 5 (period No.)

Total Soil Loss (TSL)

$$\sum_{i=1}^{m}\sum_{j=1}^{p} SLij * Xij - TSL = 0$$

m = 109 (standtype No.) (Eq. 9)

p = 5 (period No.)

Total Water Production (TWP)

$$\sum_{i=1}^{m}\sum_{j=1}^{p} WPij * Xij - TWP = 0$$

m = 109 (standtype No.) (Eq. 10)

p = 5 (period No.)

Definition of Regeneration Area (RA)

$$\sum_{i=1}^{m}\sum_{j=1}^{p} Xij - TRA = 0$$

m = 109 (standtype No.) (Eq. 11)

TRA = 2136.2 ha

Definition of Afforestation Area (AA)

$$\sum_{k=105}^{m}\sum_{j=1}^{p} Xkj - TAA = 0$$

m = 109 (standtype No.) (Eq. 12)

TAA = 4.3 ha

Area constraint

$$for\ \forall i \sum_{j=1}^{p} Xij \le TA$$

i = 1 to 109 (standtype No.) (Eq. 13)

TH >=300000 m^3 fixed for Zmin (Eq. 14)

$$\sum_{i=1}^{m}\sum_{j=1}^{p} Xij \geq 300000\ m^3 \qquad m = 109 \text{ (standtype No.)} \quad p = 5 \text{ (period No.)} \qquad \text{(Eq. 14)}$$

Even flow constraint from one period to another, the difference should be 10%.

$$TH_j - (1\text{-}y)\ TH_{j+1} > 0 \text{ and } TH_j - (1+y)\ TH_{j+1} < 0 \text{ with } y = 10\% \qquad \text{(Eq. 15)}$$

Regeneration flow constraint

$$TRA_j - (1\text{-}y)\ TRA_{j+1} > 0 \text{ and } TRA_j - (1+y)\ TRA_{j+1} < 0 \text{ with } y = 10\% \qquad \text{(Eq. 16)}$$

Afforestation flow constraint (Eq. 17)

$$TAA_j - (1\text{-}y)\ TAA_{j+1} > 0 \text{ and } TAA_j - (1+y)\ TAA_{j+1} < 0 \text{ with } y = 10\% \qquad \text{(Eq. 17)}$$

Positive constraint

$$X_i >= 0 \qquad \text{(Eq. 18)}$$

Where;

TH: Total timber production at the end of the planning horizon (m^3)

TSV: Total standing volume at the end of the planning horizon (m^3)

TCD: Total Carbon deposit at the end of the planning horizon (tonnes)

TSL: Total soil loss at the end of the planning horizon (tonnes)

TWP: Total water production at the end of the planning horizon (m^3)

X_{ij}: Harvested area of standtype i, under sylvicultural treatment option j (ha);

TA: Total area of the standtype (ha)

TRA: Total regeneration Area (ha)

TAA: Total afforestation area (ha)

i: Standtype number (from 1 to 109)

j: Period of silvicultural treatment options of 10 years each (j =1 to 5)

k: the starting number of bare land stands. (105 to 109)

Hij: Coefficient of harvesting in standtype i under sylvicultural treatment j

SVij: Coefficient of standing volume in standtype i under sylvicultural treatment j

CDij: Coefficient of carbon storage in standtype i under sylvicultural treatment

SLij: Coefficient of soil loss in standtype i under sylvicultural treatment j

WPij: Coefficient of water production in standtype i under sylvicultural treatment j

2.2.2.8. Developing Alternatives

To help develop the model that would facilitate forest management, 10 alternative planning strategies have been elaborated with different characteristics and solved (LINGO, 2006). Five of the strategies which are to maximize the production of timber and five others are to minimize soil loss (Table 12). According to climate change scenarios, five possibilities have been implemented:

Table 12. List of strategies for Lingo model

Strategy	Objective function	Constraints	Scenario
STR1	Max TH	Even flow harvest (10%) +afforestation (10%) +regeneration (10%)	Normal
STR2	Min TSL	Even flow harvest (10%) +afforestation(10%) + regeneration (10%) TH>300,000	Normal
STR3	Max TH	Even flow harvest (10%) +afforestation (10%) + regeneration (10%)	Non-adapted 4.5
STR4	Min TSL	Even flow harvest (10%) +afforestation (10%) + regeneration (10%) TH>300,000	Non-adapted 4.5
STR5	Max TH	Even flow harvest (10%) +afforestation (10%) + regeneration (10%)	Adapted 4.5
STR6	Min TSL	Even flow harvest (10%) +afforestation (10%) +regeneration (10%), TH>300,000	Adapted 4.5
STR7	Max TH	Even flow harvest (10%) +afforestation (10%) + regeneration (10%)	Non-adapted 8.5
STR8	Min TSL	Even flow harvest (10%) +afforestation (10%) + regeneration (10%) TH>300,000	Non-adapted 8.5
STR9	Max TH	Even flow harvest (10%) +afforestation (10%) + regeneration (10%)	Adapted 8.5
STR10	Min TSL	Even flow harvest (10%) +afforestation (10%) + regeneration (10%) TH>300,000	Adapted 8.5

Note: STR: Strategies, TH: Total of timber production (allowable cut) (m^3), TSL: Total soil loss at the end of the planning horizon (tonnes).

Normal scenario was consider as if there is no influence of climate change on Cerle PU all over the planning horizon, so the same tree species are planted and the growth is normal.

Non-adapted 4.5 scenario was considered as if there is the influence of climate change under the RCP4.5 scenario, but the same tree species are planted in each stand type without thinking if they are adapted or not. Non-adapted 8.5 scenario was consider as if there is the influence of climate change under the RCP8.5 scenario, but the same tree species are planted in each stand type without thinking if they are adapted or not.

Adapted 4.5 scenario was considered as if there is the influence of climate change under the RCP4.5 scenario, and adapted tree species identified are planted in vulnerable stand types. Adapted 8.5 scenario was consider as if there is the influence of climate change under the RCP8.5 scenario, and adapted tree species identified are planted in vulnerable stand types.

These strategies are formulated based on the objective of maximizing timber production and minimizing soil loss under even flow harverst of 10%, afforestation flow of 10% and regeneration flow of 10% constraint between the periods, with a maximum or minimum harvest of 300 thousand m^3 of wood for the case of minimizing total soil loss, according to normal, non-adapted and adapted to climate change scenarios. This simulation help to produce clear results to identify if climate change will affect quatitatively and qualitatively the production of forest ecosystem services in the future. Thus it is important to investigate if forestry professionals in Turkey and in other selected countries in the world are planting adapted trees in their forests to adapt to climate change.

2.2.3. Setting up and Administration of the Survey Questionnaire

The survey questionnaire method has been used to collect data on forestry professionals' perception on climate change and to access their understanding and actions elaborated as adaptation strategy. The questionnaire presented in annex 1, was formulated in English and translated in German for the respondents in Germany, in Turkish for respondents in Turkey, and in French for some French speaking respondents in Cameroon. In each country, respondents were randomly selected from the contact person in the corresponding forest institution. Each respondent received one questionnaire of 20 questions with multiple choice answers using basically the Likert scale structure, asking progressively their professional responsibility background, their opinion about climate change, their perception on climate change impacts on forest, their reaction or adaptation strategy elaborated and their willingness to change the forest structure and composition for future adaptation.

The questionnaire was divided into 5 sections. The first section collected personal information, such as their socio-demographic and forest professional characteristics. In the second section, a series of questions was asking their perceptions about climate change signs, their experience of the impacts of climate change on forests and their thinking about the risk of climate change impacts on their forest. The risk perception was measured on a five-point scale, ranging from ‘absolutely yes’ to ‘absolutely no’. In the third part, it was asked whether respondents had observed any evidence of climate change on their forests. The fourth part focused on the reaction of forestry professionals assessing whether they had reactions or made changes to their management practices based on climate change. Here, respondents were presented a list of potential measures used to adapt to climate change (Lindner et al., 2008; FAO, 2013) and they were asked to choose all those that they had carried out in their forests. The last part of the questionnaire asked about adaptation strategy and the willingness to change the forest structure and composition for adaptation to future climate conditions and their justification.

To make sure that the survey was representative, it was essential to have a large number of randomly selected participants. The equation (Eq. 16) was used for a 95% confidence level, meaning that there is only a 5% chance that the sample results differ from the true population average (Laar and Akça, 2007):

$$n = \frac{N * t^2 * p * q}{N * m^2 + t^2 * p * q} \qquad \text{(Eq. 19)}$$

Where:
N = community size,
t = confidence coefficient, t=95%
m = error percentage, m=0.05 or 5%
p, q = probabilities of engaging and not engaging in data collection activities.

A combination of directs administration of questionnaires to respondents and online survey was used because of the spread of data collection, anonymity and ability to reach a large and diverse population at low cost (Reips, 2002). A drawback of online surveys lies in the potential lack of representativeness (Evans and Mathur, 2005), excluding from the survey those who do not have access to and ability to use the Internet. Nevertheless, within the forest sector, it has become common practice for forestry professionals to communicate with their members through for example emails or training sessions, which are therefore used to this type of interaction (Blennow et al., 2012; Seidl et al., 2016, Silva et al., 2016). The respondents were encouraged to forward the questionnaire to colleagues, creating a snowball effect (Goodman, 1961).

The number of people working as foresters at the regional directorate of forestry was 230 in Antalya, 178 in İstanbul and 142 in Trabzon respectively. Then according to the formula given in Eq. 14, the sample size of respondents in each city must be at least 52 for Antalya, 40 for İstanbul and 32 for Trabzon. In order to minimize the effect of missing data, the questionnaire was distributed to at least 100 forestry professionals in each forestry administration, randomly selected and voluntarily respondents. In the three selected forest areas in Turkey, a total of 279 respondents have properly completed the questionnaire without missing in Turkey. This is above the minimum sample size targeted of 124 respondents. Using the same formula, 221 valid respondents have been recorded in Germany for questionnaires distributed around the Black forest, and 130 valid respondents in Cameroon that was largely over the minimum sized of expected responses that was 100 for each country. Data collection period was from March 2018 to September 2019 in the selected countries.

Collected data have been codified and entered in Microsoft Excel software, then uploaded in the Statistical Package for Social Science (SPSS 22.0) software and analysed using the descriptive statistics and other statistical methods. Descriptive statistics were used to summarize the characteristics of the respondents, then a Chi square and a correlation test was applied to examine the relationships among different categories of respondents (Kosmidis, 2013) and relation between the perceptions of climate change correlated with the willingness to undertake some forestry adaptation and mitigation practices (Lenart and Jones, 2014). The results were compared between the countries where the same questionnaire was used to collect data (Germany, Turkey and Cameroon).

Further information have been collected using scientific articles and administrative documents at hand in each country, scientific journals or printed papers and documents, internet documents, and other sources of information like personal contacts with experts in each country working on related topic, and who provided useful document like paper to read, books, or other sources where some data could be useful for this study. understanding future effects of climate change on forest and anticipating on silvicutural operations to help forest to produce its goods and services sustainably is the main concept of this study.

2.2.4. Conceptual Framework of the Study Approach

The conceptual framework of this thesis is presented im Figure 10.

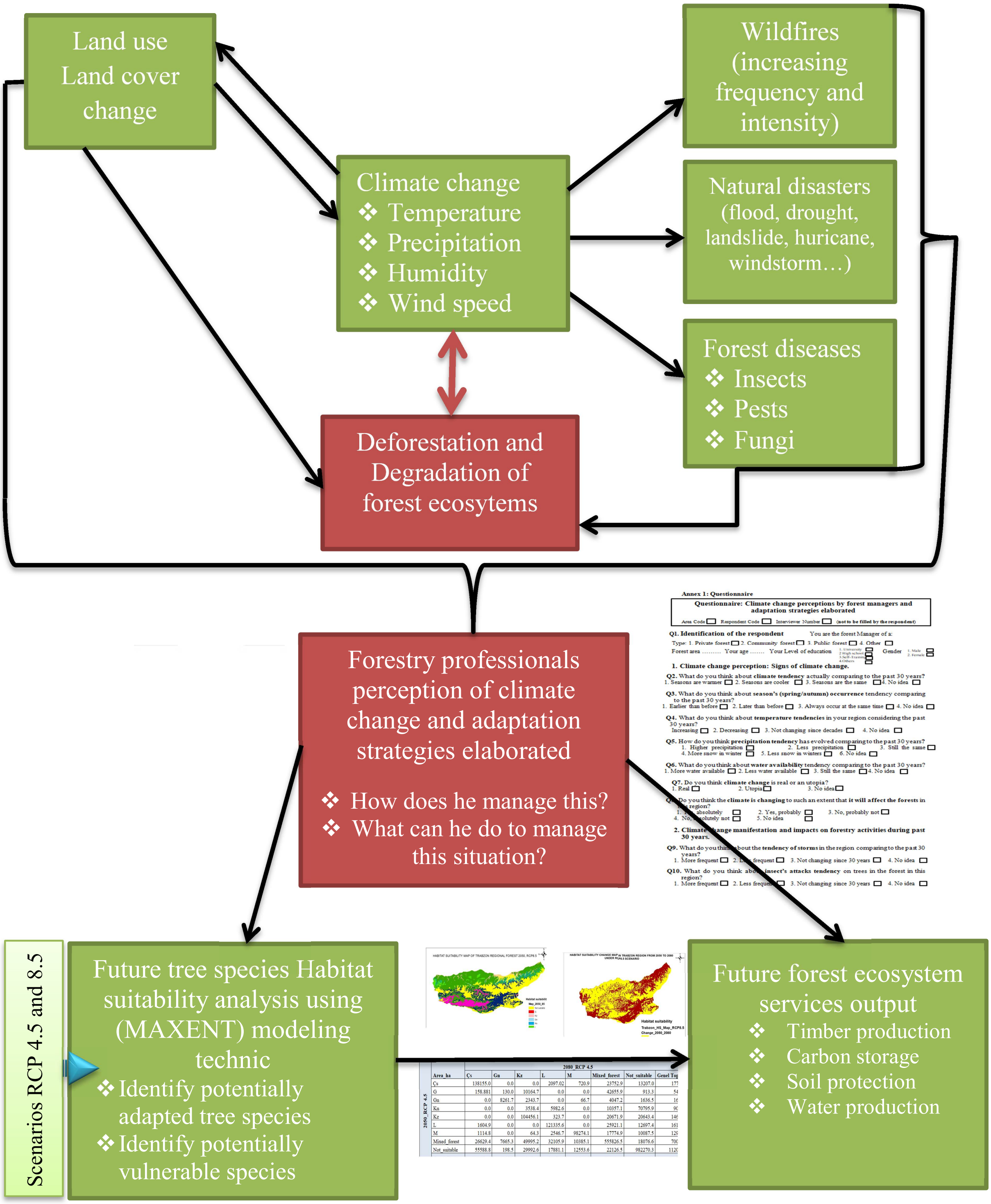


Figure 10. Conceptual framework of the integration of climate change to forest management

It is based on the principle that climate change will affect sustainably forest ecosystems in the world by increasing wild fire occurrences, natural desasters such as flood, drought, landslide, huricanes and windstorms. This will cause an increasing forest deseases with the spread of insects, pests and fungi in forest areas and decreasing forest capabilities to produce ecological services.

Forest ecological services sustainability strategy can be afford by designing good and sustainable objectives based on habitat suitability prediction, and other tools which can favor afforestation, reforestation and forest conservation for identified adapted tree species as well as identified higher vulnerable and risky species. Furthermore, performing modelling to determine the change in forest ecosystem services using modelling can help forestry professionals to decide on which objective to implement in their management activities in order to help forest to adapt to the changing climate conditions (Figure 10). Furthermore, forest laws and policies should also maintain the land use and land cover in forested areas to avoid deforestation and degradation of forest ecosystem due to the increasing presure of demography, agriculture, urbanisation, demand in energy and infrastructures as well as the increasing climate change effects on forests. The perception of forestry professionals on climate change and adaptation stragy elaborated is also useful to analyse in order to determine the level of preparation of forestry professionals to face climate change effects on their forests. (Figure 10).

In order to integrate the influence of climate change in forest management plans and practices, forest managers should also elaborate a fire management strategy, an insect control strategy and a forest ecological services sustainability strategy in planning operations. As well, forest laws and regulations should be in favour of sustainable forest management, including climate change attenuation as the key for sustainable development. Those issues were not taken into this thesis.

The distribution of future tree species and estimation of ecosystem services outputs is crutialy important for better forest management planning. Integrating climate change scenarios is also important as well as the integration of management goals and objectives on alternative planning strategies. By predicting future habitat suitability of trees, it can be easy to elaborate conservation planning for endangered species, and to control the local or regional dispersion potentialities of each tree species. This is also very important for spatial conservation prioritisation in forest management.

3. RESULTS

3.1. Habitat Suitability Modelling Results in Trabzon and Antalya

3.1.1. Habitat Suitability Modelling Results in Trabzon

Maxent model evaluation with AUC of ROC and their importance based on results provided by Jackknife analysis for some selected tree species for current environmental data in Trabzon are presented in Table 13. According to results presented in Table 13, model calibration for each of the selected tree species was satisfactory good with AUC value from 0.8 to 0.9, and great or nearly perfect with AUC value from 0.9 to 1. The findings indicated that the current distribution of all the selected species characterised by variables are excellent. It can be mentioned that *Carpinus betulus* model calibration recorded the highest AUC value, meaning that its prediction is closed to perfection with 95.2% of prediction possibility.

Table 13. Maxent model evaluation for current data of selected tree species in Trabzon

Trabzon	(L)Picea orientalis	(Kn)Fagus orientalis	(M)Quercus sp.	(Kz) Alnus glutinosa	(Çs)Pinus sylvestris	(Gn) Carpinus betulus	(G) Abies nordmaniana
AUC	0.907	0.904	0.906	0.902	0.880	0.952	0.872
Bio1	0.18	0.2	0.25	0.62	0.15	0.62	0.18
Bio2	-	-	-	-	-	-	-
Bio3	0.15	0.05	0.07	0.18	0.10	0.01	0.025
Bio4	0.54	0.62	0.17	0.74	0.18	0.85	0.22
Bio5	0.22	0.02	0.34	0.28	0.025	0.17	0.24
Bio6	0.32	0.45	0.31	0.775	0.27	0.82	0.24
Bio7	0.59	0.76	0.13	0.81	0.225	0.85	0.22
Bio8	0.13	0.03	0.02	0.16	0.04	0.18	0.07
Bio9	0.12	0.04	0.24	0.17	0.13	0.62	0.23
Bio10	0.17	0.05	0.22	0.52	0.10	0.45	0.14
Bio11	0.34	0.52	0.34	0.75	0.23	0.80	0.22
Bio12	0.18	0.41	0.37	0.44	0.28	0.41	0.15
Bio13	-	-	-	-	-	-	-
Bio14	0.35	0.15	0.52	0.62	0.37	0.64	0.08
Bio15	0.54	0.41	0.27	0.785	0.32	0.65	0.12
Bio16	0.18	0.04	0.28	0.15	0.15	0.008	0.11
Bio17	0.49	0.26	0.47	0.65	0.34	0.62	0.10
Bio18	0.38	0.22	0.52	0.58	0.42	0.52	0.07
Bio19	0.05	0.28	0.15	0.47	0.10	0.58	0.21

The Principal Component Analysis (PCA) has help to select 17 bioclimatic parameters having good correlation. Bio2 and Bio13 have been eliminated from the model calibration due to the non colinearity with other parameters. As well the test of Jackknife analysis results has been summarized for each of the species in Table 13. It can be mentioned that the distribution of *Carpinus orientalis* in Trabzon has mainly been influenced by “Temperature Seasonality” (Bio4), “Temperature Annual Range” (Bio7), “Min Temperature of Coldest Month” (Bio6) and “Mean Temperature of Coldest Quarter” (Bio11). These have contributed to up to 85% of the model calibration (see Figure 26 Jackknife of AUC for *Carpinus orientalis*). These contributions vary according to each selected tree species. For example, the distribution of *Alnus glutinosa* has been mainly influenced by Precipitation Seasonality (Bio15) and this has contributed to more than 85% of the model calibration. Species response curve depicts the relationship between the environmental variables and the probability of species to relate to the selected variable. This provides evidence on biological tolerances of the selected species and habitat preferences.

Based on the response curves provided by Maxent results for each species, it can be mentioned that *Carpinus orientalis* prefers the warmest month temperature in Trabzon regional forest area. The habitat suitability maps for each species have been produced. The gradient of suitability has been used to generate maps for each selected species for both current suitability and future suitability under climate change scenario RCP4.5 and RCP8.5. Then the mixture of the maps has been done using ArcGIS 10.3 data management tools with intersection function, to produce maps of suitability. The following maps present the habitat suitability for each species and the mixture in Trabzon and Antalya.

3.1.1.1. Habitat Suitability of *Picea orientalis* in Trabzon Regional Forest

According to Figure 11, *Picea orientalis* is well adapted to Trabzon area and persistent in future climate change conditions. It is in its natural ecological conditions with other tree species which will increase from suitable to highly suitable areas from 2020 to 2050, then 2080 under different climate change scenarios RCP4.5 and RCP8.5. It can be mentioned that bio 2, and bio 7 influence the most the distribution of *Picea orientalis*, and bio 2 contribute the most in the AUC model calibration (Figure 12). It can also be mentioned that the model is well calibrated with AUC > 0.8 for each period (Figure 13).

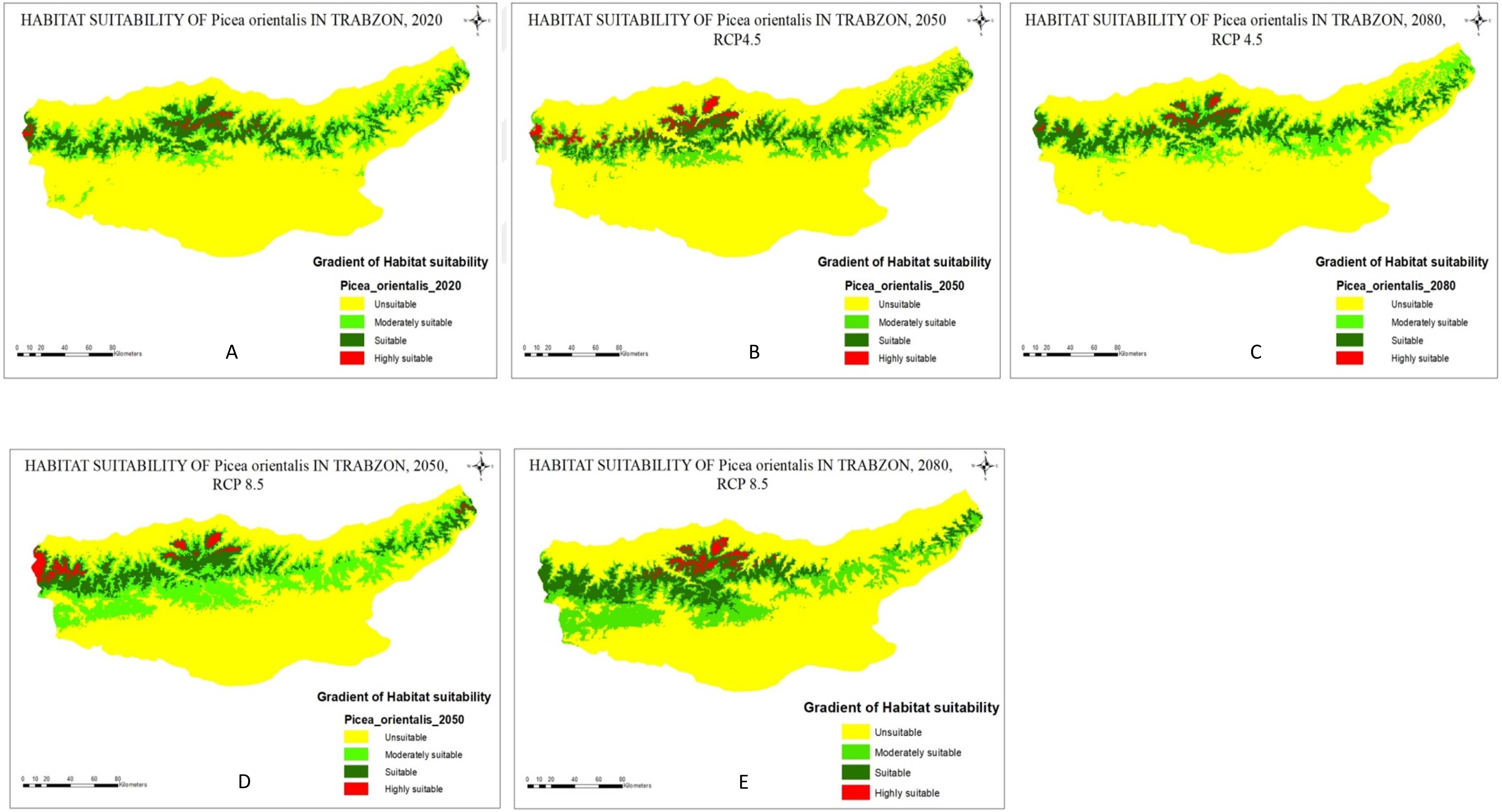


Figure 11. Habitat suitability maps from MaxEnt models for *Picea orientalis*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

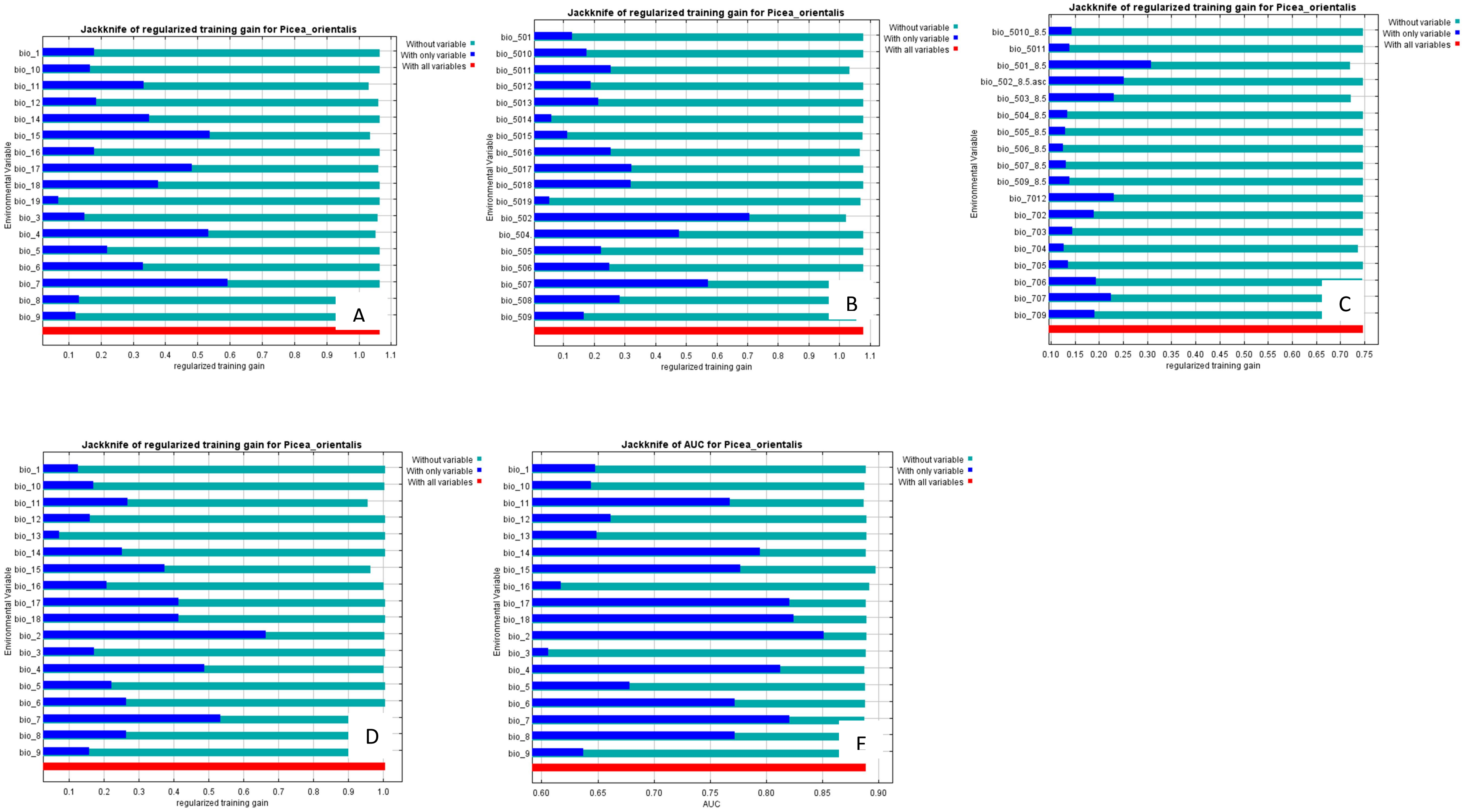


Figure 12. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Picea orientalis* A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

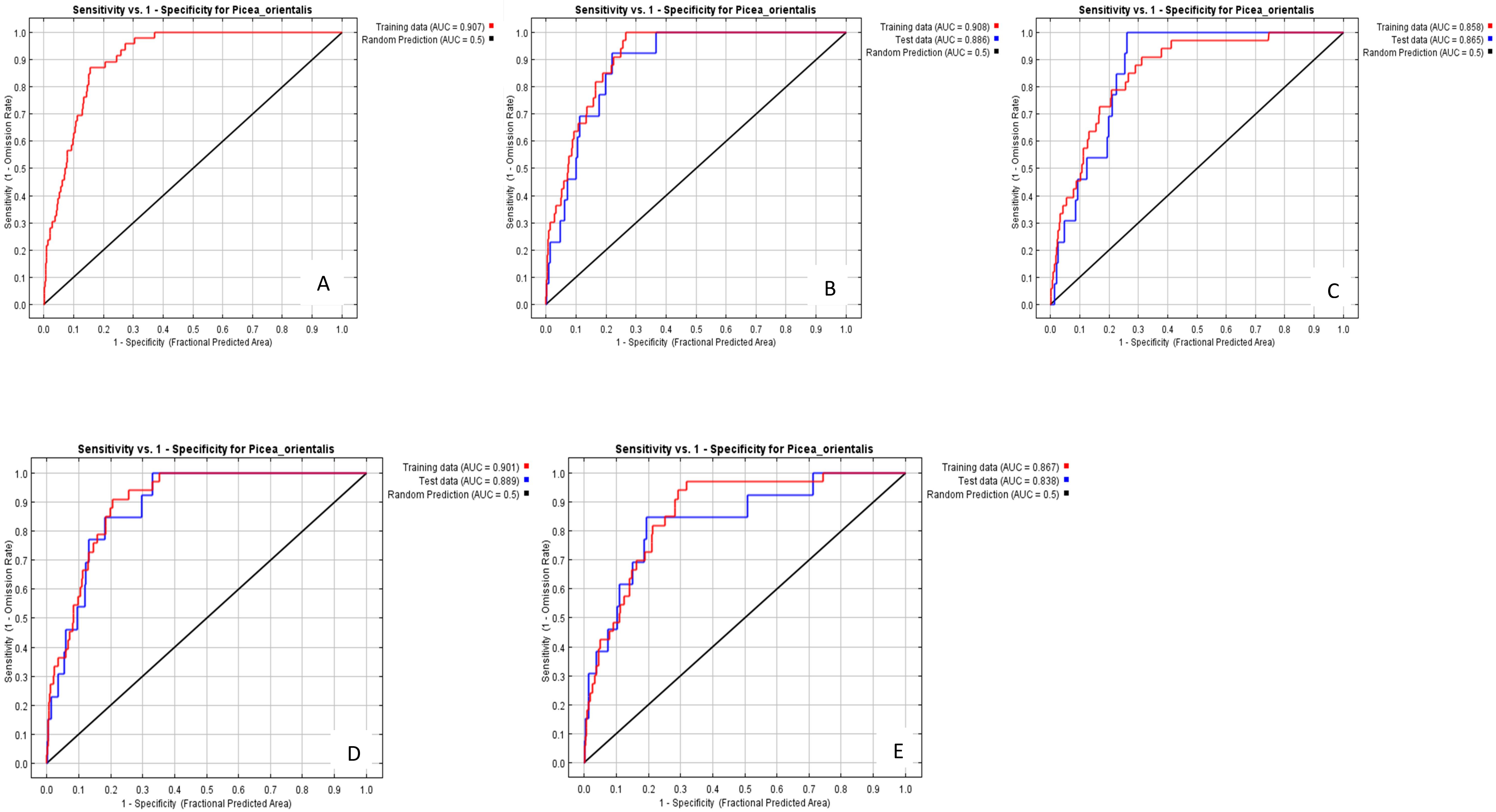


Figure 13. Area under the curve from MaxEnt models for *Picea orientalis*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

3.1.1.2. Habitat Suitability for *Fagus orientalis* in Trabzon Regional Forest

It can be mentioned from Figure 14 that the habitat suitability of *Fagus orientalis* in Trabzon will increase from 2020 to 2050, with the apparition of highly suitable areas and an extension of suitable area, switching with moderately suitable areas. At contrary, *Fagus orientalis* suitable area will disappear on the east side of Trabzon from 2050 to 2080, and the suitable areas will condense on the coastal side migrating from mountainous areas to low lands. Furthermore, according to RCP 8.5 projections, *Fagus orientali*s unsuitable areas will change to moderately suitable areas in the south of Trabzon regional Forest (Figure 14). From Figure 15, it can be mentioned that bio 7, bio 1 and bio 15 influence the most the distribution of Fagus orientalis, and bio 11, bio 6 and bio 8 contribute the most in the AUC model calibration (Figure 14).

From Figure 16, it can be mentioned that the model is well calibrated with AUC > 0.8 for each period. The AUC for 2080 RCP8.5 is a bit lower than 0.8 but test data AUC is greater than 0.8, meaning that the model calibration is autocorrected (Figure 16).

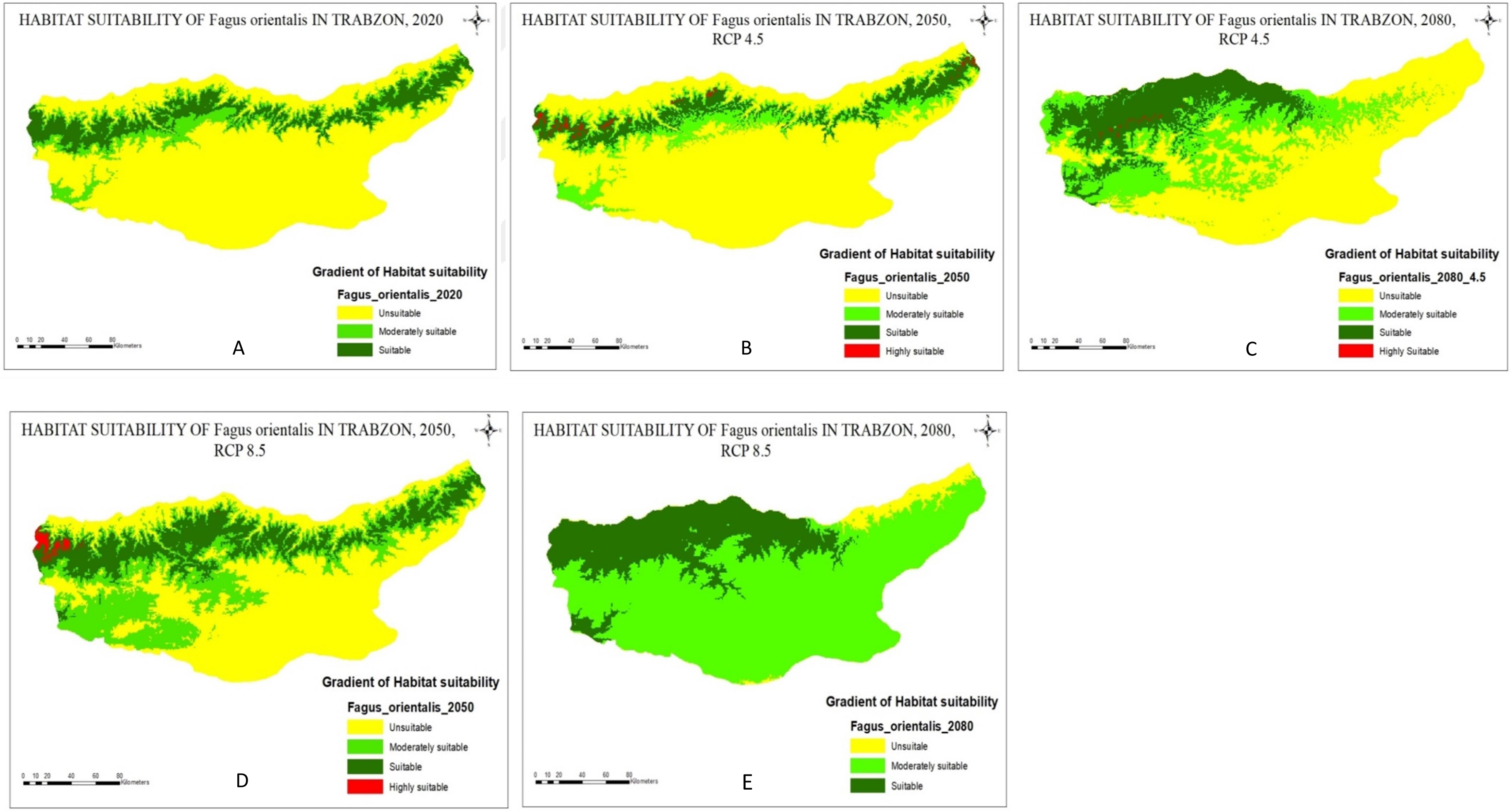


Figure 14. Habitat suitability maps from MaxEnt models for *Fagus orientalis*.
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

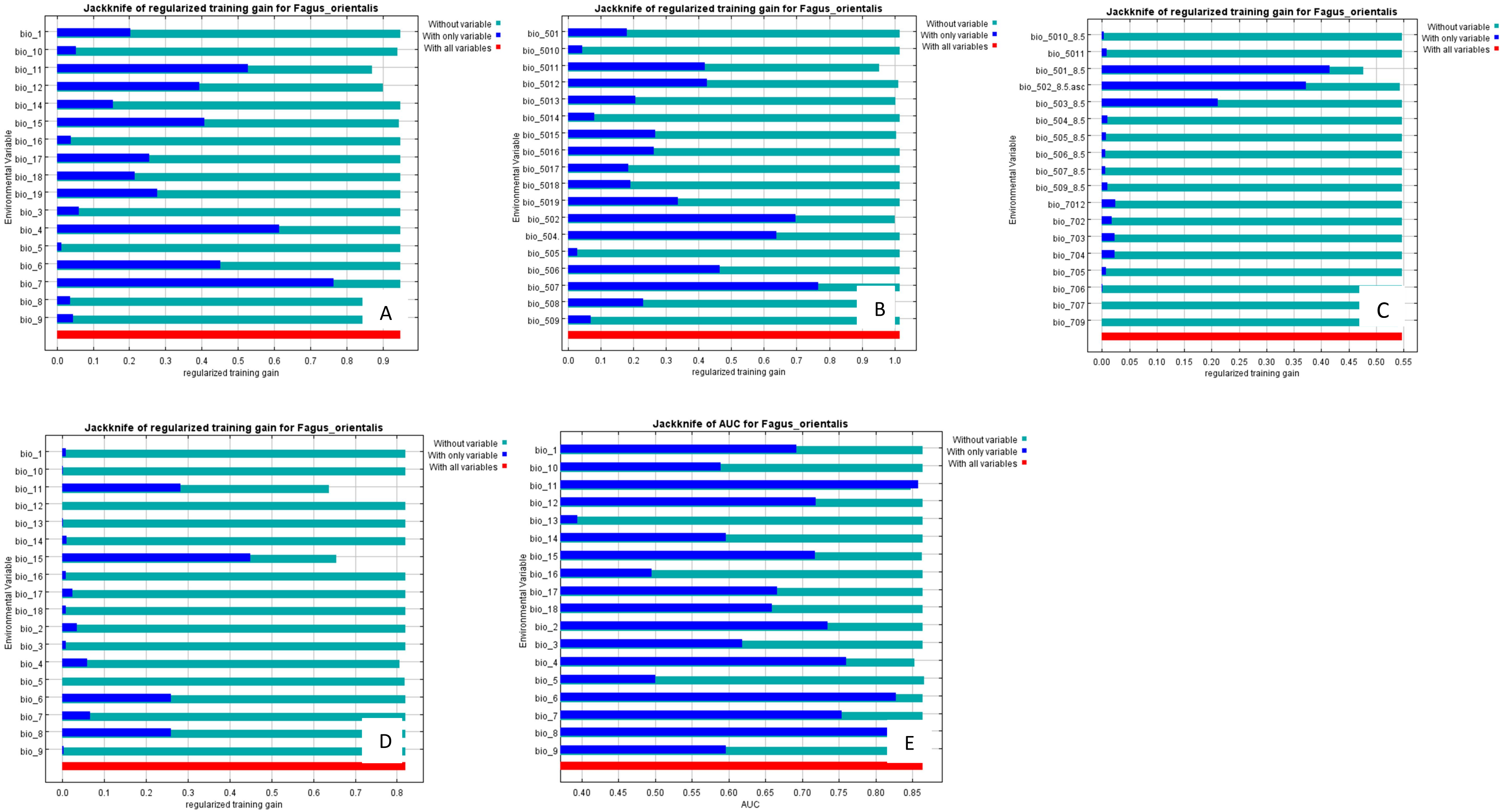


Figure 15. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Fagus orientalis*. A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

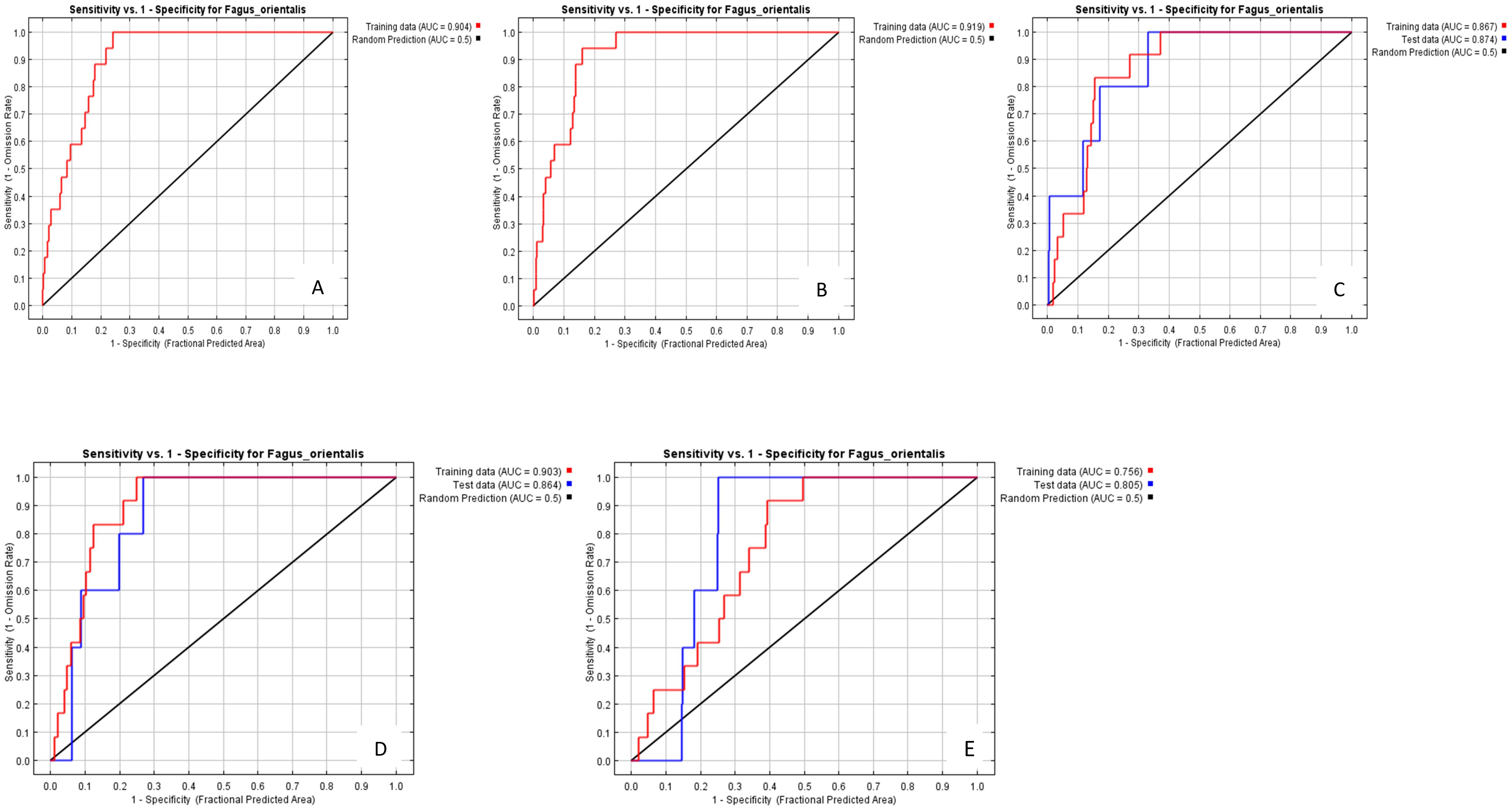


Figure 16. Area under the curve from MaxEnt models for *Fagus orientalis*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

3.1.1.3. Habitat Suitability for *Quercus spp.* in Trabzon Regional Forest

According to prediction in Figure 17 of *Quercus spp.*, highly suitable areas and suitable areas will increase from 2020 to 2050 then to 2080 under scenario RCP 4.5, while highly suitable area will decrease from 2020 to 2050 and suitable area will increase under RCP 8.5. Furthermore, highly suitable areas will increase from 2050 to 2080. Moderately suitable area and suitable area for *Quercus spp.* will expand in the region meaning that future climatic conditions will be appropriated for the establishment of this specie (Figure 17). It can be mentioned from Figure 18 that bio 14, bio 18, bio 17 and bio 2 are the most influencal climate bioclimatic parameters for the distributution of Quercus spp., while bio 18, bio 17 and bio 10 contribute the most to the AUC model calibration (Figure 18).

As well looking at Figure 19, it can be mentioned that the model is well calibrated with AUC >0.8 for each period (Figure 19).

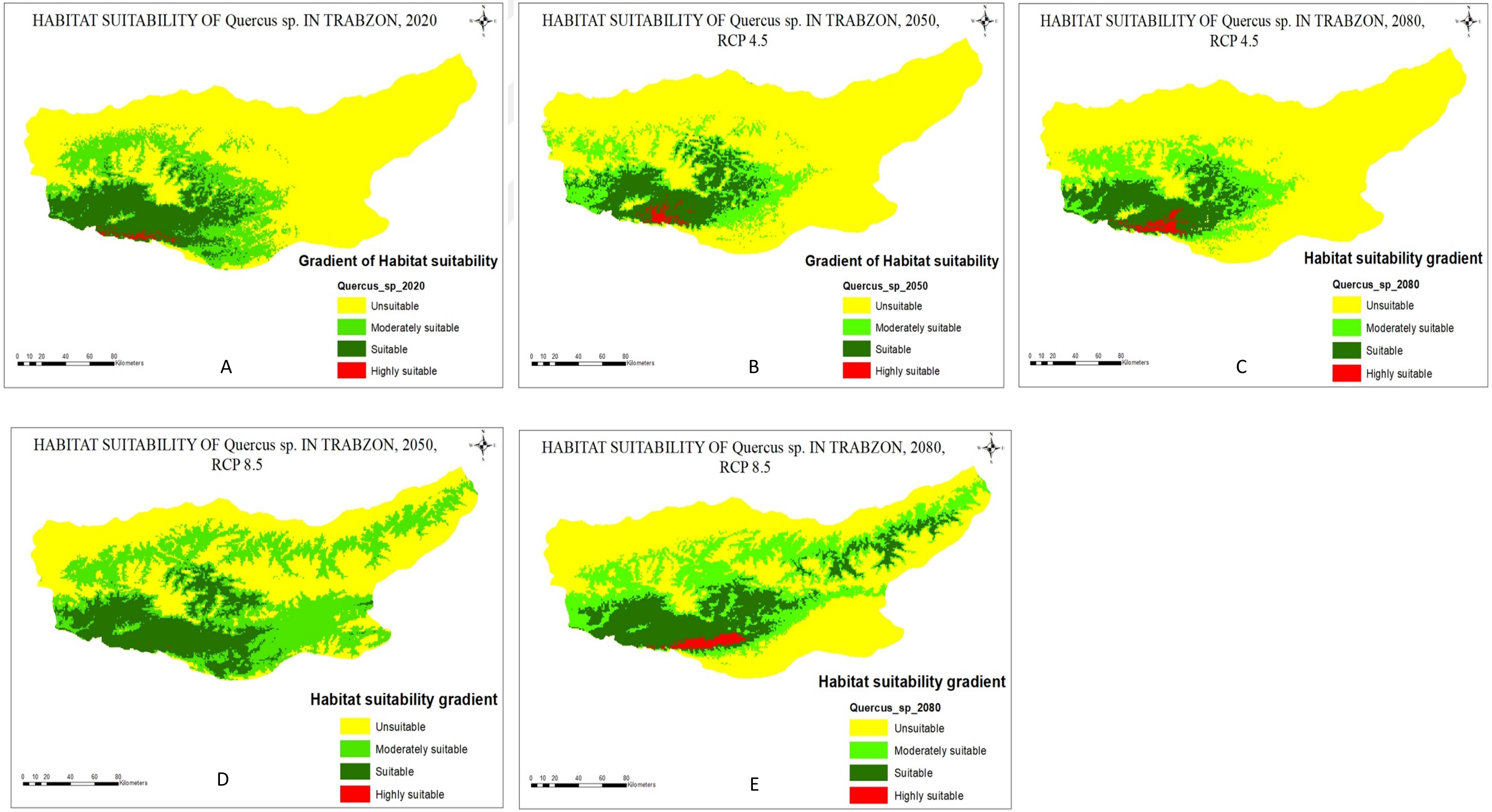


Figure 17. Habitat suitability maps from MaxEnt models for *Quercus spp.*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

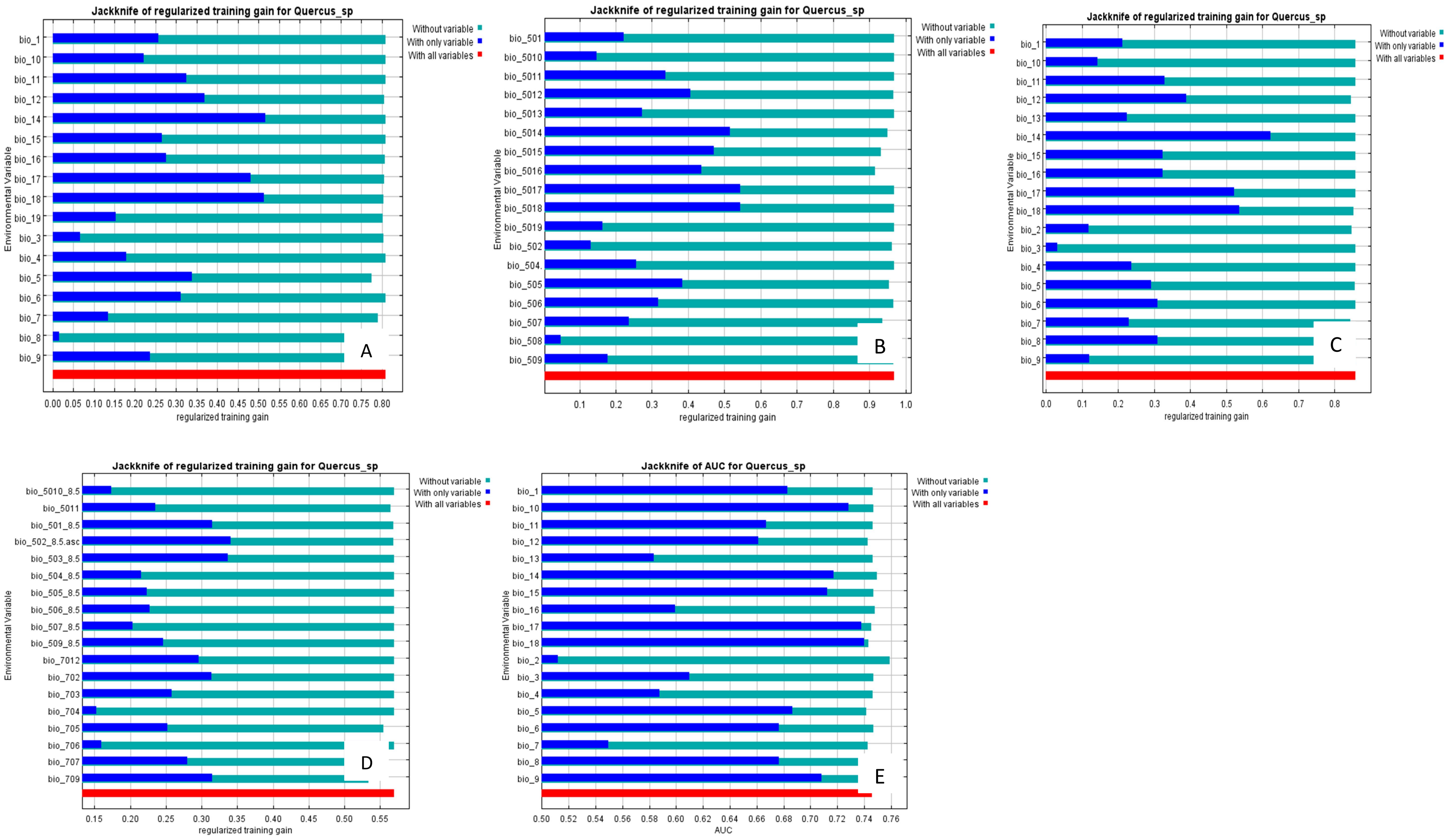


Figure 18. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Quercus spp*. A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

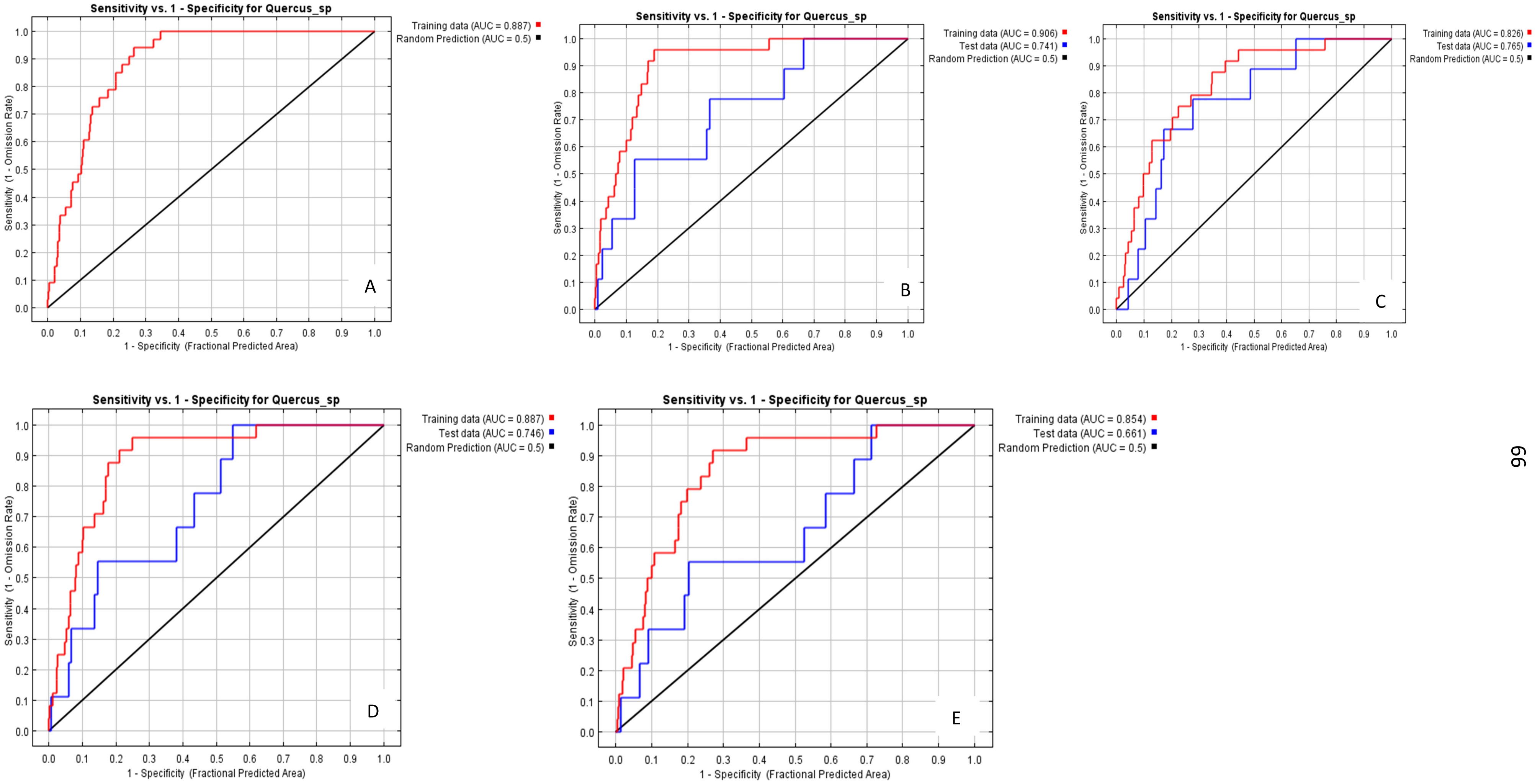


Figure 19. Area under the curve from MaxEnt models for *Quercus spp.*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5.

3.1.1.4. Habitat Suitability for *Alnus glutinosa* in Trabzon Regional Forest

According to the projection of *Alnus glutinosa* presented in Figure 20, the highly suitable areas will increase from 2020 to 2050, and then decrease from 2050 to 2080 and suitable areas will increase replacing moderately and unsuitable areas that will decrease under scenario RCP4.5. As well, the habitat suitability of *Alnus glutinosa* will increase from 2050 to 2080 according to scenario RCP8.5 (Figure 20). It can be mentioned that bio 2, bio 7 and bio 15 influence the most the distribution of *Alnus glutinosa*, and bio 15 contribute the most in the AUC model calibration (Figure 21).

It can be mentioned that the model is well calibrated with AUC> 0.8 for each period (Figure 22).

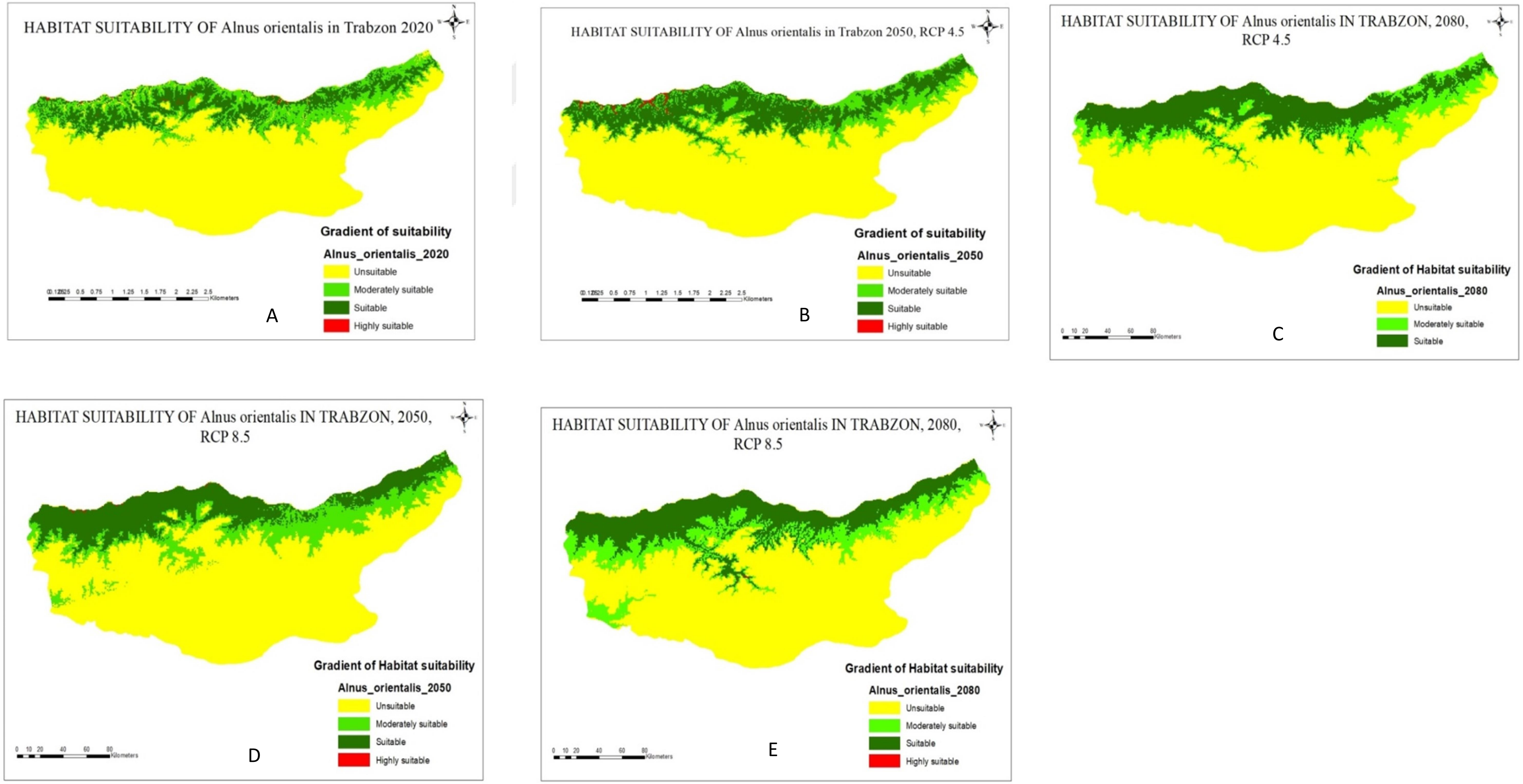


Figure 20. Habitat suitability maps from MaxEnt models for *Alnus glutinosa.*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

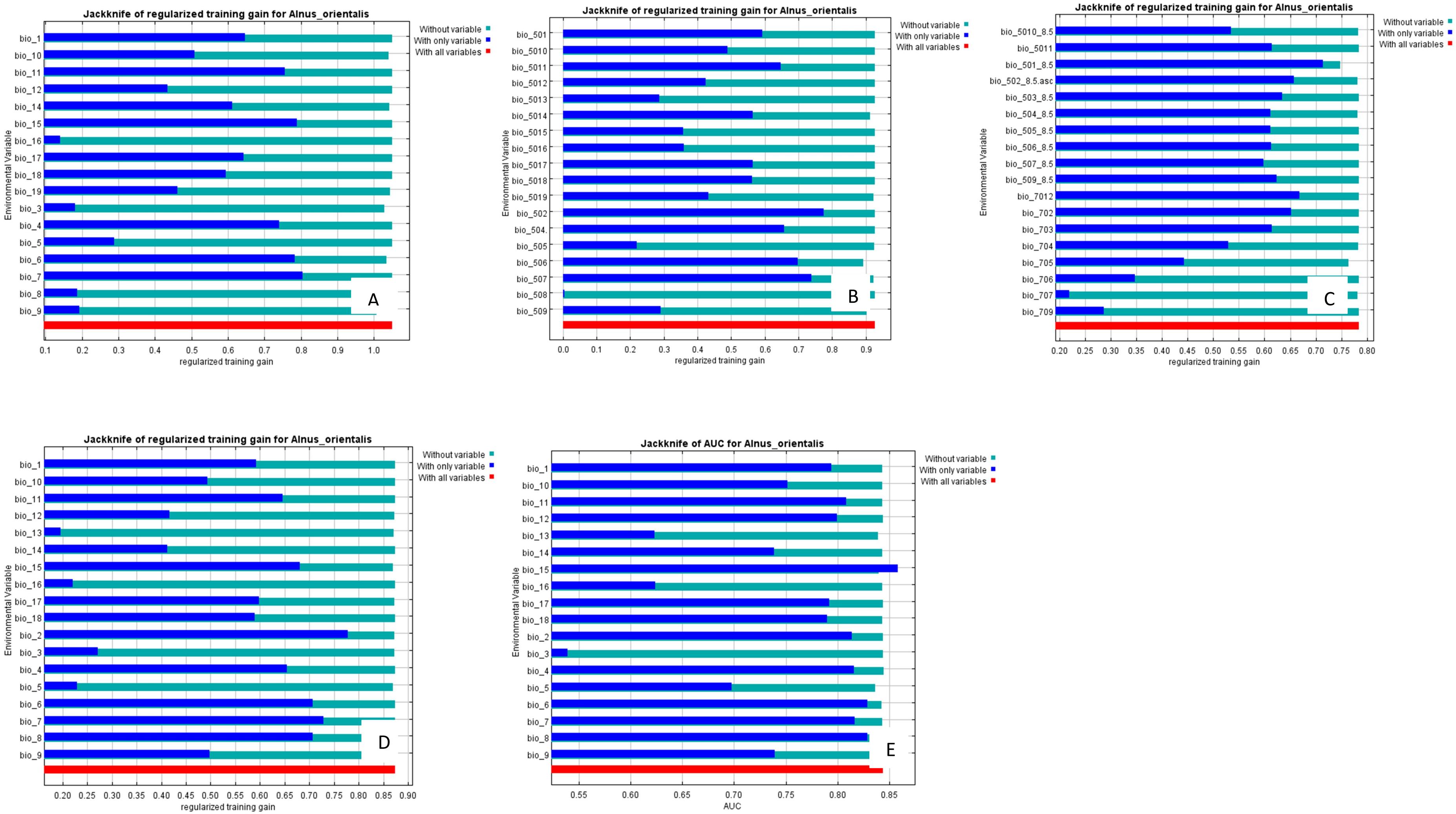


Figure 21. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Alnus glutinosa*. A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

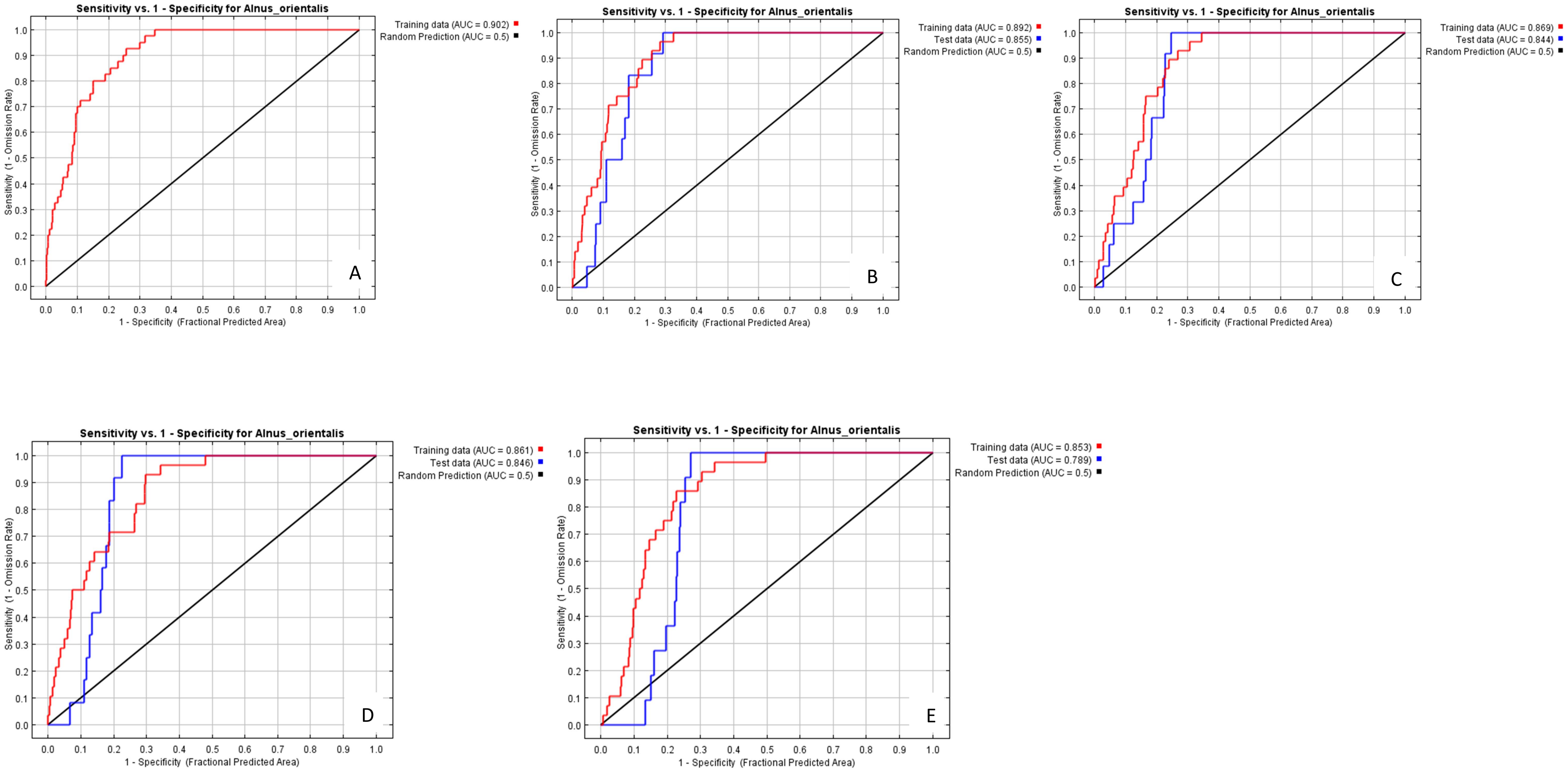


Figure 22. Area under the curve from MaxEnt models for *Alnus glutinosa*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

3.1.1.5. Habitat Suitability for *Pinus sylvestris* in Trabzon Regional Forest

As mentioned on Figure 23, The highly suitable and suitable areas of *Pinus sylvestris* will increase from 2020 to 2050 in Trabzon with an extension of moderately suitable areas in the north, and then a slightly decrease of highly suitable areas from 2050 to 2080 with an extension of suitable and moderately suitable areas accordingly to climate change scenarios RCP 4.5 and RCP 8.5 (Figure 24). It can be mentioned from Figure 24 that bio 18, bio 15, bio 16 and bio 14 are the bioclimatic parameters influencing the most the distribution of *Pinus sylvestris*, then bio 12 and bio 7 contribute the most in the AUC model calibration.

It can also be mentioned that the model is well calibrated with AUC>0.8 for each period (Figure 25).

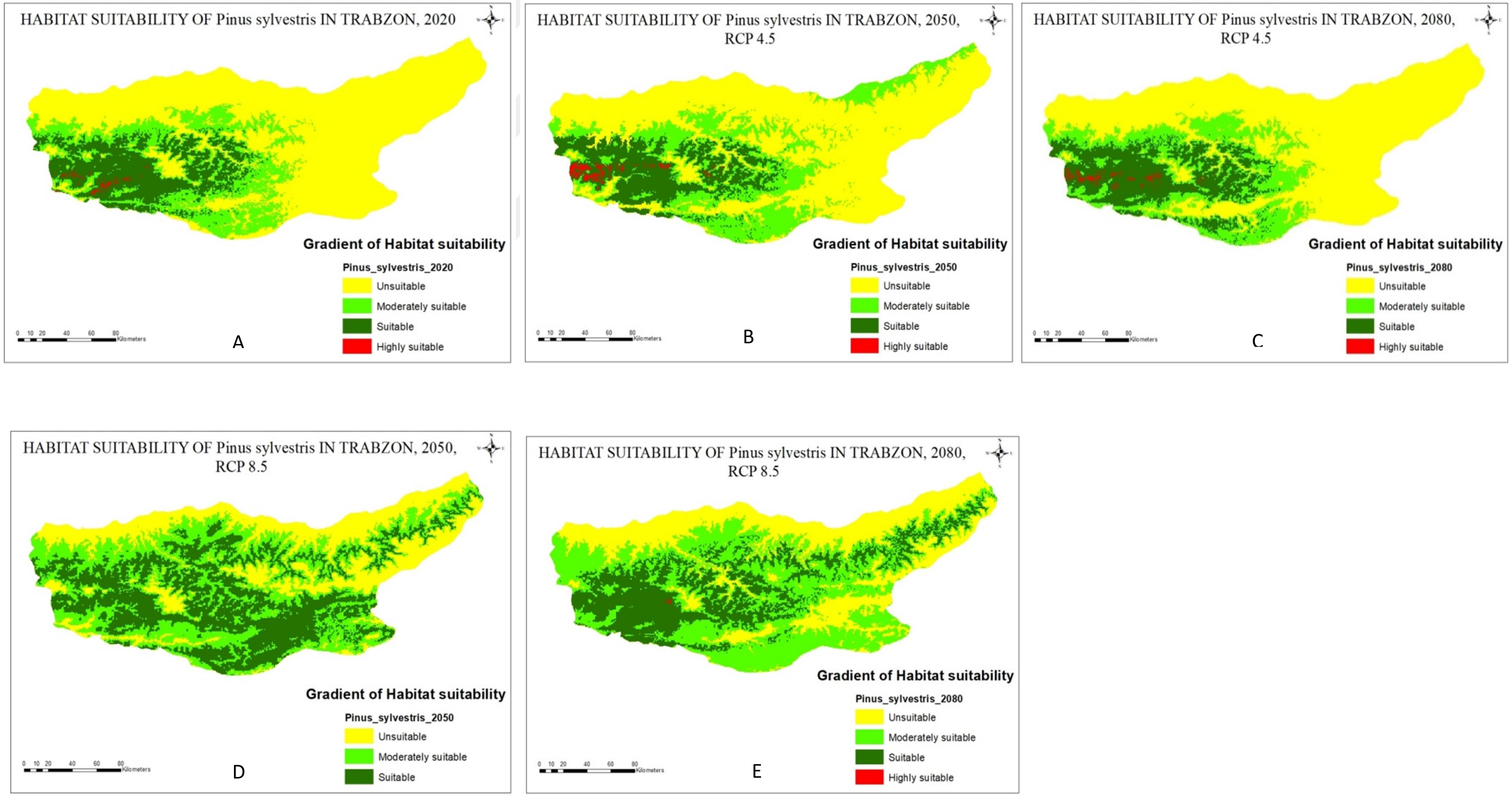


Figure 23. Habitat suitability maps from MaxEnt models for *Pinus sylvestris*.
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5.

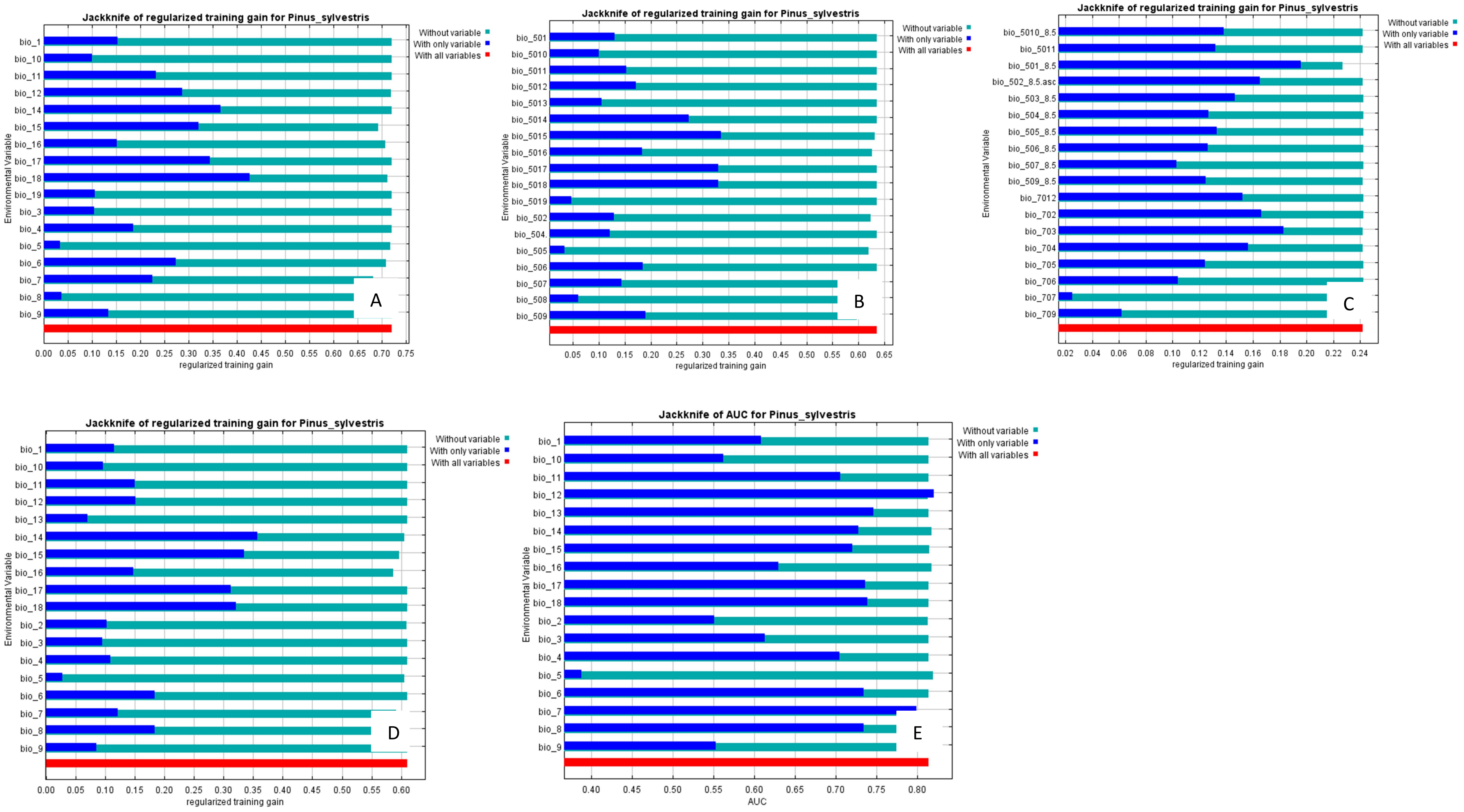


Figure 24. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Pinus sylvestris*. A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

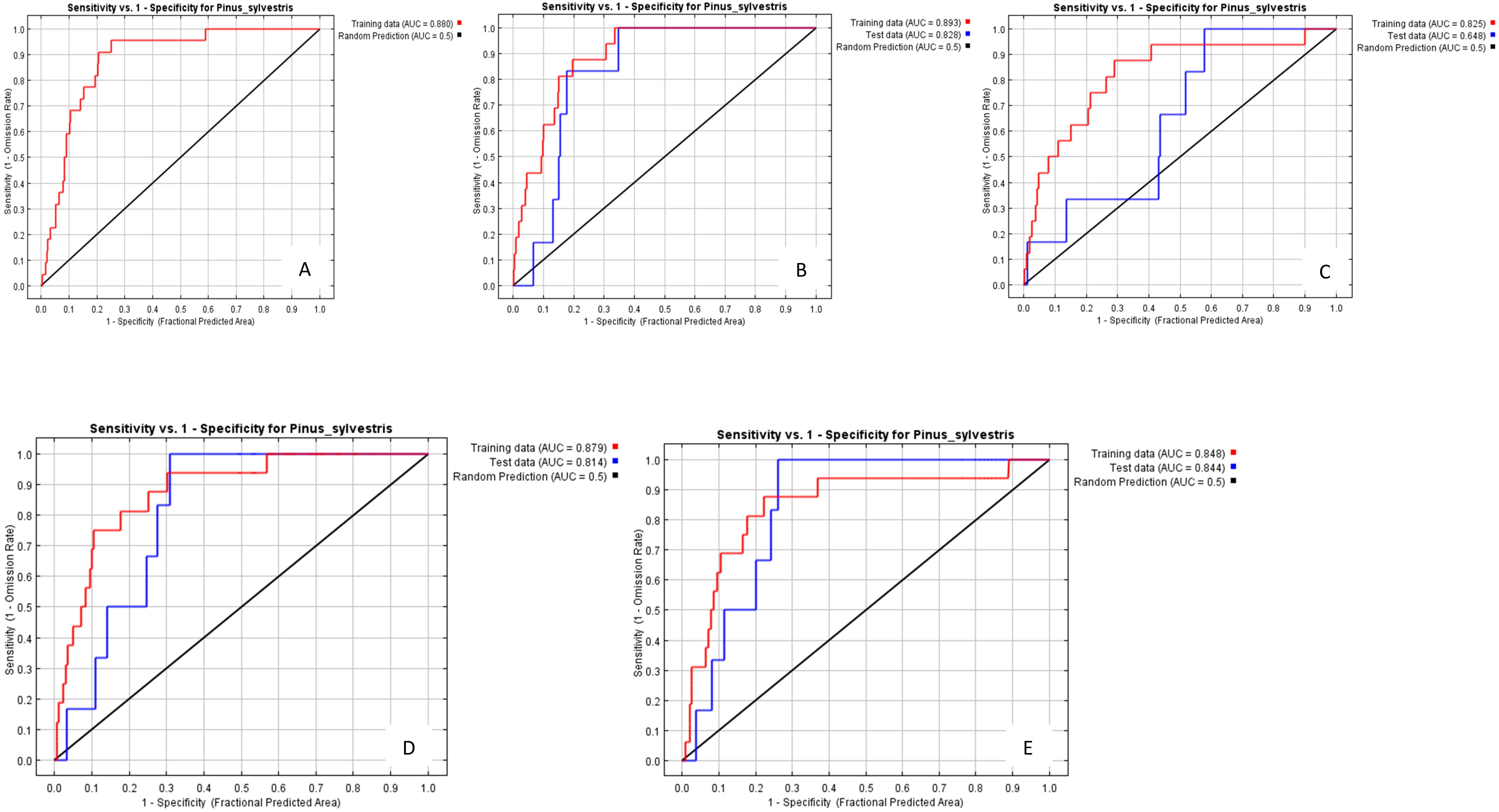


Figure 25. Area under the curve from MaxEnt models for *Pinus sylvestris*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

3.1.1.6. Habitat Suitability for *Carpinus orientalis* in Trabzon Regional Forest

From the Figure 26, it can be mentioned a slightly degradation of the moderately suitable and suitable habitats of *Carpinus orientalis*, with an increasing patch of highly suitable areas in Trabzon from 2020 to 2050 under RCP 4.5., there is a persistent increasing of highly suitable areas for *Carpinus orientalis* from 2050 to 2080. This can be showing that *Carpinus orientalis* is also well adapted to future changes conditions in Trabzon and neighbouring area (Figure 26). It can also be mentioned from Figure 27 that bio 7, bio 6, bio1 and bio 8 are the bioclimatic parameters influencing the most the distribution of Carpinus orientalis. Then bio 4 contribute the most in the AUC model calibration.

Furthermore, it can be mentioned from Figure 28 that the model is well calibrated with AUC> 0.8 for each period.

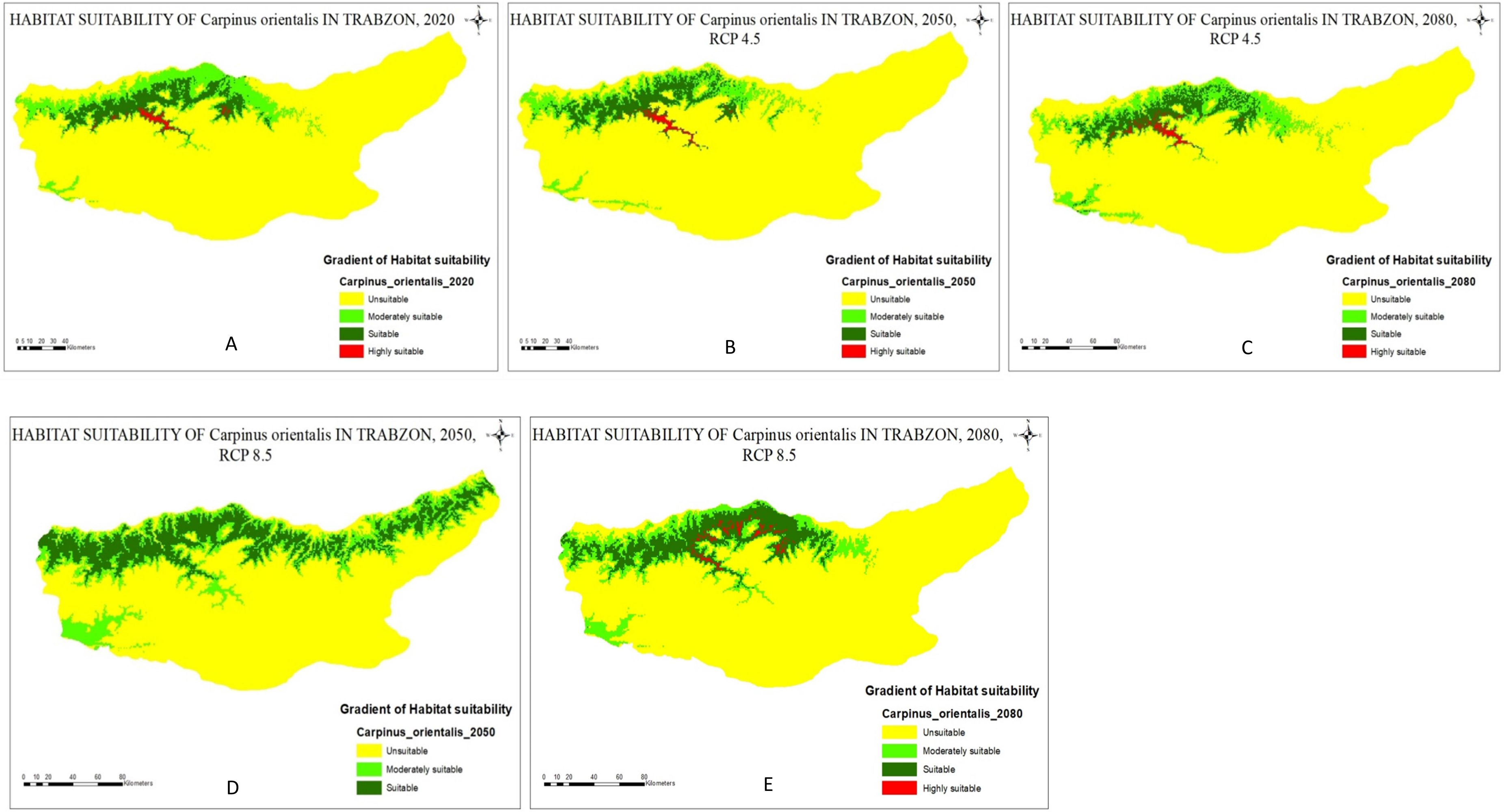


Figure 26. Habitat suitability maps from MaxEnt models for *Carpinus orientalis* A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

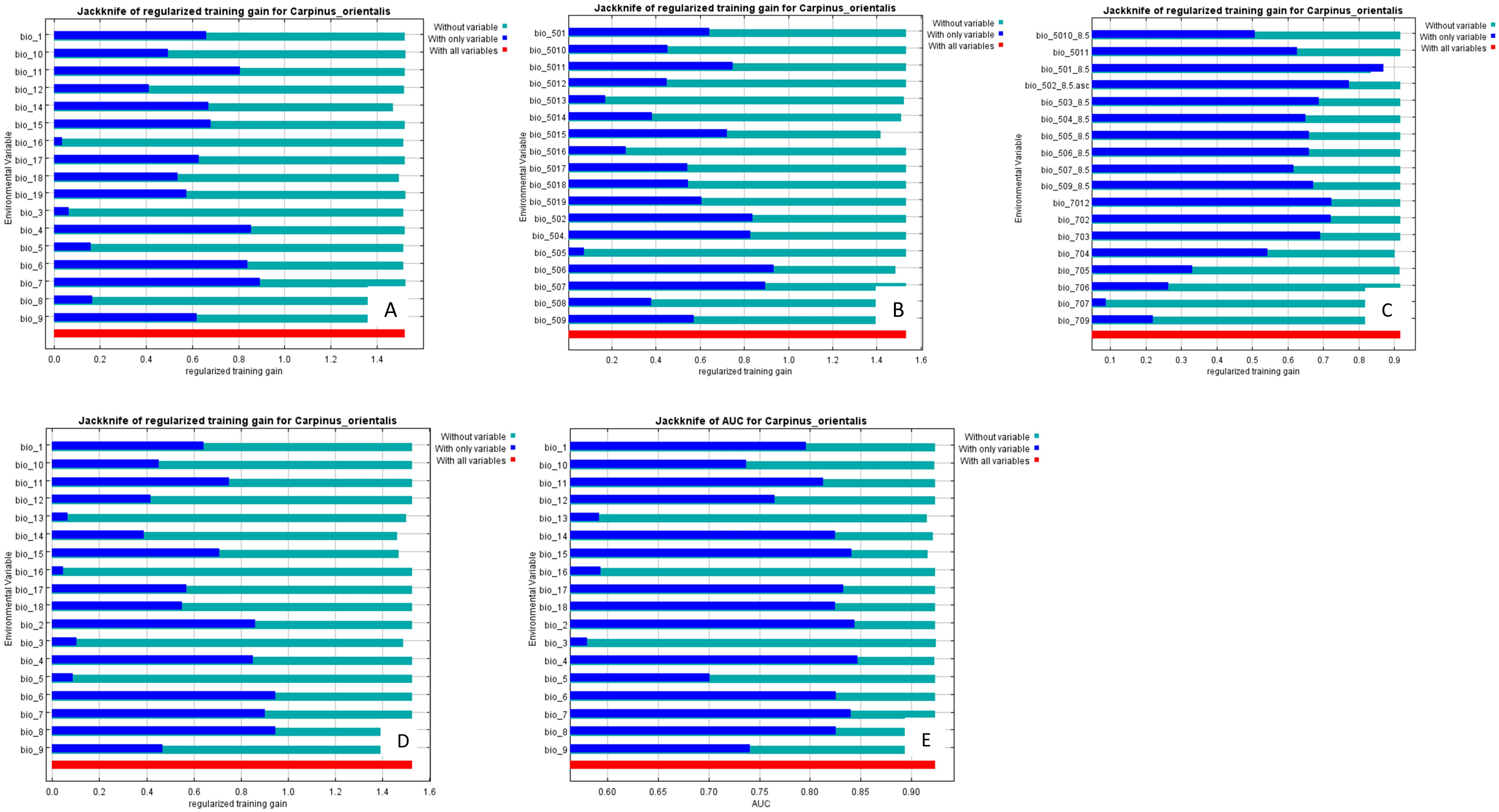


Figure 27. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Carpinus orientalis* A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

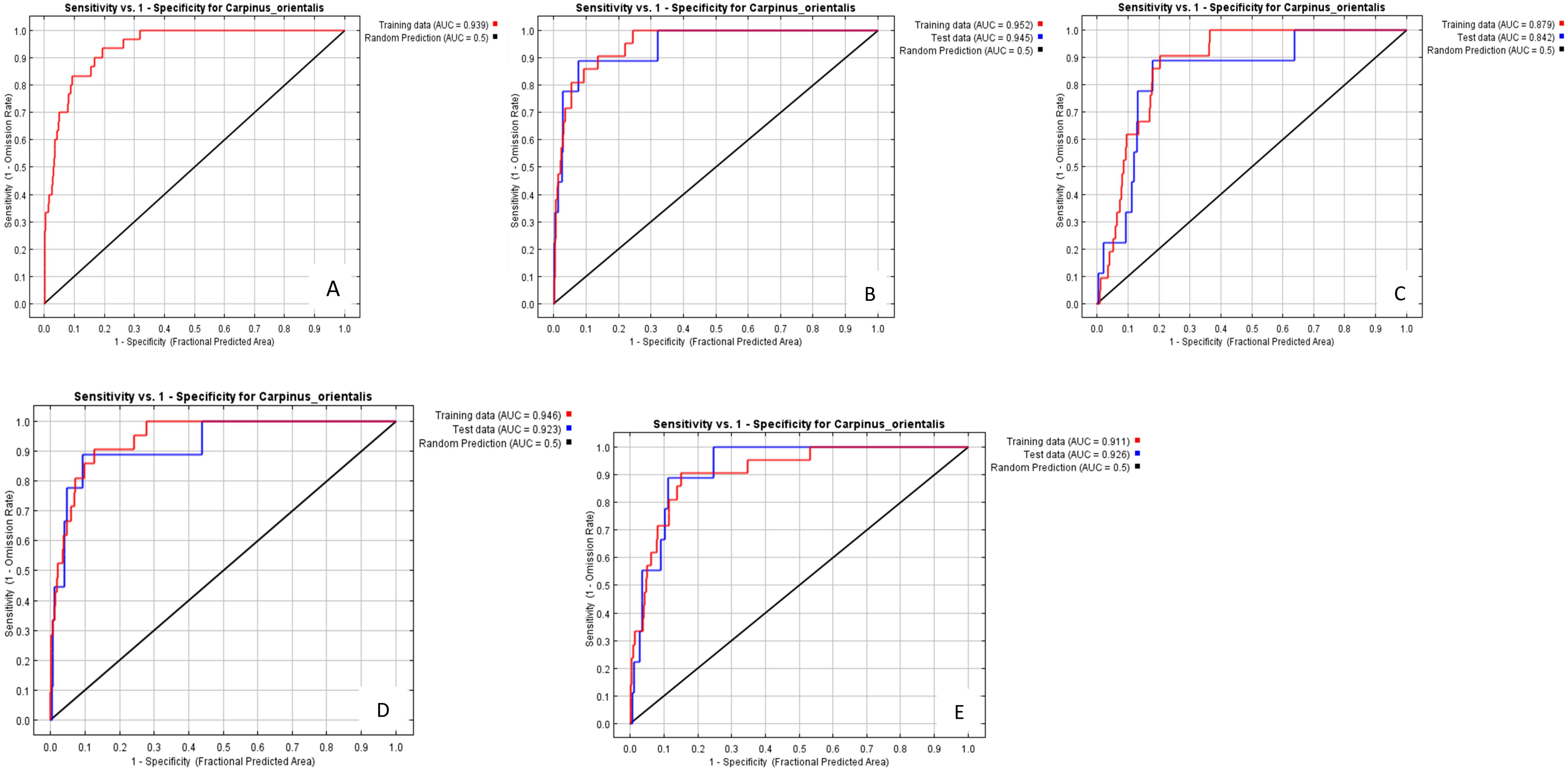


Figure 28. Area under the curve from MaxEnt models for *Carpinus orientalis*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

3.1.1.7. Habitat Suitability for *Abies nordmanianna* in Trabzon Regional Forest

It can be mentioned from Figure 29 that the highly suitable areas for Abies nordmanniana will decrease, then the suitable and moderately suitable habitats will increase from 2020 to 2050. This will reappear in 2080 under the climate change scenario RCP4.5; while highly suitable area will completely disappear from 2020 to 2080, then moderately suitable and suitable areas will increase progressively from 2020 to 2050, and from 2050 to 2080 under climate change scenario RCP8.5 (Figure 29). It can furtherly be mentioned that bio 5, bio 6 and bio 4 influence the most the distribution of Abies nordmanniana, and bio 5 contribute the most in the AUC model calibration (Figure 30).

Furthermore, it can be mentioned that the model is well calibrated with AUC> 0.8 for each period (Figure 31).

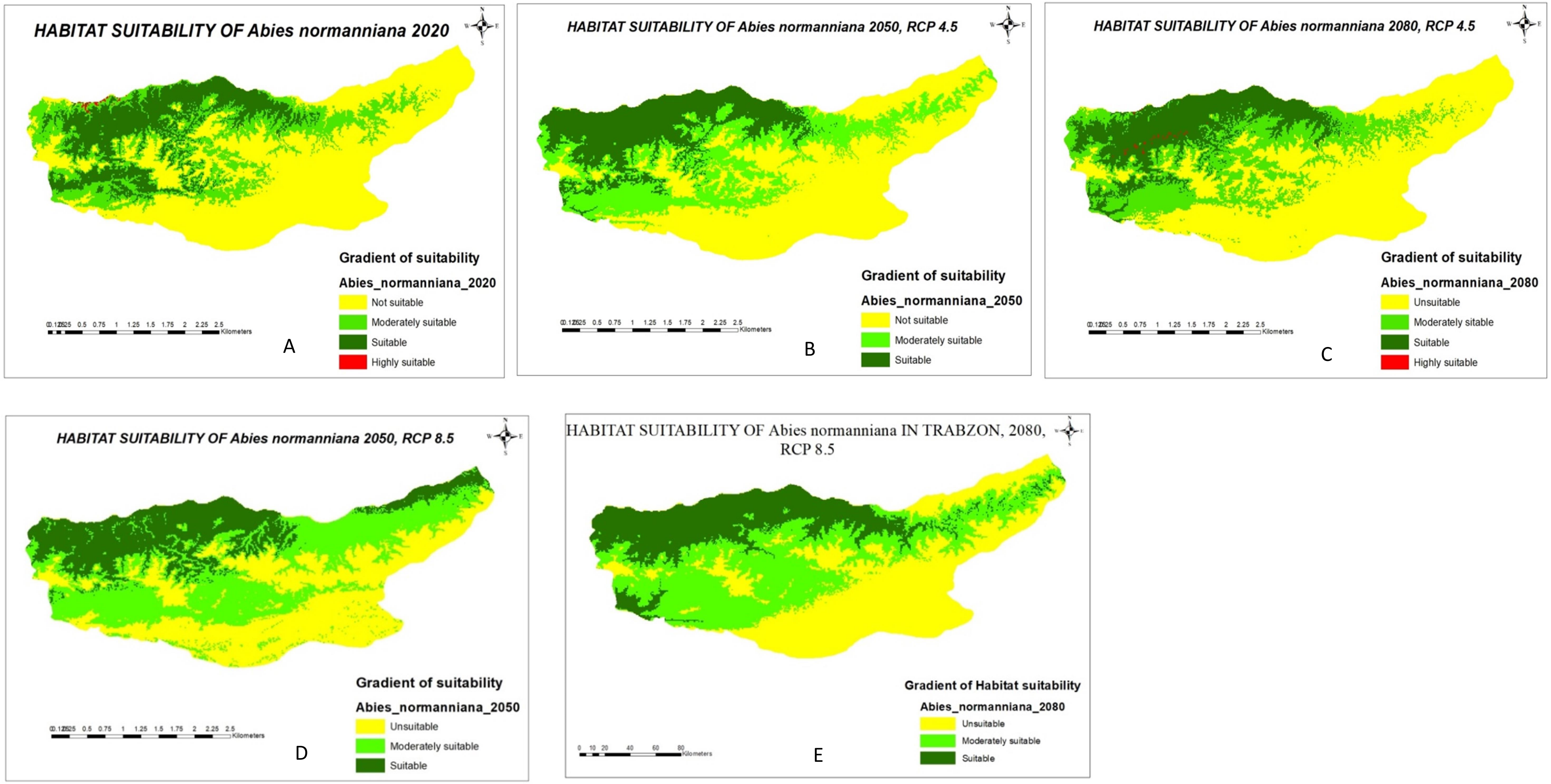


Figure 29. Habitat suitability maps from MaxEnt models for *Abies normanniana*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5.

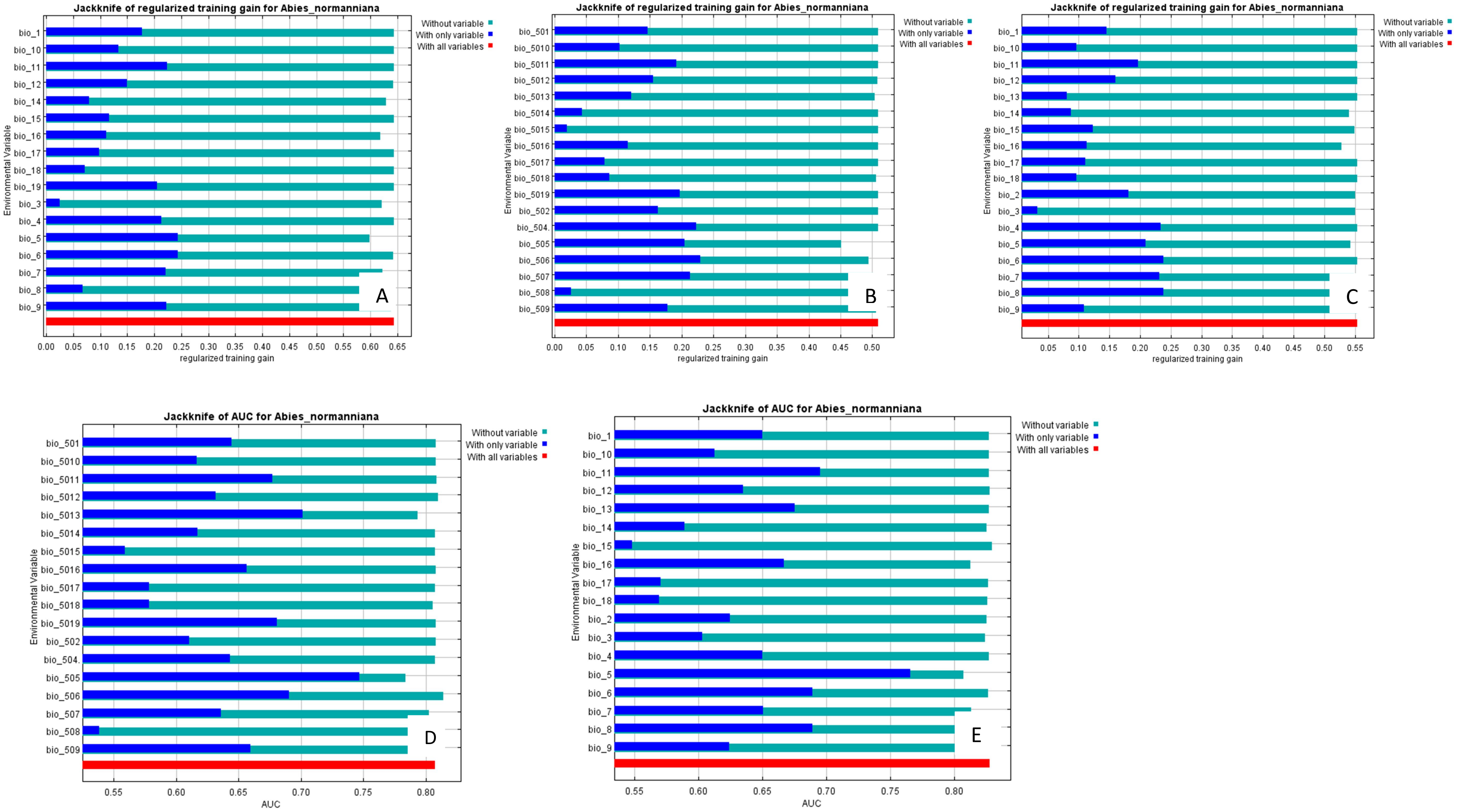


Figure 30. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Abies normanniana* A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5.

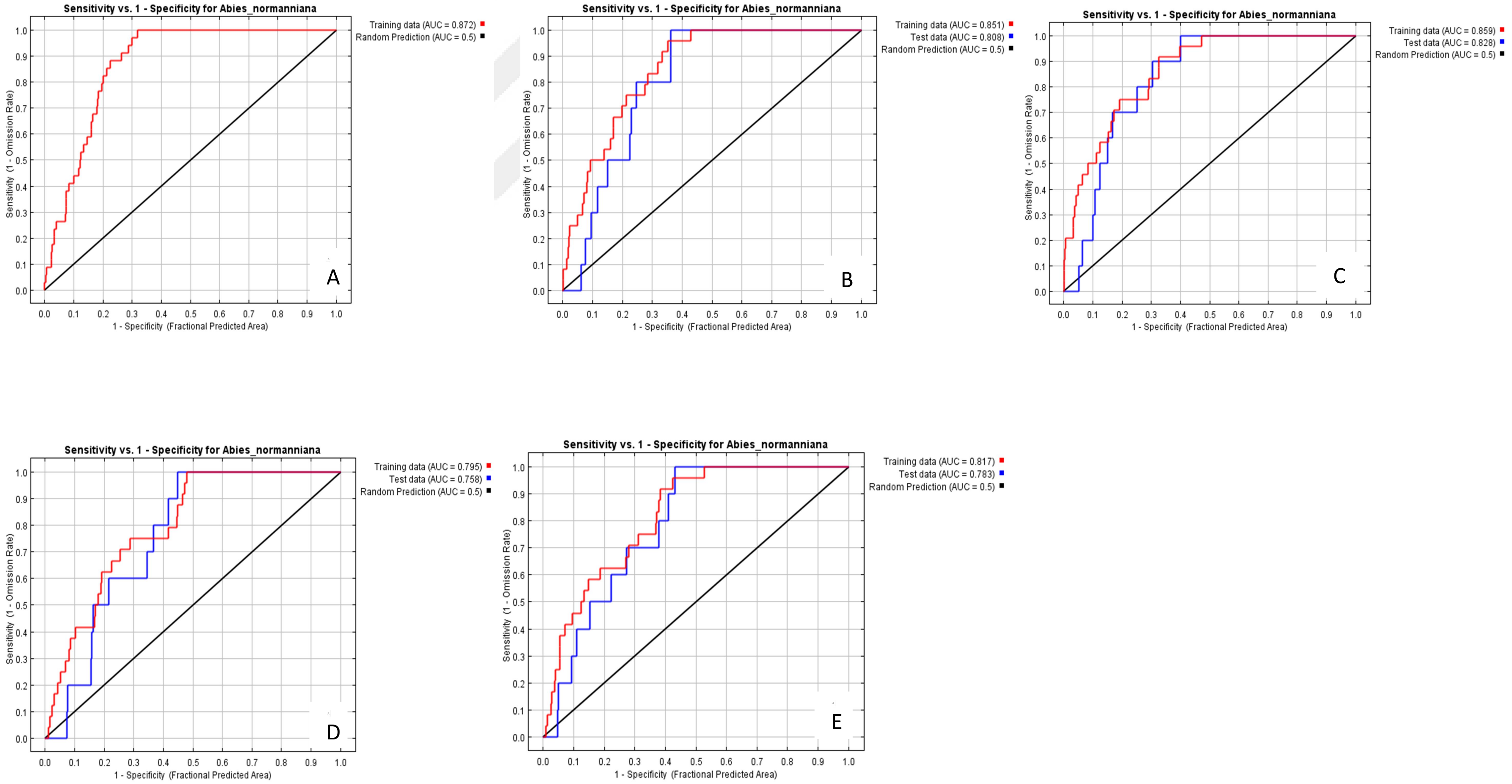


Figure 31. Area under the curve from MaxEnt models for *Carpinus orientalis*
A 2020, B 2050s RCP4.5, C 2080 RCP4.5, D 2050s RCP8.5 and E 2080 RCP8.5

3.1.1.8. Mixture of the Tree Species in Trabzon Regional Forest

According to presented changes of habitat suitability of the selected tree species, the mixture of trees will change in the future with the impact of climate change. Tree mixture have been analysed based on the dominance or codominance of in the study area. The intersection of single species maps have helped to produce tree mixture maps presented below.

From Figure 32, it can be mentioned that the suitable areas for pure stands of *Abies nordmanniana* (G), *Alnus orientalis* (Kz), mixed stands and *Pinus sylvestris* (Çs) will reduce considerably from 2020 to 2050 under climate change scenario RCP4.5. according to this scenario *Pinus sylvestris* pure habitat suitability areas will disappear on the suitablility map by 2050 and will be convert mainly in mix forest stands suitability. It can be stated that during the intersection and interpretation works, some of the species was present in mixed forests due to codominance of their gradient of suitability with others.

At contrary, the area of *Carpinus orientalis* (Gn), *Fagus orientalis* (Kn), *Picea orientalis* (L) and *Quercus spp.* (M) pure suitable stands will increase in the same period. The not suitable area (potentially rocky areas, sandy looms and areas without greening possibilities) will stay unchanged according to MaxEnt habitat suitability predictions in Trabzon regional Forestry from 2020 to 2050 under scenario RCP4.5.

It can also be mentioned that from Figure 32, the suitable areas for pure stands of *Abies nordmanniana* (G) and *Fagus orientalis* have disappear from 2050 to 2080 under scenario RCP4.5. Furthermore, *Alnus orientalis* (Kz), mixed forests stands and *Pinus sylvestris* (Çs) suitable area are expanding or reappearing as pure stands due to favourable environmental conditions that will established in the future in Trabzon region. At their contrary, *Quercus spp.* and *Carpinus orientalis* suitable area will reduce considerably in the same perion under climate change scenario RCP4.5.

It can be mentioned from Figure 33 that mixed forest suitability expand from the north-east to the north-west of Trabzon regional forest, while it decrease on the south-east side, where *Pinus sylvestris* and *Quercus spp*. will expand.

Finaly, mixed forest stands habitat suitability will expand from the north-east side to the south-west side of Trabzon regional forest, where at the same time *Alnus orientalis* will expand as pure stand and *Pinus sylvestris* as mix stand with other species in this mixed forest from 2020 to 2050 under climate change scenario RCP8.5.

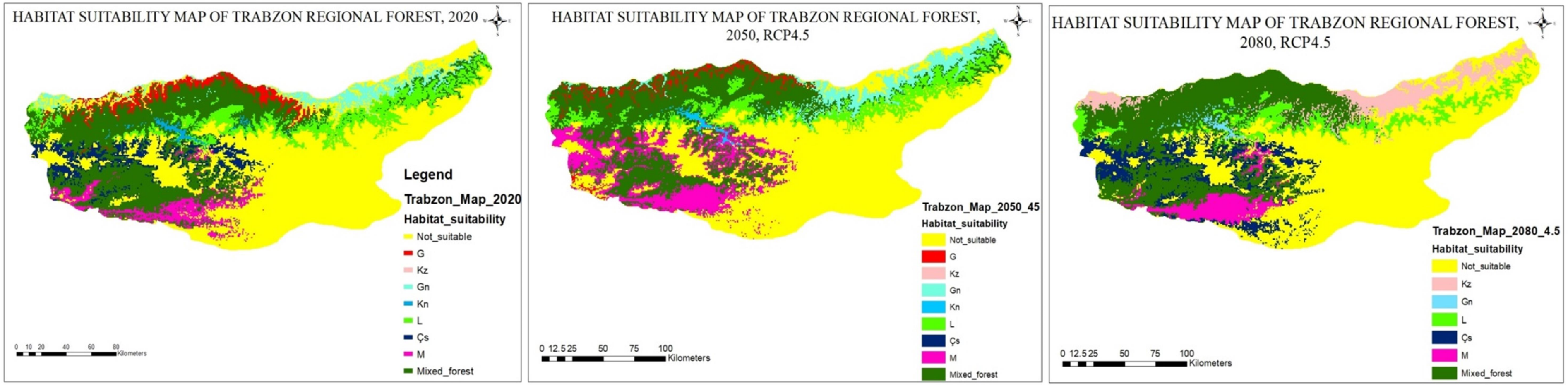


Figure 32. Habitat suitability maps from MaxEnt model for selected tree species in Trabzon regional forest in 2020, 2050 and 2080 under RCP4.5

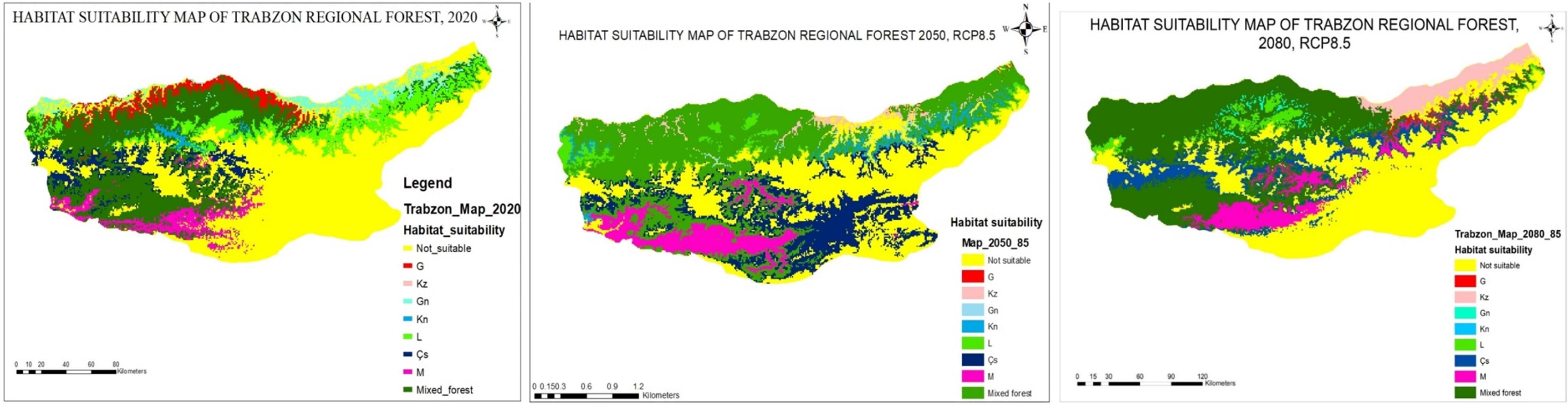


Figure 33. Habitat suitability maps from MaxEnt model for selected tree species in Trabzon regional forest in 2020, 2050 and 2080 under RCP8.5

3.1.1.9. Habitat Suitability Change Maps in Trabzon Regional Forest

Change maps have been produced in order to determine the side of the forests where the change is more perceptible and if possible, identify sample areas to implement research stations to monitor the effects of climate change on the forest. The Figure 34 below presents changes maps in Trabzon regional forest.

It can be mentioned from figure 34 that the change is accentuated on the north borders of Trabzon on the Black sea side under climate change scenario RCP 4.5. As well under climate change scenario RCP 8.5 presented in Figure 35, it can be mentioned that a large change will happen at the north border of the black sea side and the south-east side.

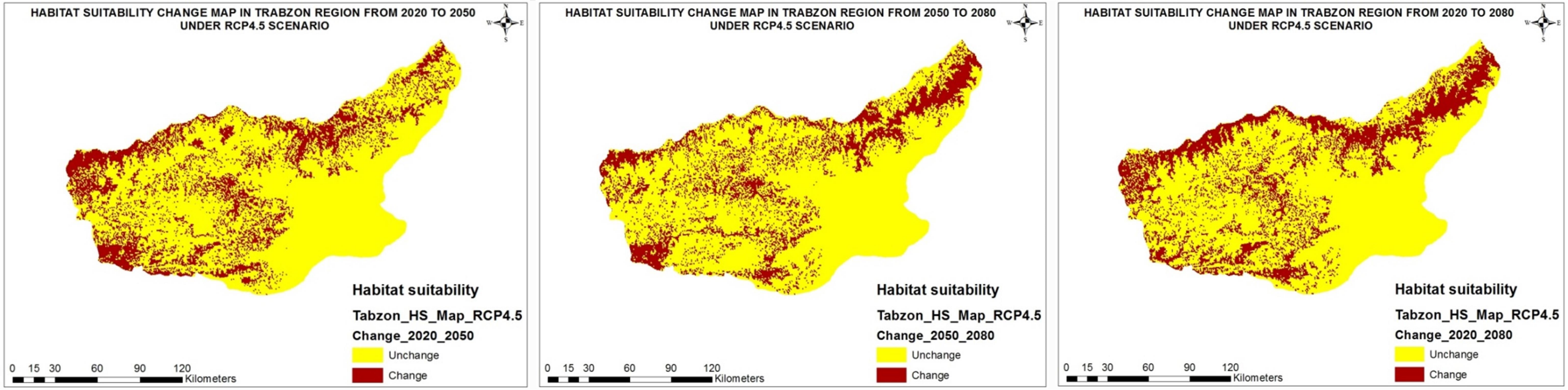


Figure 34. Habitat suitability change maps in Trabzon regional forests under climate change scenario RCP 4.5

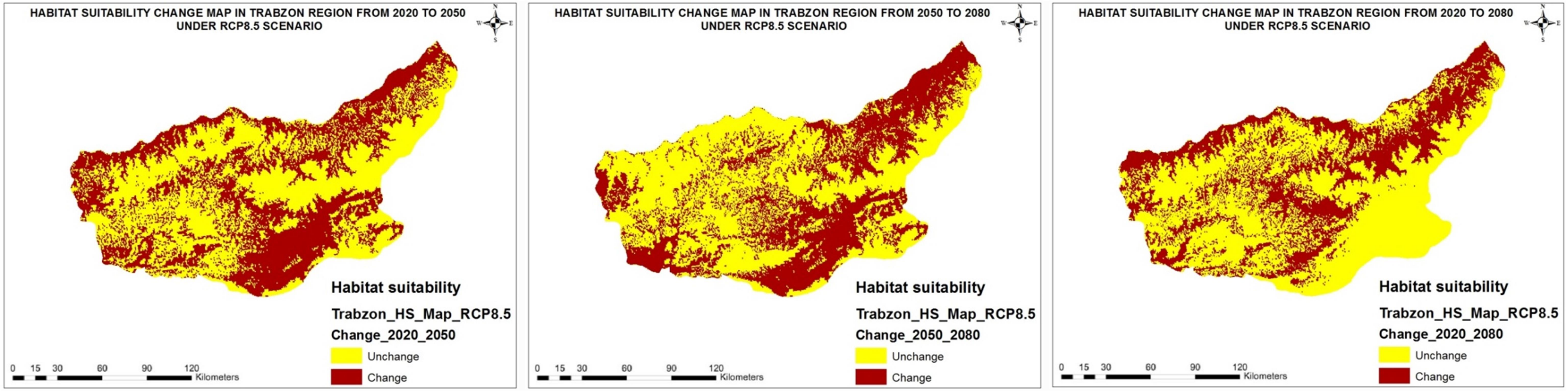


Figure 35. Habitat suitability change maps in Trabzon regional forests under climate change scenario RCP 8.5

3.1.1.10. Change Matrix in Trabzon Regional Forest

The matrix tables of change for each of the Mixture maps are presented in the following tables 14, 15, 16, 17, 18 and 19.

Table 14. Change matrix from 2020 to 2050 under RCP 4.5 in Trabzon regional forest

		2050_RCP 4.5									
	Area	**Çs**	**G**	**Gn**	**Kn**	**Kz**	**L**	**M**	**Mixed**	**Not suit.**	**Total (ha)**
2020_RCP 4.5	Çs	99561.8	0.0	0.0	0.0	0.0	1821.1	1436.4	24548.9	11543.8	138912.0
	G	21.2	29549.5	0.0	0.0	6583.8	1.1	1.5	53439.5	169.0	89765.6
	Gn	0.0	0.0	10878.7	0.0	455.7	0.0	0.0	6662.0	0.0	17996.4
	Kn	0.0	1231.0	0.0	67968.6	3311.8	3131.6	0.0	23569.1	9654.1	108866.3
	Kz	0.0	192.3	0.0	0.0	67175.0	0.0	0.0	17720.2	22400.1	107487.5
	L	322.6	131.4	842.8	1418.3	1240.7	102963.8	3001.1	19886.9	19591.8	149399.4
	M	4105.5	2464.3	0.0	0.0	0.0	0.0	67131.7	8209.4	39756.9	121667.8
	Mixed	41483.9	3417.7	2280.7	20900.8	13063.6	43947.1	40290.1	516895.3	14198.8	696478.1
	Not suit.	32437.8	17036.6	2353.7	386.2	54264.5	9694.4	18001.4	29752.5	1003297.1	1167224.2
	Total (ha)	**177932.8**	**54022.8**	**16355.8**	**90673.9**	**146095.2**	**161559.1**	**129862.1**	**700684.0**	**1120611.6**	**2597797.4**

Table 15. Change matrix from 2050 to 2080 under RCP 4.5 in Trabzon regional forest

		2080_RCP 4.5							
	Area	**Çs**	**Gn**	**Kz**	**L**	**M**	**Mixed**	**Not_suit.**	**Total (ha)**
2050_RCP 4.5	Çs	138155.0	0.0	0.0	2097.02	720.9	23752.9	13207.0	177932.8
	G	158.881	130.0	10164.7	0.0	0.0	42655.9	913.3	54022.8
	Gn	0.0	8261.7	2343.7	0.0	66.7	4047.2	1636.5	16355.8
	Kn	0.0	0.0	3538.4	5982.6	0.0	10357.1	70795.9	90673.9
	Kz	0.0	0.0	104456.1	323.7	0.0	20671.9	20643.4	146095.2
	L	1604.9	0.0	0.0	121335.6	0.0	25921.1	12697.4	161559.1
	M	1114.8	0.0	64.3	2546.7	98274.1	17774.9	10087.5	129862.1
	Mixed	26629.4	7665.3	49995.2	32105.9	10385.1	555826.5	18076.6	700684.0
	Not_suit.	55588.8	198.5	29992.6	17881.1	12553.6	22126.5	982270.3	1120611.6
	Total (ha)	**223251.8**	**16255.5**	**200554.9**	**182272.8**	**122000.5**	**723134.0**	**1130327.8**	**2597797.4**

Table 16. Change matrix from 2020 to 2080 under RCP 4.5 in Trabzon regional forest

		2080_RCP 4.5							
	Area	**Çs**	**Gn**	**Kz**	**L**	**M**	**Mixed**	**Not_suit.**	**Total (ha)**
2020_RCP 4.5	Çs	114534.6	0.0	0.0	2480.8	846.0	14487.7	6562.9	138912.0
	G	42.1	0.0	2473.0	0.7	0.2	87098.5	151.1	89765.6
	Gn	0.0	8655.0	1824.4	0.0	0.0	7516.9	0.0	17996.3
	Kn	0.0	65.1	9592.4	6225.4	0.0	12892.8	80090.5	108866.3
	Kz	0.0	0.0	88020.4	0.0	0.0	12064.2	7402.9	107487.5
	L	238.6	66.1	1299.1	112253.2	195.6	13610.7	21736.1	149399.4
	M	10649.2	131.6	0.0	326.5	68452.5	22795.4	19312.6	121667.8
	Mixed	34697.5	7337.7	30873.3	47639.2	35874.8	523141.5	16914.2	696478.1
	Not_suit.	63089.7	0.0	66472.3	13347.0	16631.5	29526.2	978157.4	1167224.2
	Total (ha)	**223251.8**	**16255.5**	**200554.9**	**182272.8**	**122000.5**	**723134.0**	**1130327.8**	**2597797.4**

Table 17. Change matrix from 2020 to 2050 under RCP 8.5 in Trabzon regional forest

2020_RCP 8.5		2050_RCP 8.5									
	Area	**Çs**	**G**	**Gn**	**Kn**	**Kz**	**L**	**M**	**Mixed**	**Not_suit.**	**Total (ha)**
	Çs	74359.0	0.0	0.0	0.0	0.0	2021.7	2440.1	36433.0	23658.2	138912.0
	G	13.6	0.0	2543.5	0.0	6203.5	0.8	0.0	78977.6	2026.6	89765.5
	Gn	0.0	0.0	3126.5	391.9	131.5	0.0	62.9	13114.5	1169.0	17996.3
	Kn	1038.1	0.0	2533.7	42501.0	0.0	2978.7	66.4	54711.8	5036.4	108866.2
	Kz	0.0	196.1	4292.1	0.0	17500.7	0.0	0.0	55088.0	30410.6	107487.5
	L	32966.8	0.0	0.0	262.8	0.0	22159.7	0.0	85084.8	8925.3	149399.4
	M	13987.5	0.0	0.0	1331.2	0.0	0.0	74185.0	24713.8	7450.3	121667.7
	Mixed	56870.6	0.0	1298.1	12418.3	2463.3	33995.9	72141.4	516440.9	849.4	696478.0
	Not_suit.	254539.8	1016.1	8234.5	814.4	16091.6	12690.2	62856.9	140372.5	670608.3	1167224.4
	Total (ha)	**433775.3**	**1212.2**	**22028.4**	**57719.6**	**42390.7**	**73847.1**	**211752.8**	**1004936.9**	**750134.2**	**2597797.3**

Table 18. Change matrix from 2050 to 2080 under RCP 8.5 in Trabzon regional forest

2050_RCP 8.5		2080_RCP_ 8.5									
	Area_ha	**Çs**	**G**	**Gn**	**Kn**	**Kz**	**L**	**M**	**Mixed**	**Not_suit.**	**Total (ha)**
	Çs	102088.79	0.75	0.0	0.18	0.0	108.96	29003.11	86272.62	216300.93	433775.34
	G	0.0	0.0	0.0	0.0	1153.60	0.0	0.0	10.27	48.33	1212.20
	Gn	0.0	932.64	1968.99	0.34	2157.93	0.0	14.45	8056.21	8897.88	22028.44
	Kn	126.60	3852.96	30.90	1296.84	0.25	217.04	7911.83	35895.54	8387.64	57719.59
	Kz	0.0	25.08	59.49	20.31	17179.08	0.0	0.0	24559.55	547.22	42390.73
	L	4154.24	49.98	0.89	30.54	0.0	24312.68	16.19	35555.79	9726.76	73847.07
	M	1129.33	0.0	0.0	65.46	442.19	194.48	100194.51	90941.97	18784.89	211752.83
	Mixed	33943.41	4365.32	13931.74	200.68	75790.30	58770.58	35298.64	689403.57	93232.62	1004936.86
	Not_suit.	99515.15	2102.84	435.84	108.56	36070.55	809.89	8245.38	36969.24	565876.78	750134.23
	Total (ha)	**240957.51**	**11329.57**	**16427.85**	**1722.91**	**132793.91**	**84413.63**	**180684.11**	**1007664.76**	**921803.05**	**2597797.30**

Table 19. Change matrix from 2020 to 2080 under RCP 8.5 in Trabzon regional forest

2020_RCP 8.5		2080_RCP8.5									
	Area	**Çs**	**G**	**Gn**	**Kn**	**Kz**	**L**	**M**	**Mixed**	**Not_suit.**	**Total (ha)**
	Çs	75722.40	0.0	0.0	0.0	0.35	6675.08	3913.78	43336.80	9263.59	138912.00
	G	28.53	56.28	0.0	1.06	14.62	1.51	0.0	89575.47	88.07	89765.54
	Gn	0.0	0.0	4017.45	0.01	0.0	16.17	0.0	13961.11	1.61	17996.36
	Kn	765.70	8592.30	0.0	956.29	132.65	397.07	13206.51	50229.24	34586.50	108866.26
	Kz	0.0	56.95	60.35	51.69	69444.57	0.0	0.0	27297.67	10576.28	107487.50
	L	19283.98	1.50	0.91	22.94	0.0	39155.57	13745.65	73748.60	3440.30	149399.45
	M	5969.89	0.0	0.0	56.11	0.0	1162.35	56462.60	46232.97	11783.81	121667.73
	Mixed	44139.34	298.38	12349.14	501.24	850.17	27965.76	27770.45	561982.58	20620.95	696478.01
	Not_suit.	95047.67	2324.16	0.0	133.56	62351.55	9040.13	65585.12	101300.32	831441.94	1167224.45
	Total (ha)	**240957.51**	**11329.57**	**16427.85**	**1722.91**	**132793.91**	**84413.63**	**180684.11**	**1007664.76**	**921803.05**	**2597797.30**

From Table 14, it can be mentioned that the area of suitability of *Pinus sylvestris (Çs)* will increase from 139.000 ha to 178.000 ha, taking more suitable area from mixed forest (41.483 ha) and not suitable area (32.437 ha). Similarly the area of suitability of *Alnus glutinosa* (Kz), *Picea orientalis* (L) and *Quercus spp* (M) will increase from 2020 to 2050 under climate scenario RCP 4.5. Furthermore, the habitat suitability of mixed forest area will slightly increase while the not suitable area will decrease from 1.167.224 ha to 1.120.611 ha. At contrary, habitat suitability area of *Abies nordmaniana* (G), *Carpinus orientalis* (Gn) and *Fagus orientalis* (Kn) will decrease.

From Table 15, it can be mentioned that the area of suitability of *Pinus sylvestris (Çs)* will increase, taking more suitable area from mixed forest and not suitable area. Similarly the area of suitability of *Alnus glutinosa* (Kz), *Picea orientalis* (L) and *Quercus spp* (M) will increase from 2050 to 2080 under climate scenario RCP 4.5. Furthermore, the habitat suitability of mixed forest area will slightly increase while the not suitable area will decrease. At contrary, habitat suitability area of *Abies normaniana (G)*, *Carpinus orientalis* (Gn) and *Fagus orientalis* (Kn) will decrease.

From Table 16, it can be mentioned that the area of suitability of *Pinus sylvestris (Çs)* will nearly double from 2020 to 2080 under RCP4.5, taking more suitable area from mixed forest and not suitable area. Similarly the area of suitability of *Alnus glutinosa* (Kz), *Picea orientalis* (L) and *Quercus spp* (M). will increase considerably from 2020 to 2080 under climate scenario RCP 4.5. Furthermore, the habitat suitability of mixed forest area will slightly increase while the not suitable area will decrease. At contrary, habitat suitability area of *Abies normaniana* and *Fagus orientalis* will disappear as pure stand from 2020 to 2080, while *Carpinus orientalis* habitat suitability area will decrease.

According to matrix table under the climate change scenario RCP 4.5, the most tree species that habitat suitability will be the most affected by climate change are *Fagus orientalis* (Kn) and *Abies normanniana* (G) whose pure stand habitat suitability will disappear due to climate change. At the contrary, *Quercus spp*. (M) and *Pinus sylvestris* (Çs) have the tendency to maintain and increase their surface over the climate change influence. This means that they are well adapted to future climate conditions in this area. Furthermore, the mixed forest stand habitat suitability is increasing meaning that the best way to help the forest to adapt to future climate condition will be by mixing tree species in the forest areas.

From this matrix Table 17, it can be mentioned that the area of suitability of *Pinus sylvestris (Çs)* will increase more than 3 times from 2020 to 2050 under RCP8.5, taking more suitable area from not suitable area. Similarly the area of suitability of *Alnus glutinosa* (Kz), *Carpinus orientalis* and *Quercus spp.* will increase. Furthermore, the habitat suitability of mixed forest area will slightly increase while the not suitable area will decrease. At contrary, habitat suitability area of *Abies normaniana*, *Picea orientalis*, and *Fagus orientalis* will decrease considerably from 2020 to 2050 under RCP 8.5.

From Table 18, it can be mentioned that the area of suitability of *Pinus sylvestris (Çs)* will decrease from 2050 to 2080 under RCP8.5. Similarly the area of suitability of *Carpinus orientalis* (Gn), and *Quercus spp* (M). will decrease from 2050 to 2080 under climate scenario RCP 4.5. Furthermore, the habitat suitability of mixed forest area and not suitable area will increase. At contrary, habitat suitability area of of *Abies nordmaniana*, *Alnus glutinosa* (Kz), *Picea orientalis* (L), and *Fagus orientalis* (Kn) will increase considerably.

From Table 19, it can be mentioned that the area of suitability of *Pinus sylvestris (Çs)* will nearly double from 2020 to 2080 under RCP8.5, taking more suitable area from mixed forest and not suitable area. Similarly the area of suitability of *Abies normaniana*, *Alnus glutinosa* (Kz), and Quercus spp. will increase from 2020 to 2050 under climate scenario RCP 4.5. Furthermore, the habitat suitability of mixed forest area will increase considerably while the not suitable area will decrease. At contrary, habitat suitability area of *Picea orientalis*, *Carpinus orientalis* and *Fagus orientalis* will decrease considerably.

Similarly, under the climate scenario RCP 8.5, *Abies normanniana* (G) and *Fagus orientalis* (Kn) are the most affected tree species by the climate change with a drastic reduction of their habitat suitability in their pure stands. As well the mixed forest stand habitat suitability is increasing meaning that mixed forest will be well adapted to the future clime conditions compared to pure stands.

3.1.2. Habitat Suitability Modelling Results in Antalya Regional Forest

3.1.2.1. Habitat Suitability for *Pinus brutia* in Antalya Regional Forest

It can be mentioned from Figure 36 that suitable area for Pinus brutia will reduce from 2020 to 2050 then from 2050 to 2080 and moderately suitable area will increase under both RCP4.5 and RCP8.5. As well, highly suitable area will disappear from 2020 to 2050 under RCP4.5 and RCP8.5 meaning that the suitable area for Pinus brutia will decrease in the future according to each future climate change scenarios. It can be mentioned from Figure 37 that bio 1 and bio 11 influence the most the distribution of Pinus brutia, and the model is well calibrated with an AUC of 0.8 as presented in Figure 38.

3.1.2.2. Habitat Suitability for *Pinus nigra* in Antalya Regional Forest

It can be mentioned from Figure 39 that highly suitable area for *Pinus nigra* will expand on the east side of Antalya from 2020 to 2050 then from 2050 to 2080 and moderately suitable area will expand on the west side of Antalya under both RCP4.5 and RCP8.5. Furthermore, the highly suitable area changes completely the side from the east to the west side of Antalya from 2050 to 2080 under RCP8.5. It can also be mentioned from Figure 40 that bio 9, bio 1 and bio 10 are contributing the most to the distribution of *Pinus nigra*, and bio 9 contribute the most to the AUC model calibration that is greater than 0.9 (Figure 41).

3.1.2.3. Habitat Suitability for *Quercus spp.* in Antalya Regional Forest

It can be mentioned from Figure 42 that suitable and moderately suitable area for *Quercus spp.* will expand all over the region of Antalya under both RCP4.5 and RCP8.5. As well, in Figure 43, it is mentioned that bio10 and bio9 are contributing the most to the expantion of Quercus spp. in the Antalya region, while in Figure 44, the AUC is greater than 0.9, meaning that the model is well calibrated.

3.1.2.4. Habitat Suitability for Cedrus libani in Antalya Regional Forest

It can be mentioned from Figure 45 that suitable and moderately suitable habitat are expanding on the west side of Antalya region from 2020 to 2050, then from 2050 to 2080 under both RCP4.5 and RCP 8.5. As well, highly suitable area appear in 2080 under

RCP4.5 and in 2050 and 2080 under RCP 8.5 meaning that the suitable area for Cedrus libani will increase under future climate scenarios. In Figure 46, bio10 and bio9 contribute highly to the expansion of Cedrus libani, with an AUC of 0.8 showing good model calibration (Figure 47).

3.1.2.5. Habitat Suitability for Abies cilicica in Antalya Regional Forest

It can be mentioned from Figure 48 that the highly suitable habitat, as well as the suitable and moderately suitable habitats for Abies cilicica will increase from 2020 to 2050 then from 2050 to 2080 under climate scenario RCP 4.5 and RCP 8.5. It can be mentioned from Figure 49 that bio3 influence the most the distribution of Abies cilicica, and contribute the most to the AUC model calibration of 0.9, meaning that the model is well calibrated as presented in Figure 50.

3.1.2.6. Distribution of all Selected Tree Species Mixture in Antalya Regional Forest

According to Figure 51, it can be mentioned that pure stand of Pinus brutia (Çz) suitable area will reduce giving place to suitable area for Quercus spp., Cedrus libani and mixed forest area from 2020 to 2050 under RCP4.5. As well, pure stand of Abies cilicica expands while pure stand of Pinus nigra reduces. As well, from 2050 to 2080, it can be mentioned that Pinus brutia (Çz) will continue to reduce giving its suitable area to Quercus sp that will have more suitable area under RCP4.5.

Furthermore, It can also be mentioned from Figure 52 that *Quercus spp.* habitat suitability will continue to expand in the Antalya region from 2050 to 2080 under the scenario RCP8.5. As well, mixed forest suitability will expand all over the Antalya region with some good spots suitable for *Pinus nigra* pure stands. *Pinus brutia* suitable area will decrease extremely from 2050 to 2080 under scenario RCP8.5.

Habitat suitability change maps in Antalya are provided in Figure 53 for the scenario RCP4.5 and in Figure 54 for the scenario RCP8.5. It can be mentioned from Figure 53 and Figure 54 that change will occur all over the Antalya region, but precisely at the centre of the region. The Cerle PU is located at the earth of Antalya region and has been used as sample forest for further analysis on forest ecosystem change as presented in Figure 55.

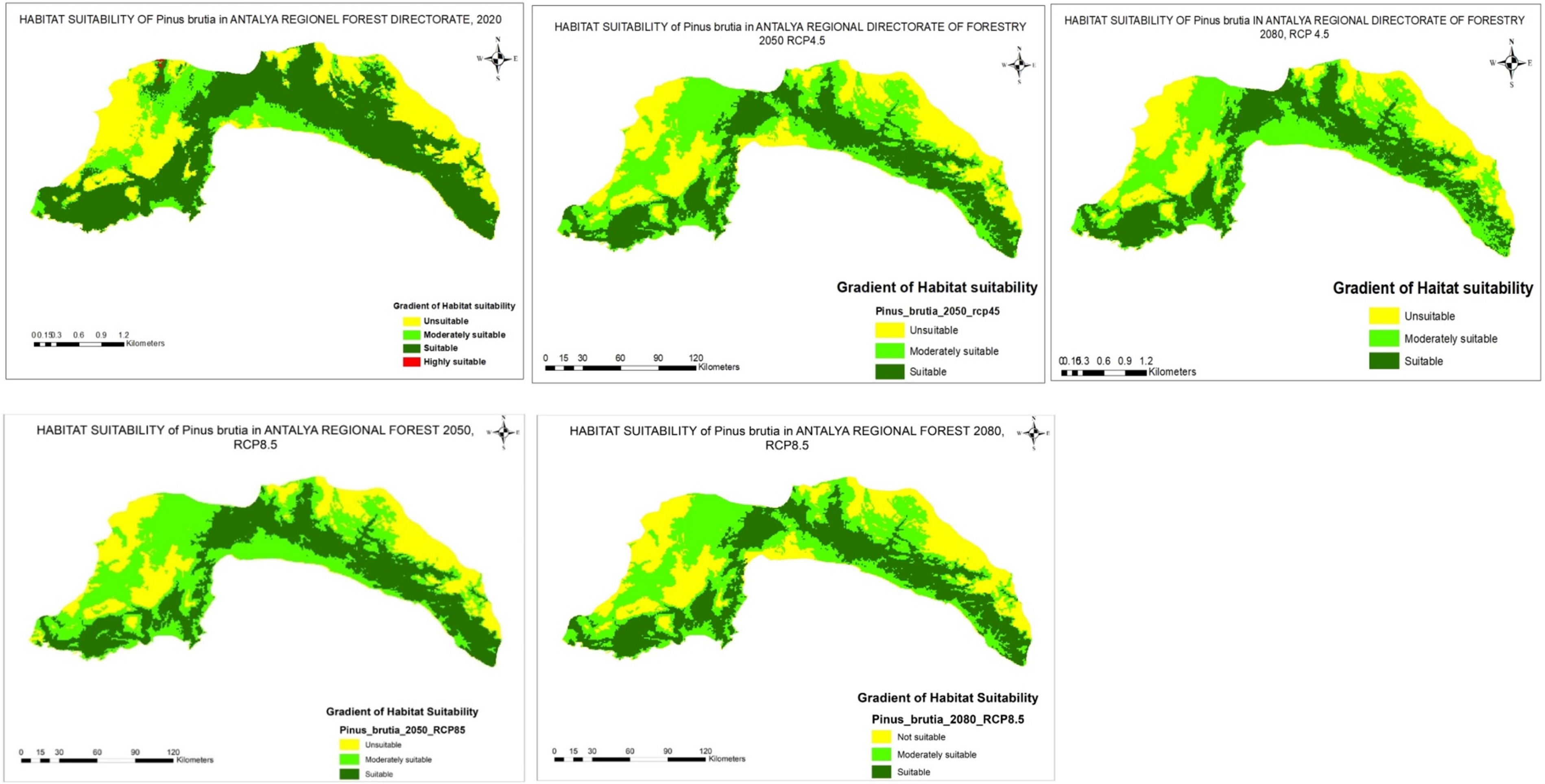


Figure 36. Habitat suitability from MaxEnt models for *Pinus brutia*

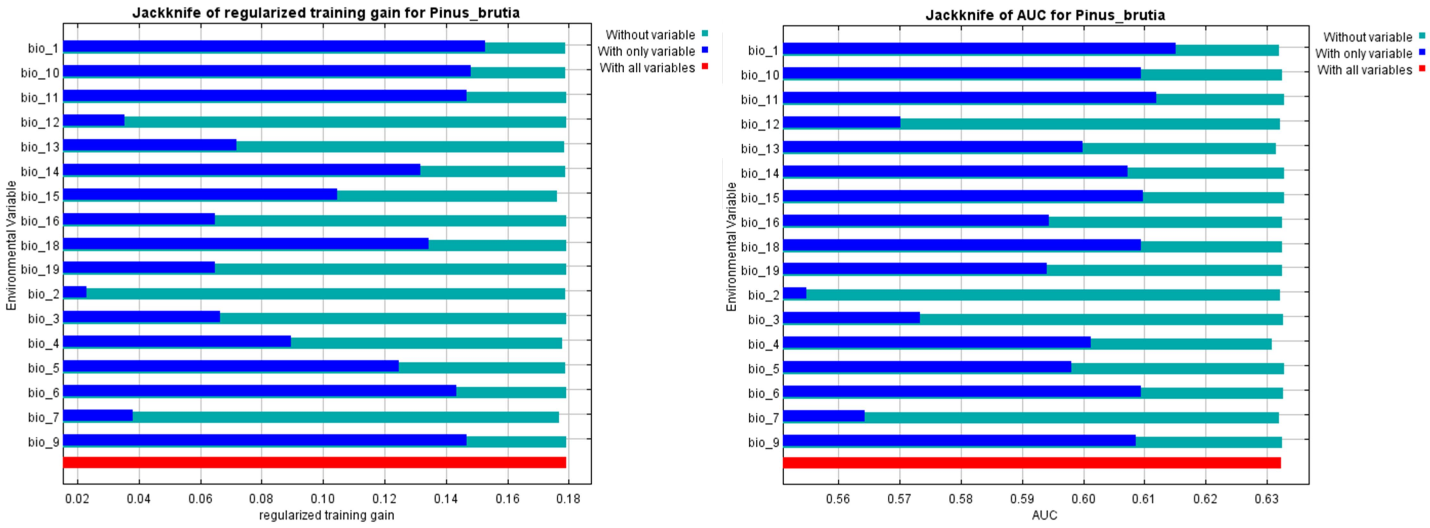


Figure 37. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Pinus brutia*

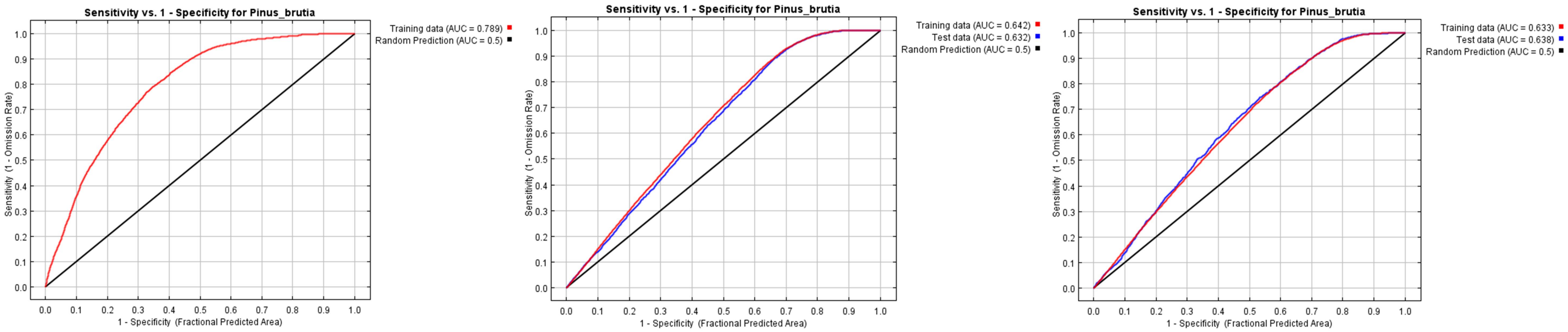


Figure 38. Area under the curve from MaxEnt models for *Pinus brutia*

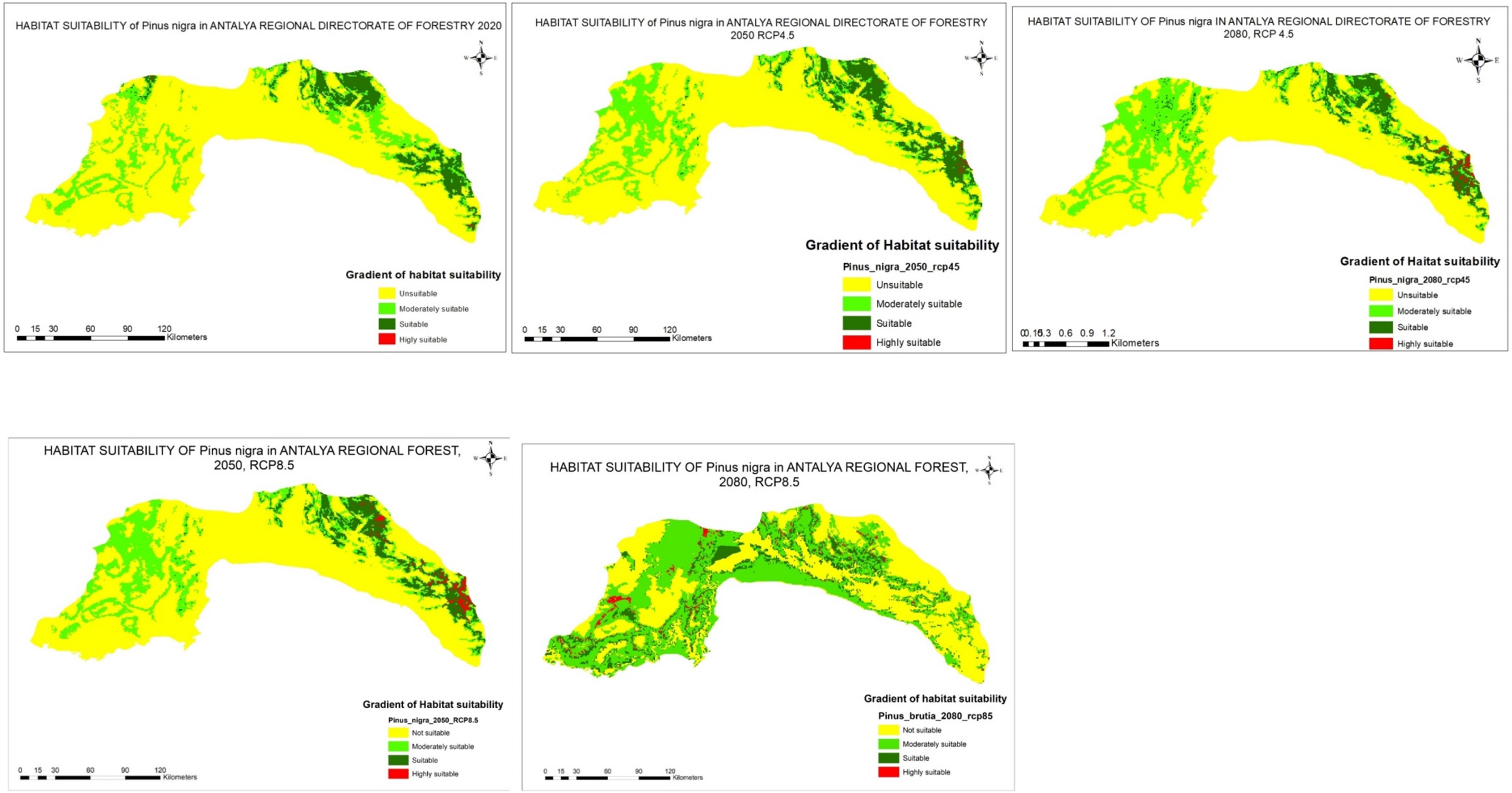


Figure 39. Habitat suitability from MaxEnt models for *Pinus nigra*

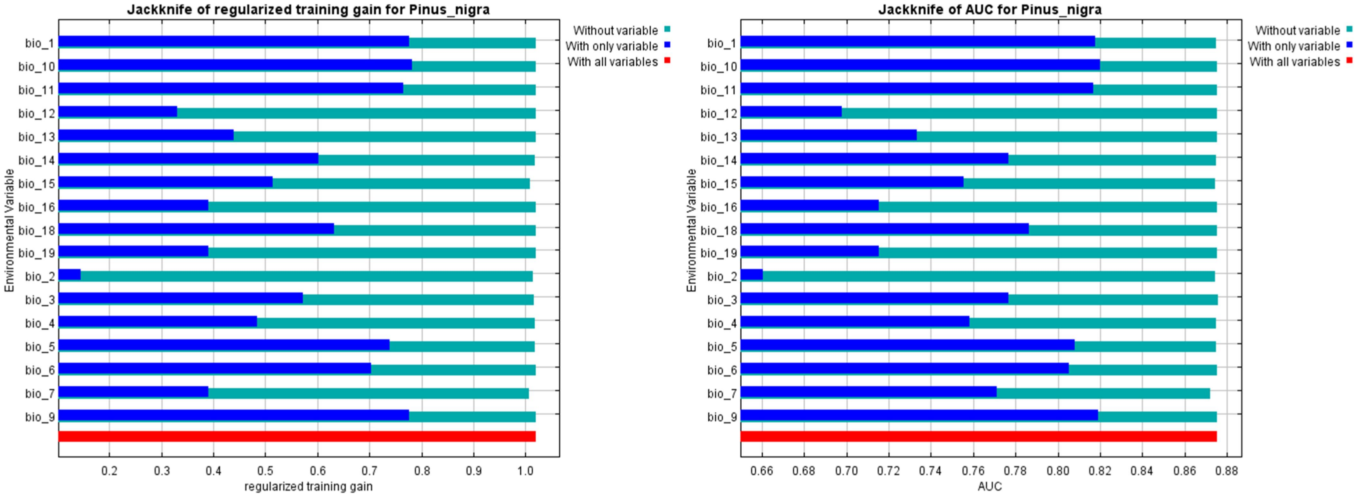


Figure 40. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Pinus nigra*

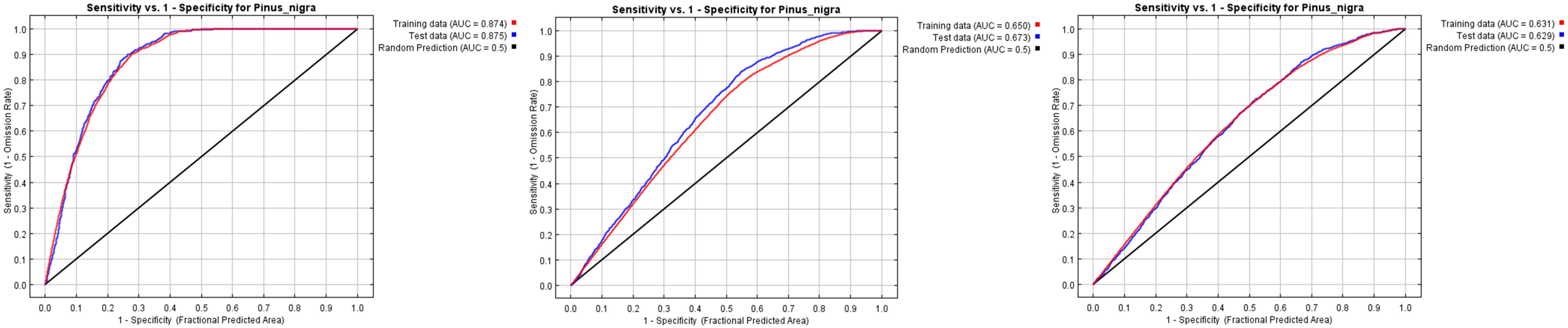


Figure 41. Area under the curve from MaxEnt models for *Pinus nigra*

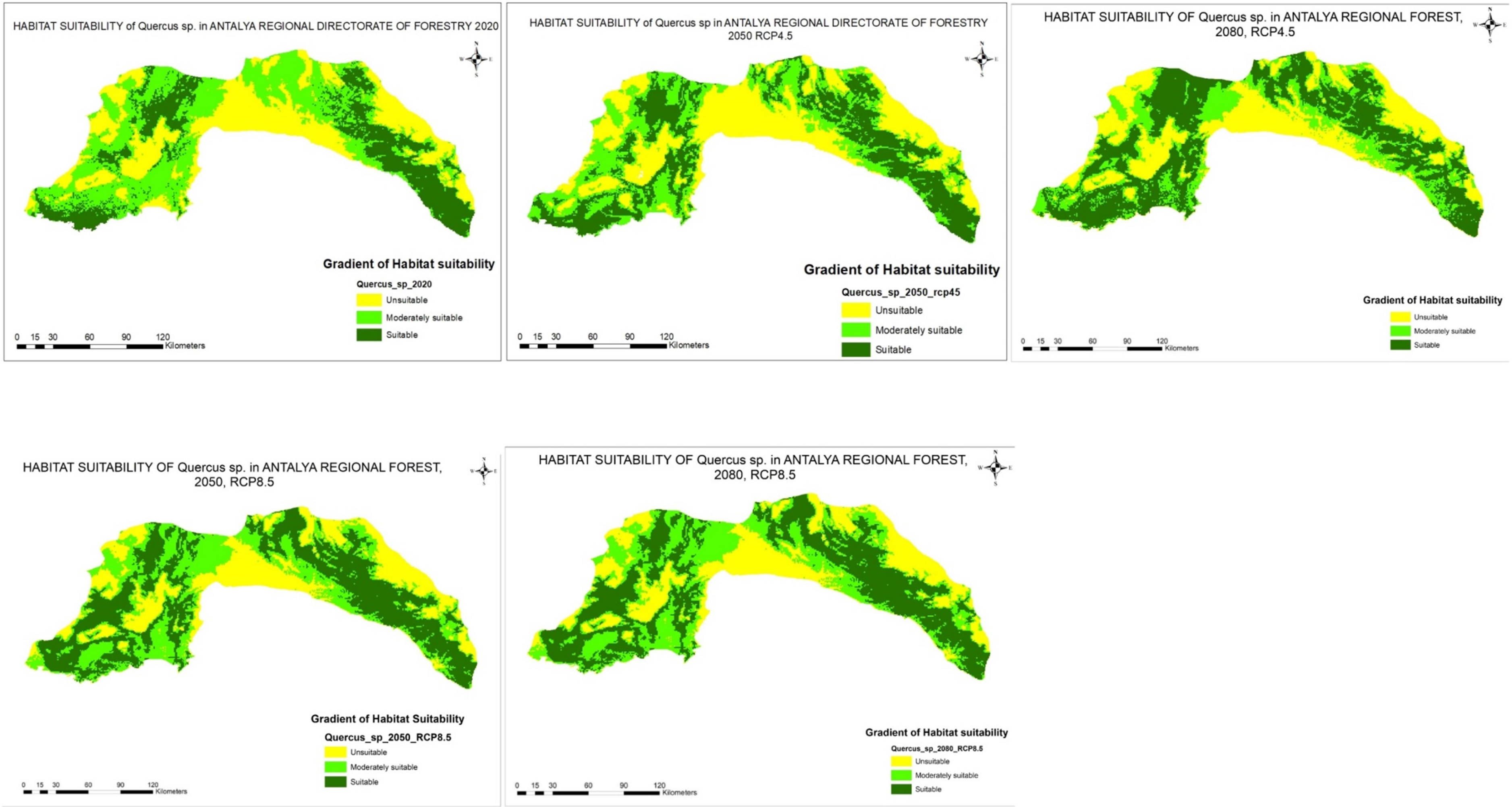


Figure 42. Habitat suitability from MaxEnt models for *Quercus spp.*

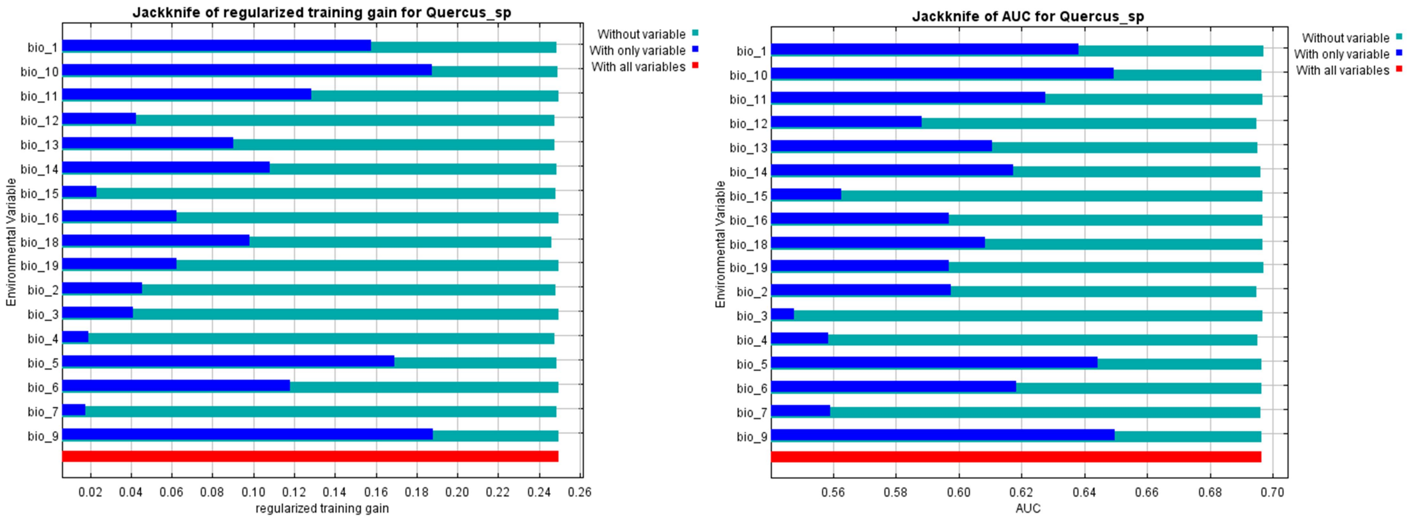


Figure 43. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Quercus spp.*

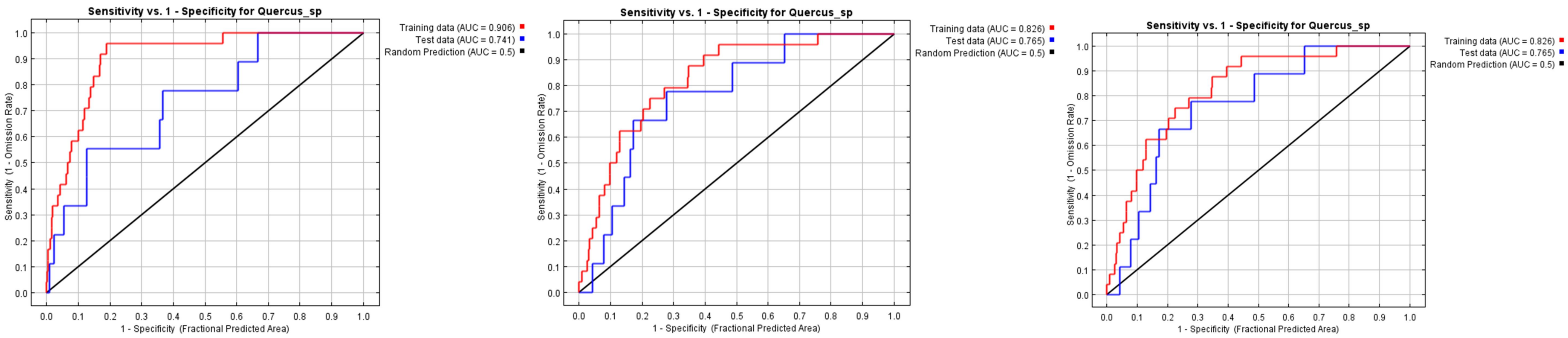


Figure 44. Area under the Curve from MaxEnt models for *Quercus spp.*

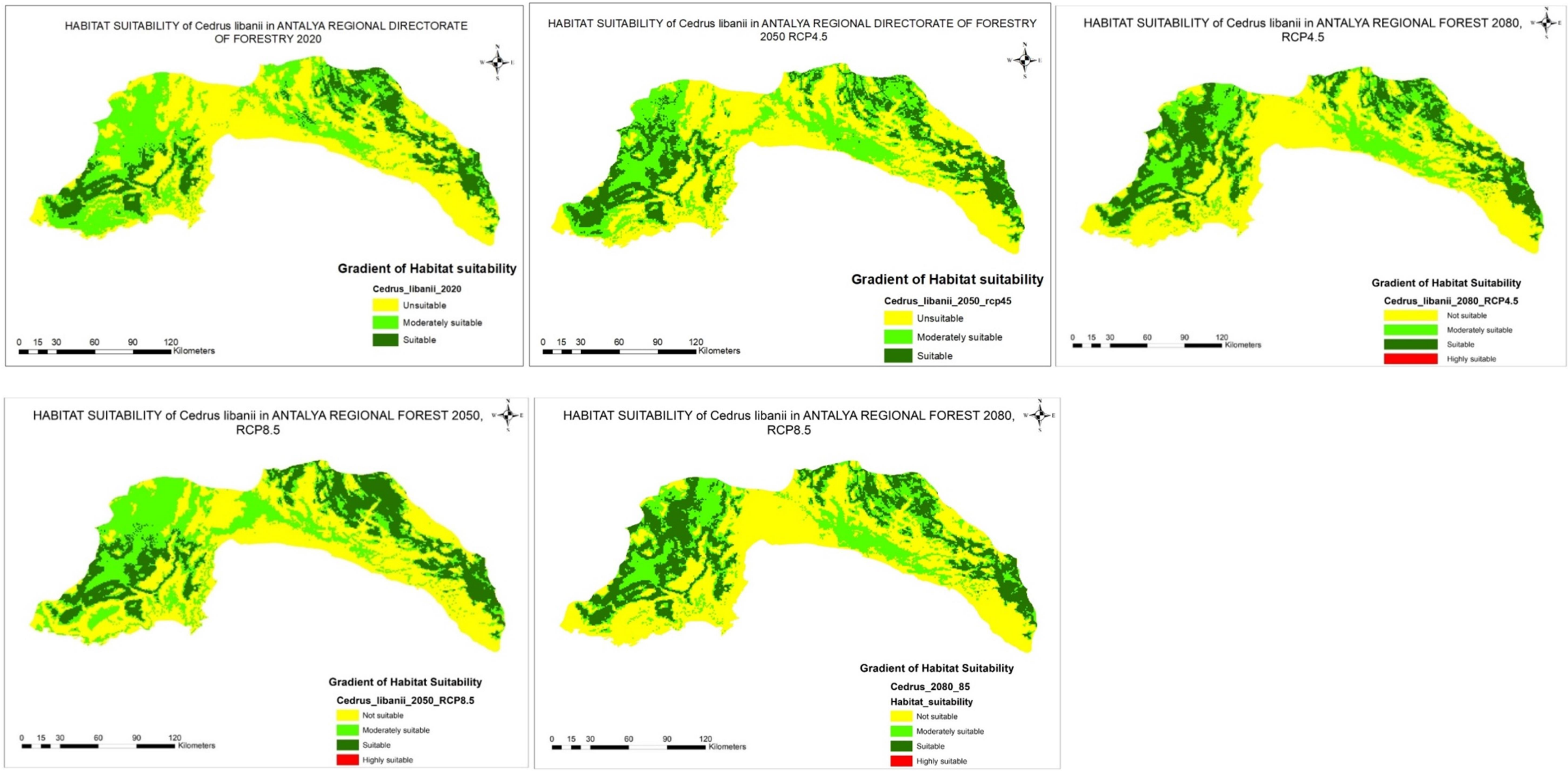


Figure 45**.** Habitat suitability from MaxEnt models for *Cedrus libani*

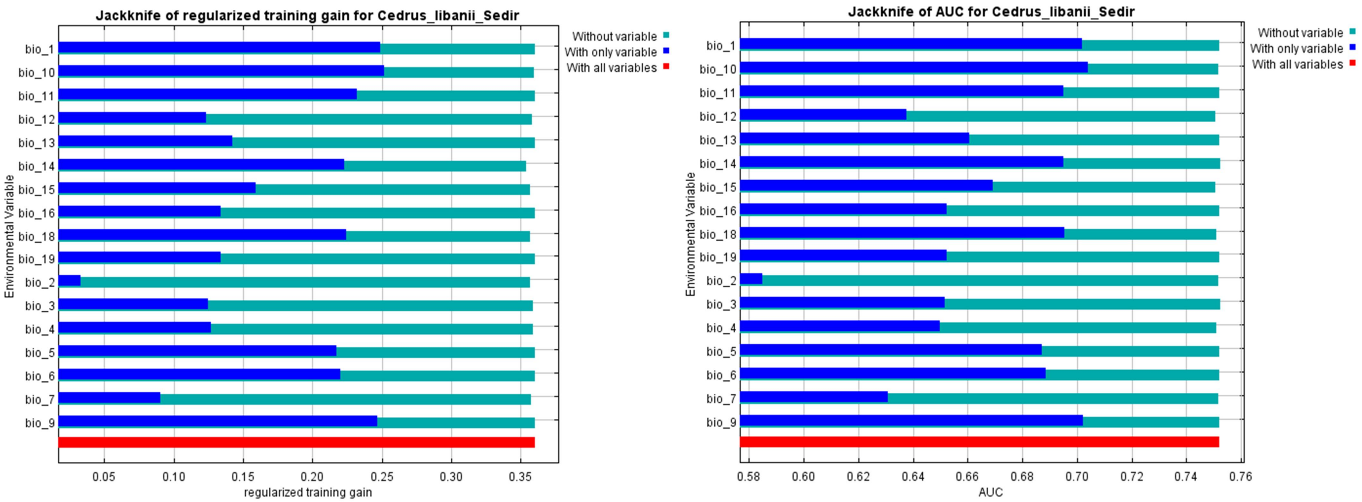


Figure 46. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Cedrus libani*

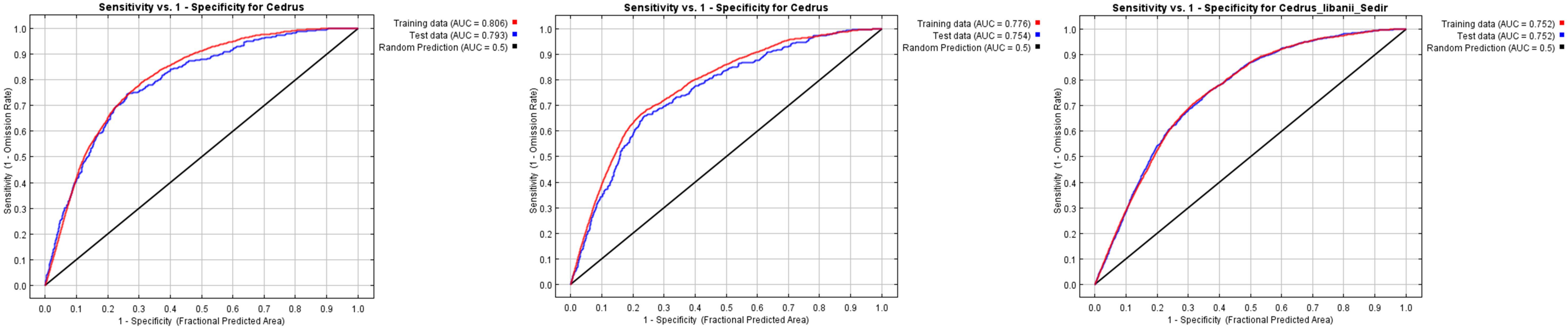


Figure 47. Area under the curve from MaxEnt models for *Cedrus libani*

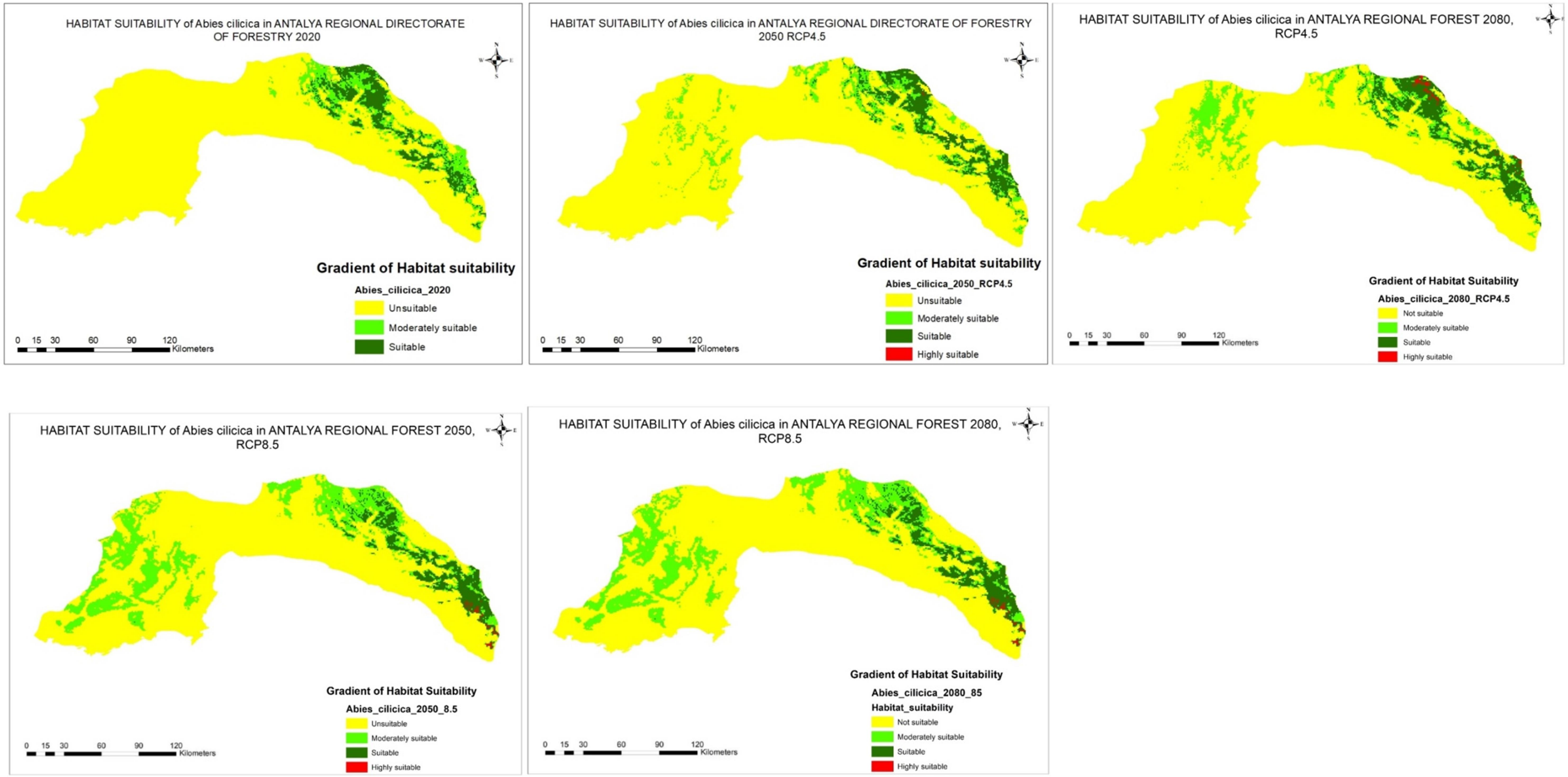


Figure 48. Habitat suitability from MaxEnt models for *Abies cilicica*

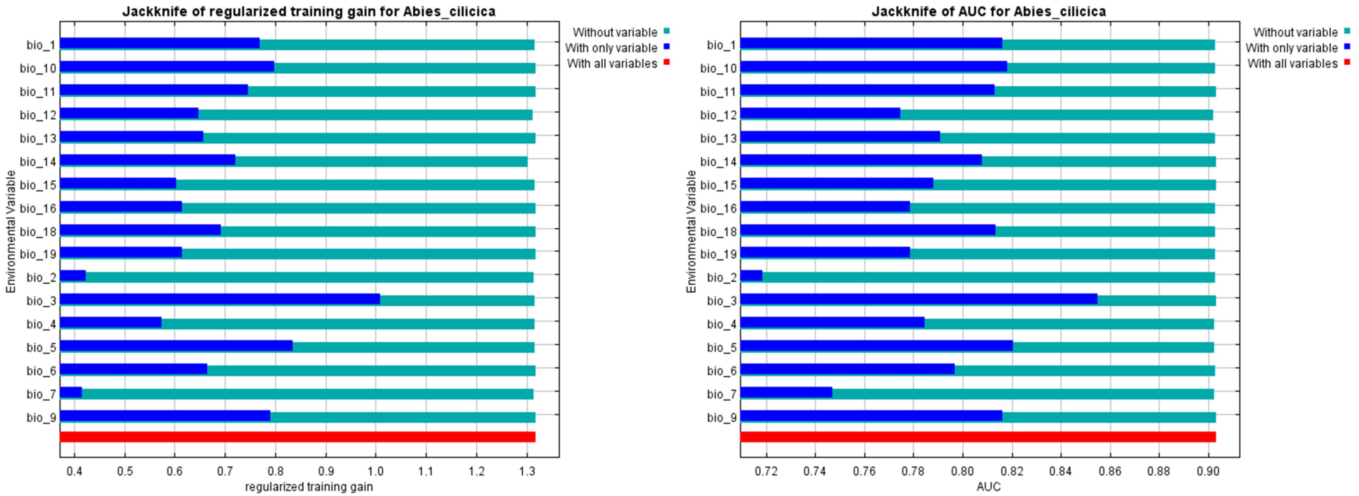


Figure 49. Jackknife of regularized training gain and the jackknife of AUC from MaxEnt models for *Abies cilicica*

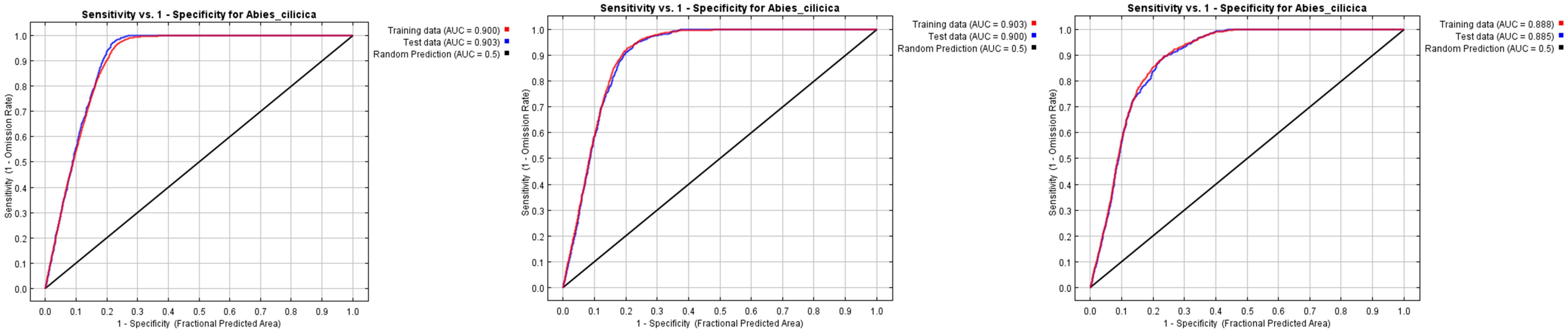


Figure 50. Area under the curve from MaxEnt models for *Abies cilicica*

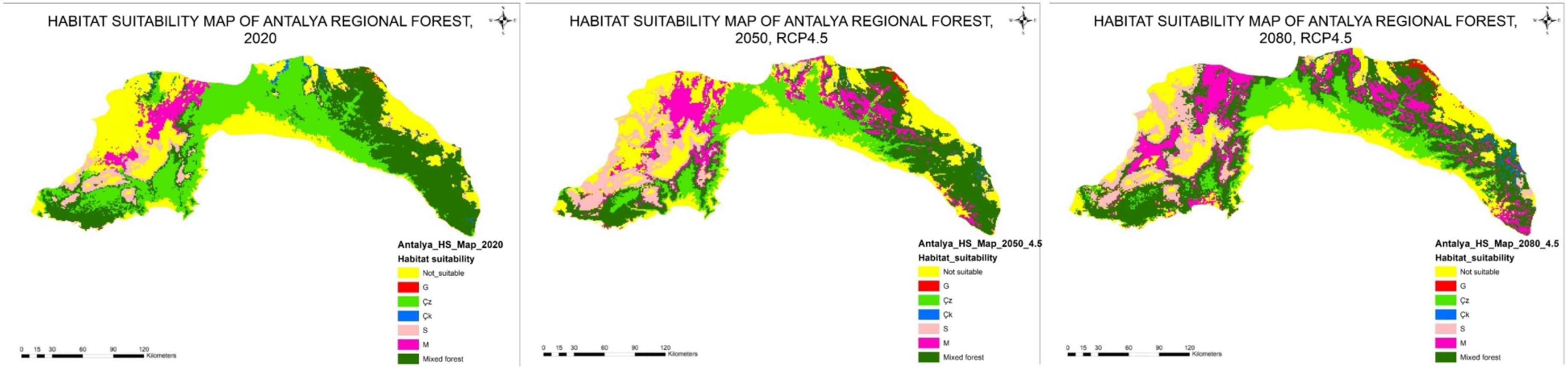


Figure 51. Habitat suitability from MaxEnt models for selected tree species in Antalya from 2020 to 2050 then 2080 under RCP 4.5

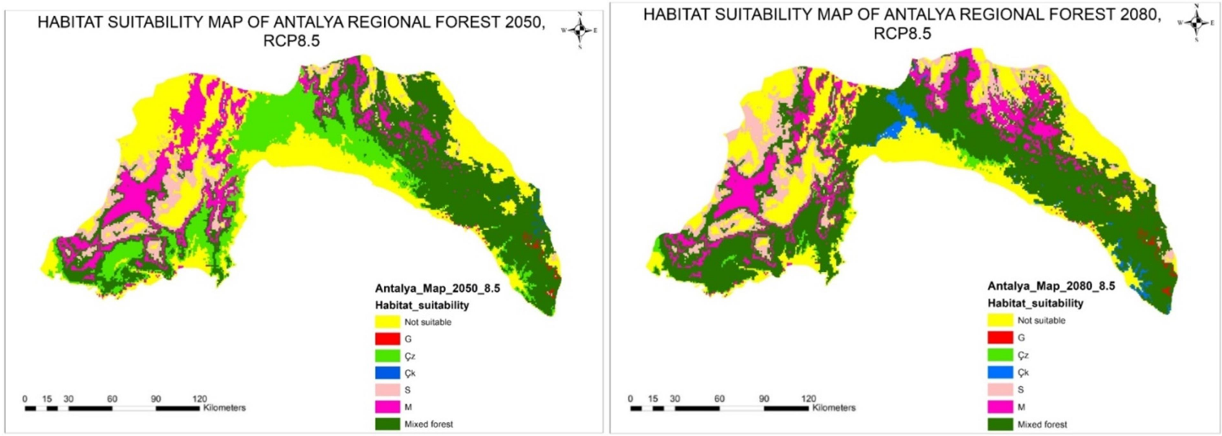


Figure 52. Habitat suitability from MaxEnt models for selected tree species in Antalya from 2020 to 2050 then 2080 under RCP 8.5

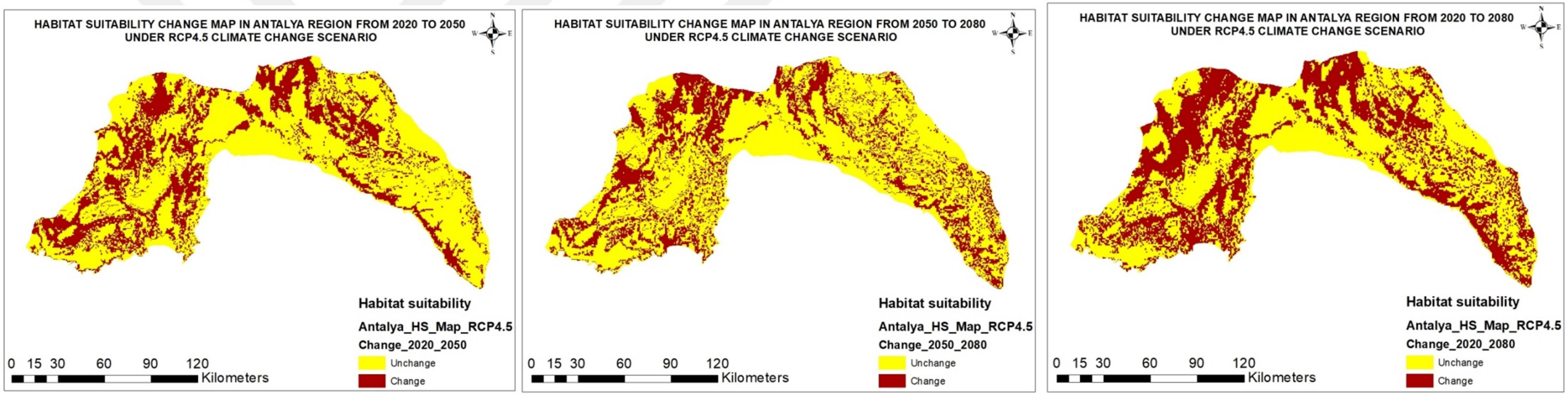


Figure 53. Habitat suitability change maps under RCP 4.5 scenario in Antalya

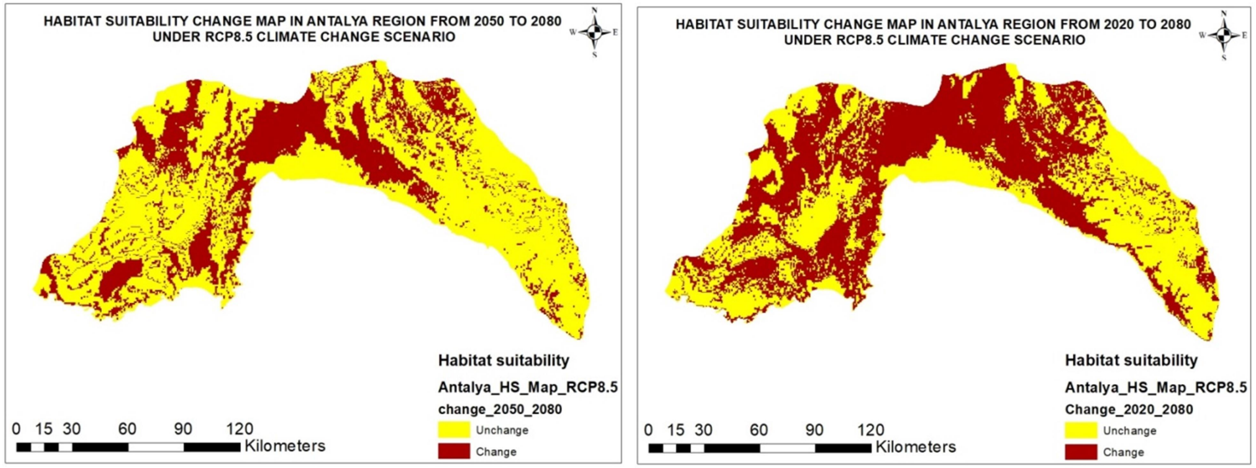


Figure 54. Habitat suitability change maps under RCP 8.5 scenario in Antalya

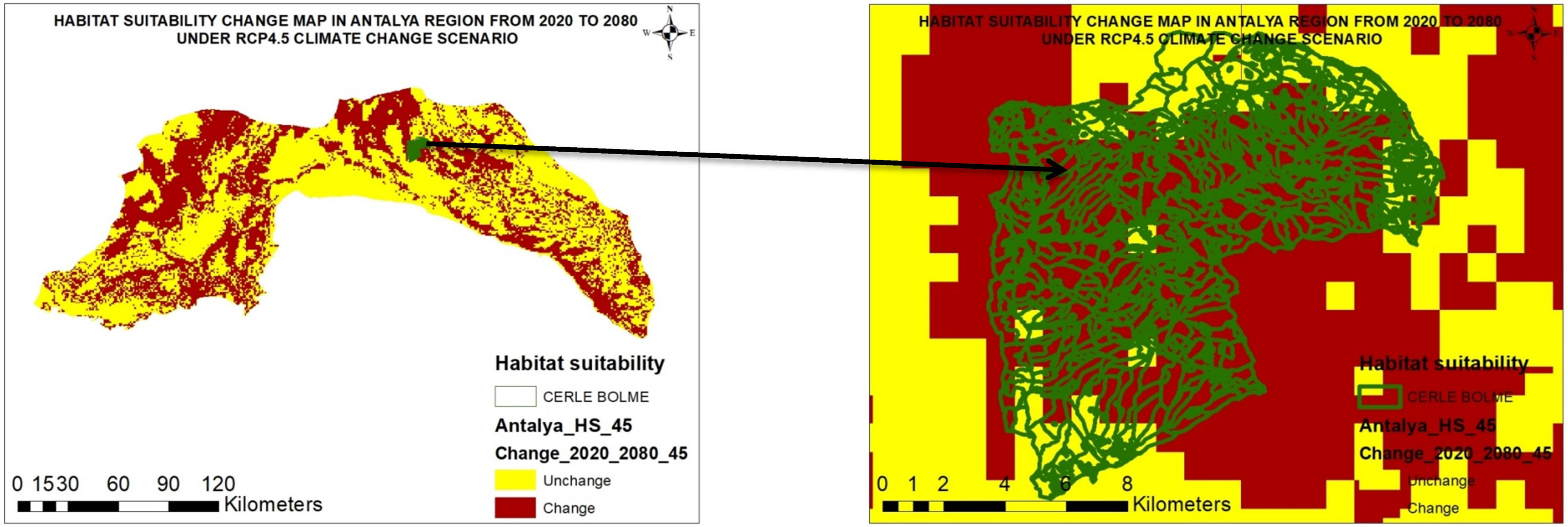


Figure 55. Habitat suitability change map of Cerle PU in Antalya region

3.1.2.7. Change Matrix Tables in Antalya Regional Forest

From Table 20, it can be mentioned that suitable area for *Pinus nigra* will reduce of 1/3 from 2020 to 2050 under RCP4.5. Similarly, suitable area for *Pinus brutia* will reduce from 599.049 ha to 345.802 ha. At contrary, *Abies cilicica*, *Quercus spp.* and *Cedrus libani* suitable area will increase from 2020 to 2050 under RCP4.5.

From Table 21, it can be mentioned that suitable area for *Pinus brutia* will decrease from 345.802 ha to 287.793 ha, while *Pinus nigra*, *Abies cilicica*, *Quercus spp.* and *Cedrus libani* will increase 2050 to 2080 under RCP4.5.

From Table 22, it can be mentioned that suitable area for *Pinus nigra* will reduce from 12.053 ha to 11.090 ha from 2020 to 2080 under RCP4.5. Similarly, suitable area for *Pinus brutia* will reduce from the half. At contrary, *Abies silicica*, *Quercus spp.* and *Cedrus libani* suitable area will increase from 2020 to 2080 under RCP4.5.

From Table 23, it can be mentioned that suitable area for *Quercus spp*, *Cedrus libani* and mixed forest will increase from 2020 to 2050 under RCP8.5.

From Table 24 it can be mentioned that suitable area for *Pinus nigra* will increase from 4,091 ha to 37,518 ha from 2050 to 2080 under the scenario RCP8.5. Similarly *Abies cilicica* and mixed forest habitat suitability will increase. At contrary, *Pinus brutia* habitat suitability will decrease 10 times from 2050 to 2080 under RCP8.5. As well *Quercus spp.* Habitat's suitability will reduce.

From Table 25, it can be mentioned that suitable area for *Quercus spp*, *Cedrus libani* and mixed forest will increase from 2020 to 2080 under RCP8.5. As well suitable area for *Pinus nigra* will increase. At contrary, suitable area for *Pinus brutia* will decrease from 599.047 ha to 33.518 ha. mixed forest will increase.

Significant transition results should also be mentioned. For instance, nearly 80.000 ha of *Pinus brutia* pure forests stands will change into *Quercus spp.* and another 80.000 ha of *Pinus brutia* will change into mixed forests between 2020 and 2050 respectively. As well the total area of *Quercus spp.* will nearly triple from 98.000 ha to 270.000 ha over the same period. Furthermore, the total suitable area of *Pinus brutia* will reduce from 599.000 ha to 346.000 ha from 2020 to 2050, then to 290.000 ha in 2080, under RCP4.5. the same situation is presented under climate chane scenario RCP8.5, where *Pinus brutia* appropriated area will considerably reduce and *Quercus spp.* area appropriateness will continuously increase.

Table 20. Change matrix from 2020 to 2050 under RCP 4.5 in Antalya regional forest

		2050_RCP 4.5							
	Area	**Çk**	**Çz**	**G**	**M**	**S**	**Mixed**	**Not_suit.**	**Total (ha)**
2020_RCP 4.5	Çk	444.03	0.00	0.00	635.74	1745.16	6426.80	2801.36	12053.09
	Çz	16.88	326046.73	0.00	79603.27	5233.83	79333.75	108815.20	599049.66
	G	0.00	0.00	1872.74	0.00	0.00	135.60	907.73	2916.07
	M	52.50	0.50	0.00	60370.06	5349.10	3759.20	28190.22	97721.57
	S	12.87	0.00	343.10	632.18	96419.85	10250.63	8774.37	116433.01
	Mixed forest	3606.91	13403.30	4102.51	97940.68	45656.40	427840.33	25298.26	617848.39
	Not_suitable	324.26	6352.08	2102.07	29490.70	83462.20	7835.56	468964.84	598531.71
	Total (ha)	**4457.45**	**345802.61**	**8420.43**	**268672.63**	**237866.53**	**535581.88**	**643751.97**	**2044553.50**

Table 21. Change matrix from 2050 to 2080 under RCP 4.5 in Antalya regional forest

		2080_RCP 4.5							
	Area	**Çk**	**Çz**	**G**	**M**	**S**	**Mixed**	**Not_suit.**	**Total (ha)**
2050_RCP 4.5	Çk	1069.26	0.00	2.48	79.74	580.69	2705.43	19.85	4457.45
	Çz	0.00	228628.01	0.00	1077.39	1.08	89429.60	26666.52	345802.61
	G	4.32	0.00	5925.86	0.00	1.40	595.32	1893.54	8420.43
	M	16.38	901.56	0.00	160311.53	11338.59	87247.61	8856.97	268672.63
	S	117.63	831.50	318.09	6867.45	170101.83	37143.06	22486.97	237866.53
	Mixed	9804.26	44354.55	5662.47	50502.10	10513.07	399114.44	15631.01	535581.88
	Not_suit.	78.93	13077.96	3164.63	80870.98	42807.07	56379.36	447373.03	643751.97
	Total (ha)	**11090.77**	**287793.58**	**15073.52**	**299709.19**	**235343.73**	**672614.80**	**522927.89**	**2044553.50**

Table 22. Change matrix from 2020 to 2080 under RCP 4.5 in Antalya regional forest

		2080_RCP 4.5							
	Area	**Çk**	**Çz**	**G**	**M**	**S**	**Mixed**	**Not_suit.**	**Total (ha)**
2020_RCP 4.5	Çk	0.00	0.00	0.00	273.18	2676.02	7752.86	1351.03	12053.09
	Çz	0.00	241434.91	0.00	56609.88	1828.54	226592.32	72484.02	599049.66
	G	0.00	0.00	1450.72	0.00	0.00	0.27	1465.08	2916.07
	M	0.00	1.68	0.00	56620.52	12435.75	26164.07	2499.55	97721.57
	S	1.49	0.00	504.27	1.83	92917.78	13253.47	9754.17	116433.01
	Mixed forest	11075.98	45018.73	10286.67	116313.92	28281.77	374662.01	32209.31	617848.39
	Not_suitable	13.30	1338.26	2831.87	69889.85	97203.88	24089.82	403164.74	598531.71
	Total (ha)	**11090.77**	**287793.58**	**15073.52**	**299709.19**	**235343.73**	**673,114.8**	**522927.89**	**2044553.50**

Table 23. Change matrix from 2020 to 2050 under RCP 8.5 in Antalya regional forest

		2050_RCP_8.5							
	Area	**Çk**	**Çz**	**G**	**M**	**S**	**Mixed**	**Not_suit.**	**Total (ha)**
2020_RCP 8.5	Çk	0.00	0.00	503.68	25.56	1671.04	6707.96	3144.04	12052.28
	Çz	1.41	290571.90	0.00	88809.78	540.36	146014.26	73109.39	599047.10
	G	0.00	0.00	0.00	0.00	34.41	101.19	2780.47	2916.07
	M	140.40	80.18	0.00	64489.50	389.09	8288.63	24380.98	97768.78
	S	15.75	0.00	56.60	1111.74	80694.60	28456.07	6097.95	116432.71
	Mixed	3390.60	40626.35	3520.57	68773.14	12108.62	456832.21	32593.19	617844.68
	Not_suit.	543.50	5881.32	28.75	56944.72	54827.57	22448.07	457817.94	598491.86
	Total (ha)	**4091.65**	**337159.76**	**4109.60**	**280153.44**	**150265.69**	**668848.39**	**599923.96**	**2044553.50**

Table 24. Change matrix from 2050 to 2080 under RCP 8.5 in Antalya regional forest

		2080_RCP 8.5							
	Area (ha)	**Çk**	**Çz**	**G**	**M**	**S**	**Mixed**	**Not_suit.**	**Total (ha)**
2050_RCP 8.5	Çk	0.00	0.00	145.89	0.00	839.43	3091.80	14.54	4091.65
	Çz	37507.27	11.56	0.00	8.25	0.00	299563.99	68.68	337159.76
	G	0.00	0.00	4092.26	0.00	0.00	17.33	0.00	4109.60
	M	0.65	2.61	0.01	199224.32	1.30	80899.77	26.80	280154.44
	S	0.00	0.00	309.85	19.47	123330.28	400.58	26205.51	150265.69
	Mixed forest	0.00	0.62	6085.91	50513.07	39192.15	567305.47	5751.17	668848.39
	Not_suitable	10.63	33912.68	0.00	25.72	67628.00	97.19	498249.74	599923.96
	Total (ha)	**37518.55**	**33927.46**	**10633.93**	**249789.83**	**230991.16**	**951376.14**	**530316.44**	**2044553.50**

Table 25. Change matrix from 2020 to 2080 under RCP 8.5 in Antalya regional forest

		2080_RCP 8.5							
	Area (ha)	**Çk**	**Çz**	**G**	**M**	**S**	**Mixed**	**Not_suit.**	**Total (ha)**
2020 RCP 8.5	Çk	0.00	0.00	607.38	231.97	7956.69	1430.54	1825.71	12052.28
	Çz	23355.25	26046.91	109.18	84383.60	1692.67	416840.55	46618.94	599047.10
	G	0.00	0.00	31.90	0.00	0.27	0.00	2883.90	2916.07
	M	0.00	17.96	0.00	37696.71	2688.92	35155.88	22209.32	97768.78
	S	0.00	0.00	88.06	18.26	77478.70	28729.79	10117.89	116432.71
	Mixed	9699.54	1973.01	8894.69	80544.91	48755.74	439366.73	28610.06	617844.68
	Not_suit.	4463.76	5889.58	902.71	46914.38	92418.16	29852.64	418050.63	598491.86
	Total (ha)	**37518.55**	**33927.46**	**10633.93**	**249789.83**	**230991.16**	**951376.14**	**530316.44**	**2044553.50**

3.2. Results of Future Ecosystem Services Modelling

3.2.1. Results of Various Planning Strategies Over the Planning Horizon

Timber production, standing volume, carbon storage, soil loss and water production outputs of the strategies generated are given in Table 26.

It can be mentionned that the highest amount of timber production or allowable cut is produced in Strategy 9 with 447816.5 m^3 over the planning horizon. In this strategy, adapted tree species are planted to face climate change impact on the forest under the RCP8.5 climate change scenario. Futhermore, in that same scenario, the highest amount of standing volume (1029176.0 m^3) and carbon storage (1248191.0 m^3) are produced. As well the minimum total soil loss (17263.5 tonnes) is recorded in strategy 10 in which adapted tree species are planted under climate change scenario RCP8.5. It is good to mentionned that the regeneration area in strategy 1, 3, 5, 7 and 9 are the same as well as afforestation area. But this regeneration area varies in strategy 2, 4, 6, 8, and 10 while afforestation area is null. These results show the evidence of the necessity for adaptation in forest management in order to maintain the multiple ecosystem services in a satisfactory quantity and quality over the next decades. Since LINGO^{TM} is an optimization sofware, it provides the optimal solution for our equations. The best production of ecosytem services on a sustainable way is done when forestry professionals apply the adaptation strategy of planting adapted tree species in their forests, what ever the objective function of their management strategy. That is why in our linear modelling results, both maximum timber harvesting and minimum total soil loss produce their best performances when adapted tree species are planted both under climate change scenarios RCP4.5 and RCP8.5.

While strategy 7 yielded the most timber production in the first two periods, in the last three periods strategy 9 yielded much more timber than other strategies. As well strategy 2 recorded the lowest quantity of soil loss and water production all over the planning horizon.

Table 26. Results output for selected ecological services production over the planning horizon

Strategy	**Period**					
	Timber production (m^3)					
	P1	**P2**	**P3**	**P4**	**P5**	**TH**
STR1	69902.4	77669.3	86299.2	95888.0	106542.2	436301.1
STR2	48064.8	53405.3	59339.2	65932.5	73258.3	300000.0
STR3	69379.5	77088.3	85653.7	85534.5	95038.2	412694.1
STR4	52374.4	58193.7	64659.7	59102.6	65669.5	300000.0
STR5	69624.3	77360.4	85956.0	95506.6	106118.5	434565.8
STR6	48064.8	53405.3	59339.2	65932.5	73258.3	300000.0
STR7	83105.3	88271.6	80246.9	72951.7	66319.8	390895.4
STR8	57507.4	63897.1	65287.2	59352.0	53956.3	300000.0
STR9	**71747.3**	**79719.2**	**88576.9**	**98418.8**	**109354.2**	**447816.5**
STR10	48064.8	53405.3	59339.2	65932.5	73258.3	300000.0
Standing volume (m^3)						
						TSV
STR1	212557.1	191113.3	177641.7	162363.1	141023.9	884699.1
STR2	163489.6	144153.6	119986.6	86921.6	43877.5	558429.0
STR3	211700.1	190314.8	177590.2	107807.4	39392.3	726804.8
STR4	161493.7	139354.4	111364.0	64532.0	12436.9	489180.8
STR5	212817.9	195821.9	178999.2	160731.3	129274.7	877645.1
STR6	164235.9	145880.6	118676.2	83148.5	39171.0	551112.2
STR7	196347.0	159597.7	147162.8	74684.2	26380.6	604172.4
STR8	159402.3	133120.6	104821.0	47733.6	1264.2	446341.6
STR9	**207654.6**	**216806.7**	**207729.8**	**205396.2**	**191588.7**	**1029176.0**
STR10	157011.0	148344.2	129943.3	111209.0	82401.21	628908.8
Carbon storage (tonnes)						
						TCD
STR1	249492.8	242471.8	239501.2	234841.3	228178.7	1194486.0
STR2	119942.9	112987.8	104246.8	92321.7	76786.5	506285.7
STR3	249236.4	241758.9	239147.1	125621.6	104357.8	960121.8
STR4	125768.7	117909.3	107896.9	59373.1	42926.1	453874.1
STR5	249350.3	244229.3	242125.5	238738.4	234030.5	1208474.0
STR6	120515.2	114556.2	108913.8	93627.3	79813.4	517426.0
STR7	243688.8	230828.6	227880.6	100038.0	85318.6	887754.5
STR8	130671.9	121518.6	111487.1	50533.6	36203.7	450414.9
STR9	**247291.1**	**251388.3**	**250261.6**	**249602.9**	**249647.4**	**1248191.0**
STR10	116975.2	114499.1	108548.7	95504.40	90572.90	526100.3
Soil loss (tonnes)						
						TSL
STR1	17977.6	16535.3	13846.1	12630.2	12201.2	73190.4
STR2	3590.8	3897.5	3752.5	4255.4	4799.8	20295.9
STR3	18143.1	16645.0	14377.6	20615.8	21623.6	91405.2
STR4	4424.2	4650.4	4826.8	7757.9	8723.1	30382.4
STR5	17859.4	16272.2	14159.4	13180.4	13151.2	74622.7
STR6	3614.4	3969.1	4181.3	4608.4	5126.3	21499.6
STR7	18518.6	17518.9	15300.6	22262.8	22877.2	96478.1
STR8	5318.4	5512.2	5948.8	9231.0	10371.5	36382.0
STR9	18327.1	14523.3	13149.3	11540.0	11811.3	69351.0
STR10	**3696.4**	**3149.6**	**3301.1**	**3140.2**	**3976.2**	**17263.5**

Water production *10^6 (m^3)						
						TWP
STR1	10.3	10.7	10.9	11.2	11.4	54.6
STR2	**3.2**	**3.4**	**3.5**	**3.8**	**4.1**	**18.0**
STR3	10.3	10.6	10.9	12.0	12.4	56.2
STR4	3.6	3.8	4.0	4.6	4.9	21.0
STR5	10.3	10.6	11.0	11.4	11.7	55.0
STR6	**3.2**	**3.4**	**3.6**	**3.8**	**4.2**	**18.3**
STR7	10.4	10.7	11.0	12.2	12.5	56.8
STR8	4.0	4.2	4.4	5.1	5.4	23.2
STR9	10.3	10.6	11.0	11.3	11.7	54.9
STR10	**3.2**	**3.4**	**3.6**	**3.8**	**4.1**	**18.1**
Regeneration area (ha)						
						TRA
STR1	489.8	445.3	404.8	368.0	334.6	2042.5
STR2	143.6	130.5	135.0	150.0	166.7	725.8
STR3	489.8	445.3	404.8	368.0	334.6	2042.5
STR4	163.6	148.8	157.1	170.0	163.3	802.8
STR5	489.8	445.3	404.8	368.0	334.6	2042.5
STR6	143.8	130.8	135.9	151.1	167.8	729.4
STR7	489.8	445.3	404.8	368.0	334.6	2042.5
STR8	158.6	153.3	170.3	189.2	199.1	870.5
STR9	489.8	445.3	404.8	368.0	334.6	2042.5
STR10	146.8	133.5	135.9	151.0	150.6	717.8
Afforestation area (ha)						
						TAA
STR1	1.0	0.9	0.8	0.8	0.7	4.2
STR2	0.0	0.0	0.0	0.0	0.0	0.0
STR3	1.0	0.9	0.8	0.8	0.7	4.2
STR4	0.0	0.0	0.0	0.0	0.0	0.0
STR5	1.0	0.9	0.8	0.8	0.7	4.2
STR6	0.0	0.0	0.0	0.0	0.0	0.0
STR7	1.0	0.9	0.8	0.8	0.7	4.2
STR8	0.0	0.0	0.0	0.0	0.0	0.0
STR9	1.0	0.9	0.8	0.8	0.7	4.2
STR10	0.0	0.0	0.0	0.0	0.0	0.0

3.2.2. Timber Production

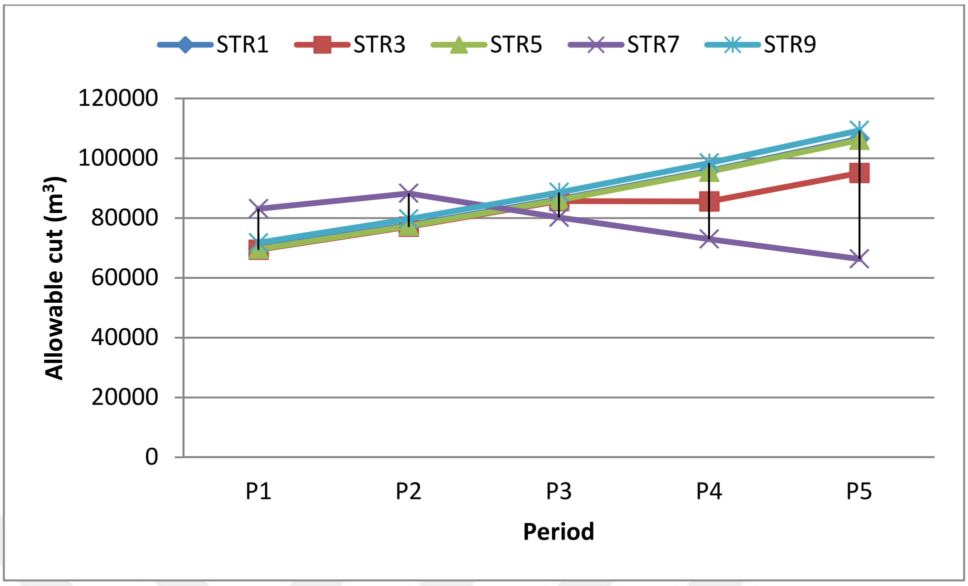


Figure 56. Timber production in strategies maximising timber over the planning horizon

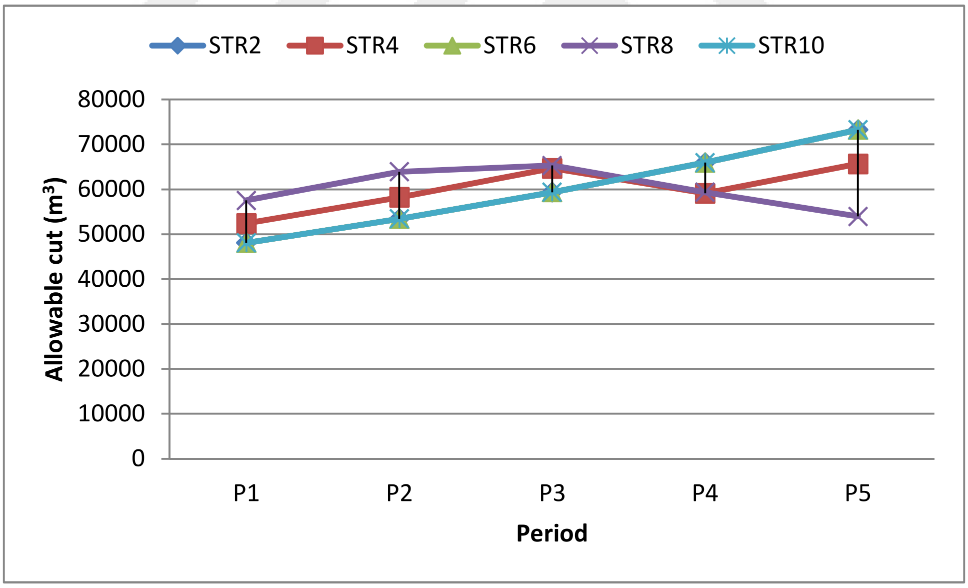


Figure 57. Timber production in strategies minimising soil loss over the planning horizon

It can be mentionned from Figure 56 that under the objective to maximize timber harverst over the planning horizon, maximum timber production is realised at strategy 9 and 5. According to the trend presented in figure 56, strategies 9 and 5 yielded from 70.000 m^3 at the first period up to 110.000 m^3 of timber at the fifth period progressively over the planning horizon. Furthermore, under minimum soil loss objective function presented in figure 48, timber production is increasing under strategy 10 and 6. In Figure 57, all strategies yielded a total of 300.000 m^3 of timber (STR2, STR4, STR6, STR8 and STR10), because all strategies have the objective of minimising soil loss, and at the same time they have to yield a total of 300.000 m^3 to accomodate timber demand. Both strategies 9 and 10 are implementing adapted tree species planting under climate change scenario RCP8.5, as well as strategy 5 and 6 where adaptes tree species are planted under climate change scenario RCP4.5.

3.2.3. Standing Volume

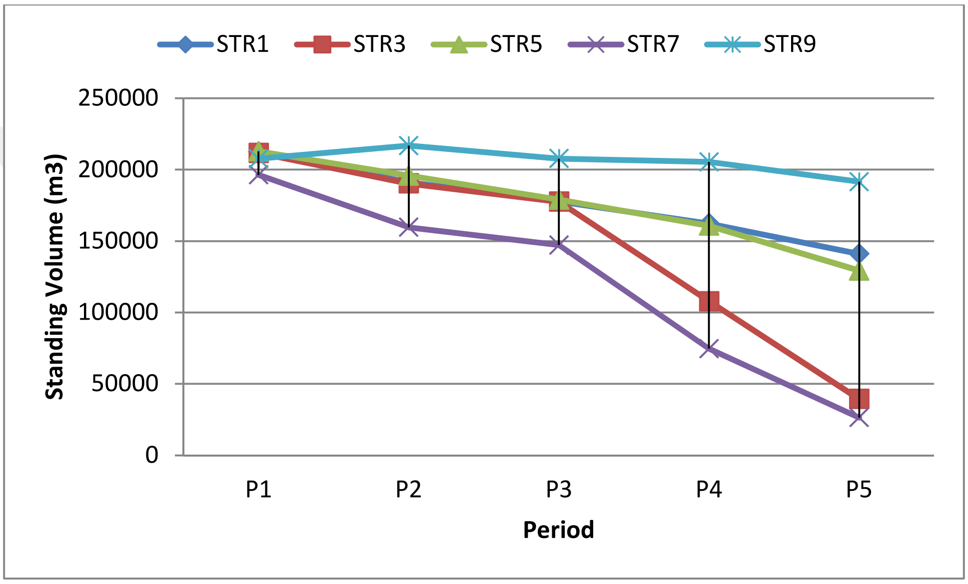


Figure 58. Standing volume in strategies maximising timber production

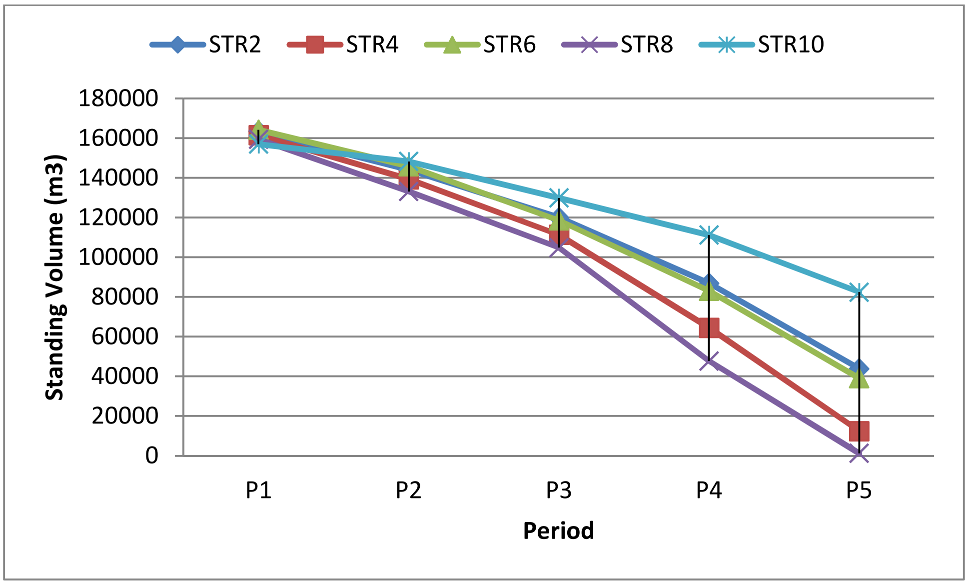


Figure 59. Standing volume in strategies minimising soil loss

As it has been mentionned for timber production, standing volume is higher under the strategies 9 and 5 for strategies maximising timber haversting, as well as 10 and 6 for strategies minimising soil loss, as presented in Figure 58 and Figure 59. Strategies 7 and 8 where non adapted tree species are planted produce the lowest performance for standing volume as well as for wood production and carbon storage. Standing volume in strategy minimising soil loss generated a slighly decrease in timber production (Figure 59).

3.2.4. Carbon Storage

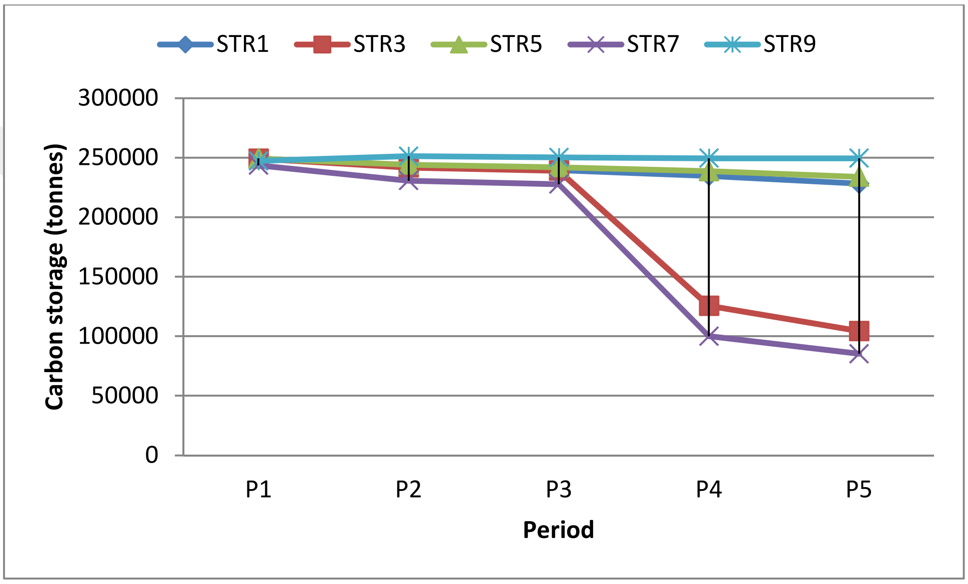


Figure 60. Carbon storage in strategies maximixing timber production

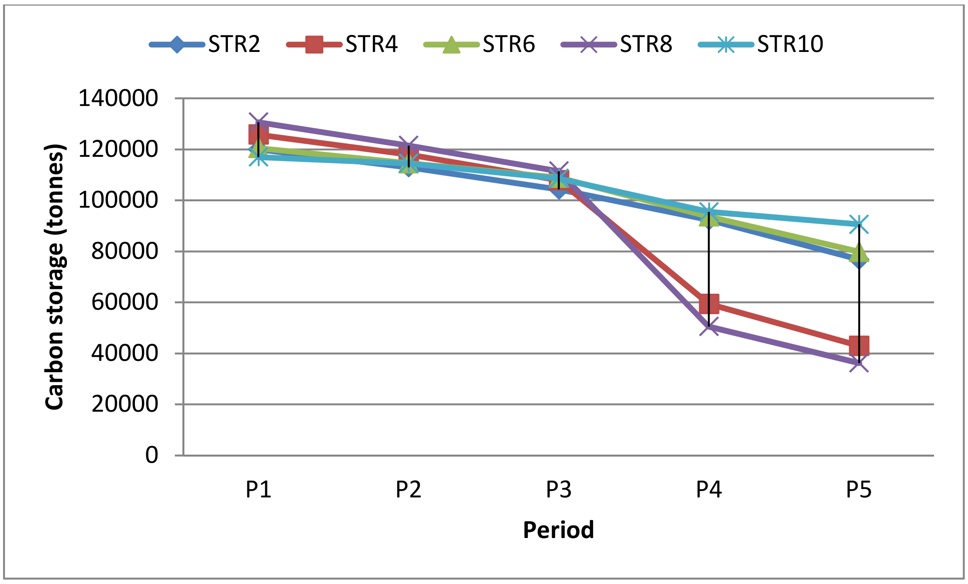


Figure 61. Carbon storage in strategies minimising soil loss

According to Figure 60 and Figure 61, carbon storage services will decrease from period 3 to 4, then from period 4 to 5 for strategies 3 and 7 where non adapted tree species are planted. Similarly, the same pattern can be observed for strategy 4 and strategy 8 where the objective function is minimising soil loss.

3.2.5. Soil Loss Results

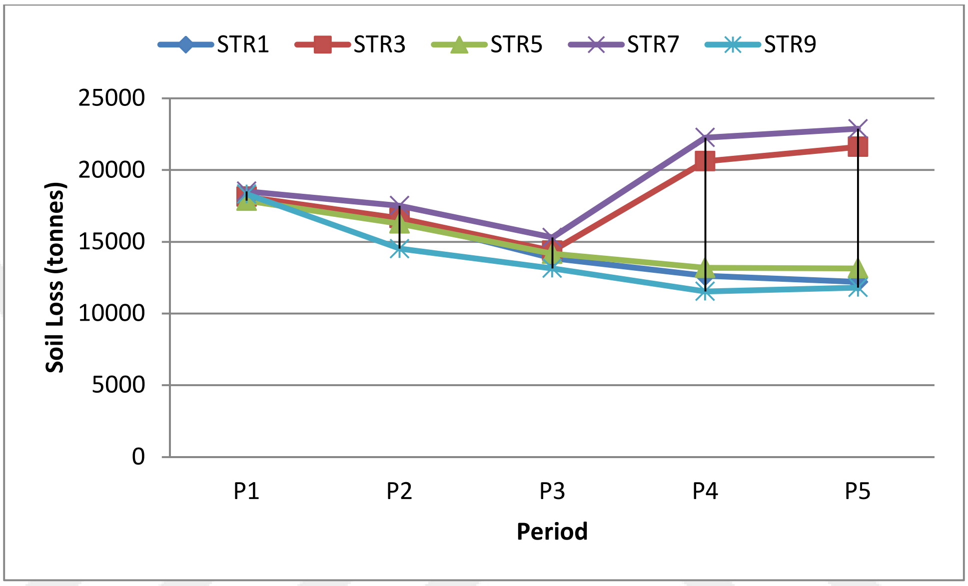


Figure 62. Soil loss in strategies maximizing timber production

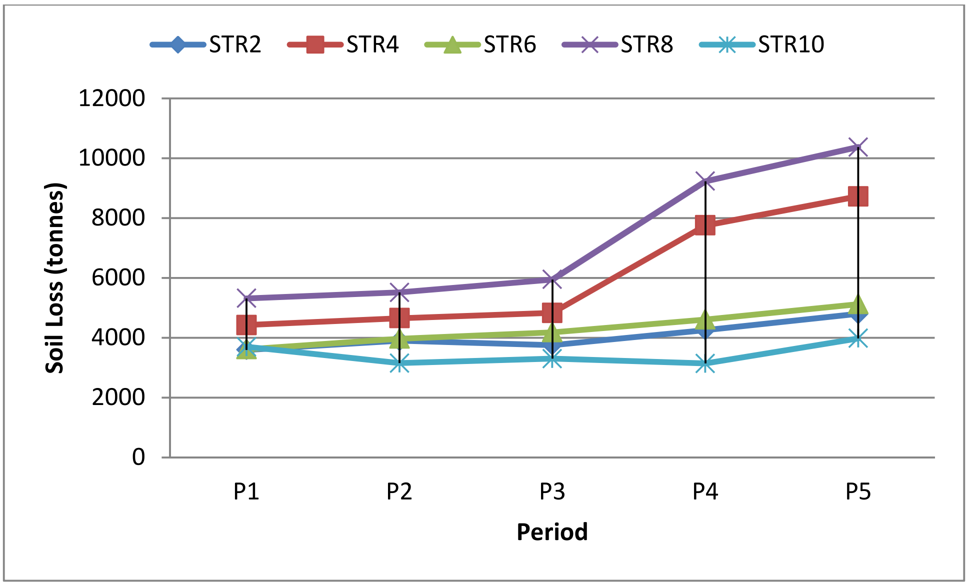


Figure 63. Soil loss in strategies minimising soil loss

According to Figure 62 and Figure 63, it can be mentioned that strategy 3 and strategy 7 are following different patterns. As well as strategy 4 and strategy 8. This means that planting adapted tree species will increase considerably soil conservation in forest management planning by reducing soil loss.

3.2.6. Water Production Results

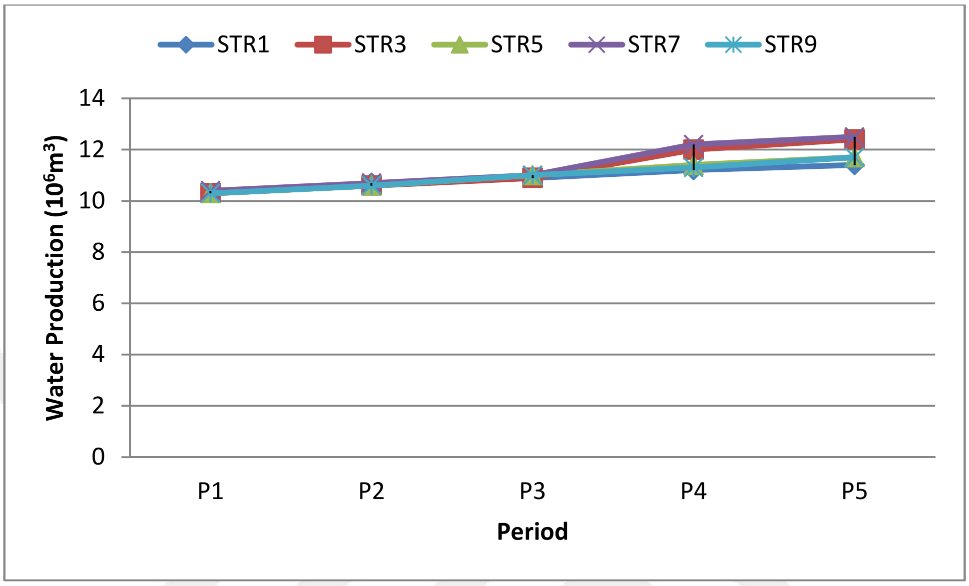


Figure 64. Water production in strategies maximizing timber production

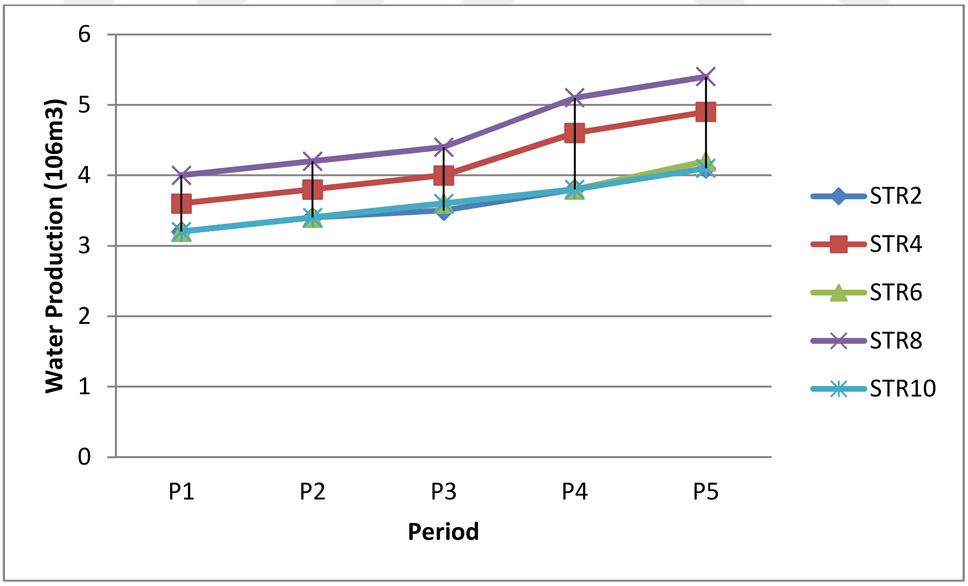


Figure 65. Water production in strategies minimising soil loss

According to the trends presented, all strategies gave nearly the same pattern in Figure 64. However, strategy 2, strategy 6 and strategy 10 followed the same pattern while strategy 4 and strategy 8 showed a different pattern in Figure 65. Meaning that planting adapted tree species will reduced water loss in forest management planning.

3.2.7. Regeneration Area

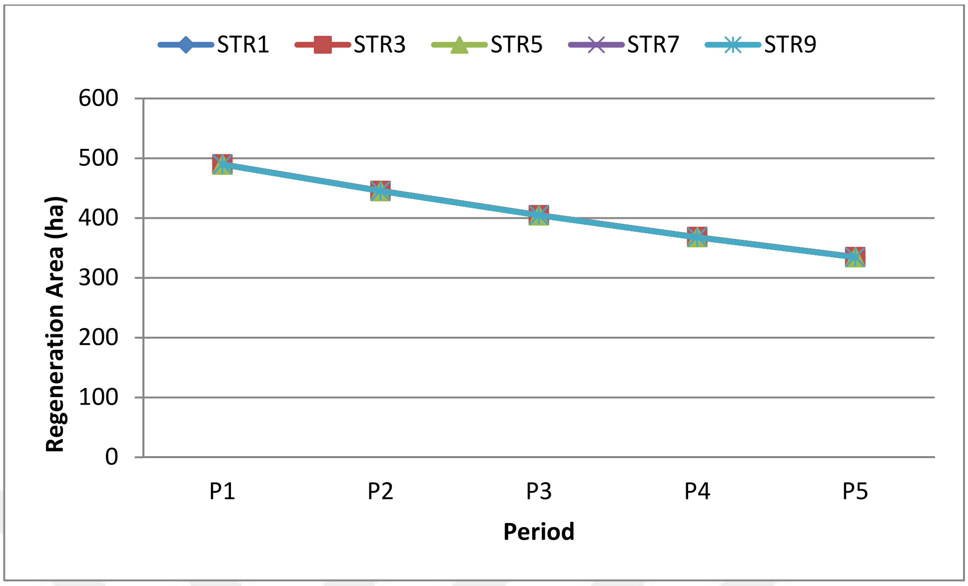


Figure 66. Regeneration area in strategies maximizing timber production

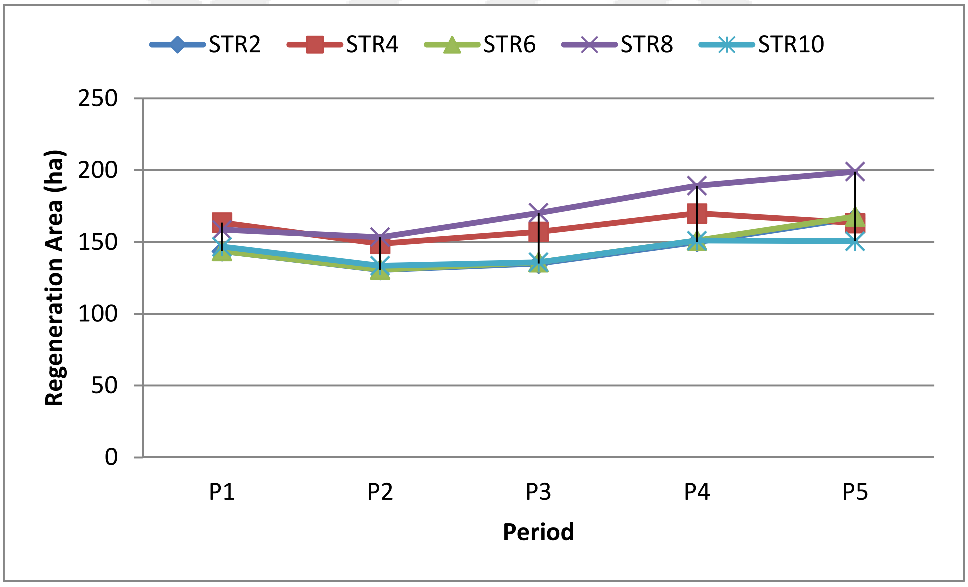


Figure 67. Regeneration area in strategies minimising soil loss

According to results presented in Figure 66 and Figure 67, regeneration forest area showed similar results for strategies 1,3,5,7 and 9, beacuse in the modelling section it was stated to harvest 10% less or more timber and to regenerated 10% less or more area. It can also be mentioned that regeneration area under maximizing timber production is decreasing constantly on a 10% value from the first periods to the others. This can be explained by the fact that maximising wood production objective doesn't take into consideration regeneration activities. At contrary, regeneration area varies for strategies 2, 4, 6, 8 and 10 and is considerably increasing for strategy 8. This can be explained by the fact that minimising soil loss strategy is based on minimum haversting of timber, with a fixed maximum amount of timber harversted for each period of 300.000 m^3 of timber.

3.2.8. Afforestation Area

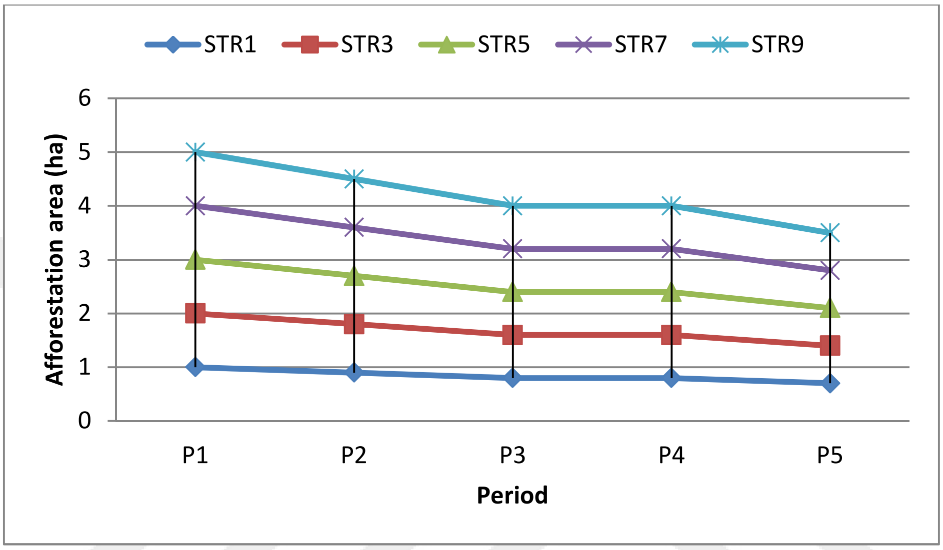


Figure 68. Afforestation area in strategies maximizing timber production

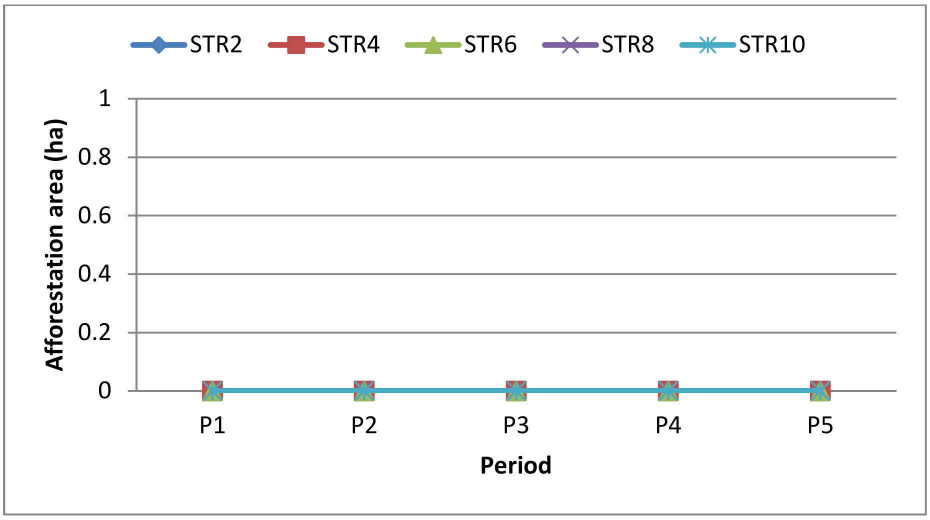


Figure 69. Afforestation area in strategies minimising soil loss

According to Figure 68, afforestation area has a decreasing pattern from one period to another in strategies maximizing timber production, while in Figure 69, afforestation area is null for strategies minimising soil loss meaning that the model also consider the option in which no afforestation is possible.

3.3. Results on the Perception of Climate Change by Forestry Professionals

3.3.1. Description of the Study Areas in Germany, Turkey and Cameroon

Table 27. Summary on the description of the selected forest study areas

Item	Unit	Germany	Turkey	Cameroon
Situation		Central Europe	Europe and Asia	Central Africa
Selected forest		Black Forest	Cerle forest	Boumba Bek forest
Statue		Regional forest	Planning Unit	National Park
Localization		SW-Germany	SW-Turkey	S.E Cameroon
Area	ha	391,000	10, 000	238 000
Climate		temperate	Mediterranean	tropical
Topography	m a.s.l.	1500	1000 - 1500	1200
Temperature	°C / year	8-10	18-20	23-25
precipitation	mm/year	1800-2000	800-1000	1500-1700
Ecology		Mono or mix forest	Mono or mix forest	Poly specific forest
Human society in forest		For. professionals	For. professionals	Local + autochth. Communities + For. Pr
Temperature Futur Change	°C by 2050	+3	+3.85	+2-3
Precipitation Futur change	% by 2050	-20	-5	-30

In Table 27, the description of the variance between these countries is presented. It can be mentioned that there is a large variability between the factors of comparison. But the global climate change will lead to +3°C in Germany, +4°C in Turkey and +3°C in Cameroon by 2050. Precipitation decrease will be more accentuated in the Germany (-20%) and Cameroon (-30%) compared to Turkey (-5%). Previous results published by Fosso and Karahalil (2020) have analysed the change in climatic conditions in Cerle PU from 1960 to 2010. It has been found that an increase of 1.9°C has been recorded over the past 50 years and a projection using Mann-Kendall test analysis shows a significant increasing trend in summer, spring and full seasons, as well as the annual mean temperature will reach 3.85 °C of increase in the following 50 years. Simmilarly in Germany, temperature increase predictions have been published by Matzarakis and Endler (2010), with prediction of warm summers of up to 3°C increase by 2070 to 2100, and a decreasing in precipitation of 20% over the same period. This is also the case for Cameroon where precipitation will decrease drastically according to CSC (2013).

3.3.2. Socio-demographic Characteristics of Respondents

The socio-demographic characteristics of the respondents are presented in Table 28.

Table 28. Socio-demographic characteristics of the respondents

	Germany	**Turkey**	**Cameroon**	**Total**	**Chi square**	**P-value**
Respondent Count	221	279	130	630	**263.61**^{a}	**0.000***
%	35	44	21	100		
Unit	%	%	%	**Average**		
Gender					**30.38**^{a}	**0.000***
Male	85	69	58	71	31.33	0.000
Female	15	31	42	29	30.02	0.000
Age Group (years)					**56.83**^{a}	**0.000***
<30	0	4	6	3	1.15	0.000
31-40	33	40	32	35	66.34	0.284
41-50	49	51	35	45	0.04	0.284
>50	18	5	27	17	0.56	0.214
Level of Education					**130.87**^{a}	**0.000***
Vocational School	35	1	12	16	155.21	0.000
University	62	99	86	82	25.08	0.000
Other	3	0	2	2	0.27	0.000
Type of forest					**263.61**^{a}	**0.000***
Private	23	0	2	8	7.24	0.000
Community	25	0	43	23	279.25	0.000
Public	27	92	41	53	0.11	0.007
Other institution	25	8	14	16	0.07	0.088
Size of forest (ha)					**141.46**^{a}	**0.002***
Non specific	38	70	23	44	139.55	0.000
0 - 1000	6	0	5	4	8.03	0.000
1001 - 5000	10	5	3	6	0.11	0.005
5001 - 10000	15	3	3	7	0.09	0.005
> 10000	31	22	66	39	2.85	0.015

Each subscript letter denotes a subset of location categories whose column proportions do not differ significantly from each other at the 0.05 level. As well the (*) indicates significant difference of Chi square test between the observed value and the expected frequencies at 0.05 confidence.

It can be mentioned that the respondents caracteristics were more male than female, aged between 31 to 50 years, having a university education level and working for public state forests on different forest sizes. Nearly an equal distribution is observed concerning the type of forest in which respondents are working in Germany. Comparatively, in Turkey, the majority of respondents were working for public forests administrations, while in Cameroon respondents were working for community, public or other type of forest institutions (Fosso and Karahalil, 2021). For instance, private forests in Germany like in Cameroon are owned by individuals, companies or associations like church forests in Germany. Forest managers in private forests are directly involved in decision-making and active forest management. As well, community forests are managed by communities living around the forest for their common interests, but belonging to the state. Furthermore, respondents working for other institutions like research institutions, NGOs, nature conservation or protection. It is claimed that the university education of forestry professionals can increase their perception of climate change and increase their capacity to react in case of climate change risk. In Table 28, the chi-square test shows a significant difference between the socio-demographic characteritics of respondents and their country.

3.3.3. Understanding Climate Change Signs and Manifestations

Table 29. Opinion of respondents on climate change signs and manifestations

	Germany	**Turkey**	**Cameroon**	**Average**	**Chi square**	**P-value**
Unit	%	%	%	%		
Season's tendency					**169.66**[a]	**0.000**[*]
Seasons are warmer	98	56	96	83	210.45	0.000
Seasons are cooler	0	37	2	13	6.82	0.009
Seasons are the same	2	2	1	2	2.62	0.009
No idea	0	5	1	2	3.49	0.001
Season sequence					**86.16**[a]	**0.000**[*]
Earlier than before	85	52	56	64	95.34	0.000
Later than before	3	27	21	17	16.92	0.093
Same periods	5	10	20	12	4.17	0.000
No idea	7	11	3	7	6.03	0.000
Temperature tendencies					**21.43**[a]	**0.002**[*]
Increasing	98	86	88	91	25.95	0.000
Decreasing	1	4	1	2	14.23	0.000
Not changing	1	4	6	4	3.81	0.000
No idea	0	6	5	3	3.28	0.000
Precipitation tendencies					**486.78**[a]	**0.000**[*]
More than before	4	3	15	7	540.23	0.000
Less than before	15	54	75	48	110.70	0.000
Still the same	7	4	7	6	4.02	0.045
More snow in winter	67	1	0	23	4.17	0.280
Less snow in winter	1	36	0	12	11.58	0.330
No idea	6	2	3	4	11.17	0.000

Table 29 more

Water availability					**44.62^{a}**	**0.001***
More water available	6	10	9	8	44.23	0.000
Less water available	74	79	59	71	0.45	0.003
Still the same	14	4	27	15	0.76	0.450
No idea	6	7	5	6	0.74	0.050
Climate change Perception					**40.44^{a}**	**0.000***
Real	97	88	76	87	40.23	0.037
Utopia	1	6	16	8	24.09	0.196
No idea	2	6	8	5	5.87	0.228
Climate affects the forests?					**22.04^{a}**	**0.000***
Yes, absolutely	72	32	28	44	**99.27^{a}**	0.000*
Yes, probably	26	47	49	41	109.60	0.327
No, probably not	1	16	19	12	67.11	0.368
No, absolutely not	0	4	3	2	8.66	0.000
No idea	1	1	1	1	9.91	0.034
Storm tendency					**130.59**	**0.000***
More frequent	79	47	72	66	149.58	0.000
Less frequent	0	22	2	8	3.50	0.061
Not changing	17	12	24	18	1.87	0.075
No idea	4	19	2	8	2.70	0.107
Insect's attack tendencies					**61.65^{a}**	**0.000***
More frequent	87	72	56	72	67.43	0.000
Less frequent	1	6	3	3	44.73	0.267
Not changing	10	7	20	12	6.93	0.266
No idea	2	15	21	13	6.91	0.036
Forest fire occurrence					**168.24^{a}**	**0.000***
More frequent	25	66	63	51	185.15	0.000
Less frequent	2	13	2	6	9.56	0.036
Not changing	56	14	35	35	79.99	0.000
No idea	17	7	0	8	9.97	0.370
Drought tendency					**99.63^{a}**	**0.001***
More frequent	95	74	65	78	108.71	0.280
Less frequent	0	13	9	7	38.26	0.035
Not changing	5	7	26	13	6.37	0.245
No idea	0	6	0	2	0.247	0.000
Tree mortality tendency					**134.07^{a}**	**0.000***
More frequent	38	58	49	49	147.19	0.038
Less frequent	2	20	0	7	4.32	0.083
Not changing	39	9	22	23	2.08	0.097
No idea	21	13	29	21	2.43	0.000
Overall hazards mortality					**202.52^{a}**	**0.000***
Increasing storm tendency	15	1	5	7	239.72	0.000
Increasing insect's attacks	5	24	3	12	2.35	0.125
Increasing forest fires	0	19	24	14	1.54	0.109
Extended drought period	36	16	3	18	1.60	0.061

Table 29 more

All these factors combined	40	32	61	44	2.35	0.000
Other causes	1	3	2	2	1.54	0.610
No idea	3	5	2	3	2.35	0.038
Growth rate of trees					**169.70[a]**	**0.000[*]**
Growing faster	45	15	5	22	162.91	0.000
Growing slower	23	51	18	31	72.67	0.340
Not changing	18	18	49	28	9.06	0.349
No idea	14	15	28	19	9.35	0.038
Are they climate change consequences?					**107.58**	**0.000[*]**
Yes, absolutely	60	48	9	39	118.74	0.000
Yes, probably	31	40	69	47	24.67	0.311
No, probably not	1	4	11	5	5.06	0.036
No, absolutely not	1	1	5	2	8.20	0.000
No idea	7	7	6	7	4.00	0.000

The opinion of foresters on climate change signs and manifestations is presented in Table 29. It can be mentioned in Table 29 that almost all of the respondents in Germany (98%) were stating that seasons have the tendency to be warmer now compared to the past. Comparatively, the same opinion is shared by forestry professionals in Cameroon with nearly the same proportion of respondents as in Germany, while in Turkey; the opinion is not fixed within the respondents, though the majority of them were thinking that seasons have become warmer (Fosso and Karahalil, 2021). As well, it can be observed that almost the majority of respondents in Germany (85%) were thinking that seasons are occurring earlier now than in the past. This opinion is also shared by the majority of respondents in Turkey and Cameroon.

As well almost all of the respondents in Germany (98%) perceive that temperature has an increasing tendency. This opinion is shared by a large majority of the respondents in Turkey and Cameroon.

On the other hand, nearly ¾ of the respondents in Germany stated that precipitations are more abundant now than before with more snow in winters. Only ¼ perceived less abundant precipitation now comparing to the past around the Black forest. Previous analysis of precipitation data in Freiburg from 1961 to 1990 and projection from 2071 to 2100 show a decrease in precipitation of 20%. So the perception of about ¾ of the respondent forestry professionals on rainfall tendency around the Black Forest in Germany was relatively wrong. At the contrary, a majority of respondents in Turkey (90%) have stated that there is less precipitation abundance nowadays compared to the past in their forest area with less snow abundance during winters (Fosso and Karahalil, 2021). As well, the majority of respondents in Cameroon (74.6%) perceived less abundant precipitation. It is good to mention that there is no snow in Cameroon, but respondents have mentioned that fog thickness has the tendency to be reducing around forest areas.

Water availability is mentioned to be less abundant by the majority of the respondents in all the countries. More than a quarter of respondents in Cameroon stated that water availability is still the same now compared to the past in their forest area. But as stated by climate change experts, the increasing temperature will lead to an increase in evapotranspiration of forests leading to more water scarcity. So the perception of a decreasing tendency of water availability in forest is well perceived by the majority (75%) of respondents.

It can be mentioned that almost the majority of the respondents in Germany (97%), Turkey (88%) and Cameroon (76%) have stated that climate change is a reality. But about ¼ of respondents in Cameroon were still thinking that climate change is a utopia or just a political concept and respectively 1% and 6% of respondents in Germany and Turkey are thinking the same. Furthermore, almost all the respondents in Germany (97%) thinking that climate change is having a progressive impact affecting forest sustainability. As well respectively 79% and 78% of the respondents in Turkey and Cameroon are thinking the same. In contrary, nearly 20% of respondents in Turkey and more than 20% of respondents in Cameroon were thinking that the predicted impact of climate change on forest will not be considerable. So according to them, climate change will not affect their forest.

Accordingly, the majority of respondents in each country have well identified climate change signs and manifestations with more frequent storm tendency, more frequent insects in the forest, more frequent forest fire in each area even if in Germany forestry professionals stated majoritarily that the tendency is not changing, more frequent drought in forest areas and a more frequent natural mortality of trees in the forests. Many researchers are working to find drought adapted tree species like *Pseudotsuga menziesii* in Germany that will be planted to replace actual non adapted tree species like *Picea abies* in the Black Forest (Sohn et al., 2016). Furthermore, respondents in Germany (75.5%) have identified the increasing drought tendency combined with other natural hazards as the main cause of tree mortality in the Black forest, while in Turkey, increasing forest fire and drought combined with other factors have been identified to be the main caused of tree mortality, and in Cameroon, the combination of all cited factors have been identified by respondents as the main cause of forest destruction. Respondents have stated that all these natural hazards effects on trees are causing a slowing growth rate and are identified as climate change consequences on forests with 91%, 88% and 78% of respondents in Germany, Turkey and Cameroon respectively.

3.3.4 Reaction and Actions Taken to Help the Forest to Adapt to Climate Change

The reaction of respondents in case of extreme climatic event in their forests is presented in Table 30.

Table 30. Reactions and adaptation strategies elaborated in case of extreme climatic event

	Germany	**Turkey**	**Cameroon**	**Average**	**Chi square**	**P-value**
Unit	%	%	%	%		
Reactions in case of extreme climatic events					**250.88**[a]	**0.000***
No action taken	8	28	60	**32**	295.70	0.006*
Action with self-experience	1	12	5	**6**	180.93	0.029*
Action with an expert	3	21	8	**10**	15.92	0.536
Building mix forest stocks	2	6	12	**7**	15.21	0.000
Plant tolerant tree species	86	33	15	**45**	0.029	0.028
Adaptation strategies elaborated					**156.46**[a]	**0.000***
No action taken	10	22	59	**30**	149.11	0.012
Action in implementing laws	18	30	17	**22**	7.26	0.000
Action with an expert	12	16	7	**12**	2.71	0.010
Action with self-experience	17	17	9	**14**	3.43	0.282
Action with a risk management team	43	15	8	**22**	0.135	0.000
Willingness to change forest structure for adaptation					**196.49**[a]	**0.000***
Yes, absolutely	69	23	11	**33**	207.80	0.000
Yes, probably	24	32	56	**37**	65.59	0.000
No, probably not	1	14	19	**11**	8.52	0.000
No, absolutely not	1	11	2	**5**	12.02	0.000
No idea	5	20	12	**12**	0.433	0.323

It can be observed from Table 30 that the majority of respondents in Germany (85%) stated that their reaction is perceptible through taking action in planting more tolerant tree species. Other reactions like building mixed stocks, working with a climate change expert or action based on self-experience of the past events have been stated. Furthermore, it is good to mention that about 8% of the respondents in Germany stated to take no action and prefer to adopt a passive adaptation strategy. In Turkey, nearly equal proportion of respondents have stated to take no action or planting tolerant tree species (Fosso and Karahalil, 2021). But 1/3 of the respondents in Turkey said to rely on climate change experts or self-experience of past events management as their reaction to present climate change events. In Cameroon, about 2/3 of the respondents stated to take no action in case of extreme climatic events. Only ¼ of the respondents in Cameroon said to plant adapted tree species and building mix stocks in their forests.

The Cameroon's forest is very large in terms of biodiversity and climate change threatens their sustainability. The most cited adaptation strategy elaborated in Germany is taking action with risk management teams who are specialized in climate change risk management in forest areas. As well, the most cited adaptation strategy elaborated in Turkey is taking action by implementing laws on the management of climate change in forests. At the contrary, more respondents in Cameroon (58.5%) stated to take no action (passive adaptation) comparing to respondents in Turkey (22.1%) and in Germany (10.9%). But more than 40% of the respondents in Cameroon stated to elaborate adaptation strategies according to their knowledge on the phenomenon, like 80% of the respondents in Turkey and 90% of the respondents in Germany.

For instance, the willingness to change the forest structure and composition for future adaptation is supported by 93.2% of the respondents in Germany, 55.4% in Turkey, and 66.8% in Cameroon. Furthermore, there are 4.5% of the respondents in Germany stating to have no idea about the future change of forest structure due to climate change, 19.5% in Turkey and only 12.2% in Cameroon. This means that the awareness of climate change is high in Cameroon, but the capacities to take action to elaborate an adaptation strategy are limited. Comparatively, forestry professionals in Turkey need more training on climate change adaptation strategies comparing to Cameroon and Germany in other to elaborate an active reaction to climate change's future events in their forest areas.

The most cited justification stated by the respondents for their willingness to take action is that, taking action is the logical duty of foresters to help to preserve the forest from climate change destruction, while continuously producing ecosystem's goods and services for future generations. Some tolerant tree species cited by the respondents in Germany are presented in Table 31, for Turkey in Table 32 and for Cameroon in Table 33. It can be mentionned that 28 different known adapted tree species have been cited by respondents in Germany, 11 tree species in Turkey and 8 tree species cited by respondents in Cameroon. The most cited tree species that are adapted to future climatic conditions in the Black forest are *Fagus sylvatica*, *Quercus petraea* and *Pseudotsuga menziesii.* These tree species are well adapted to drought and have low needs in terms of water.

The justification of the respondents who stated that they are not willing to take action to help the forest to adapt to the future climatic events is that, future climate change scenarios are not clearly sure at 100%. As well according to this group, forests have the natural capacities to adapt to future changes, since it has survived the past climatic events on forest's natural capacities to adapt to future climate change have been analysed using habitat suitability modelling in Trabzon and Antalya regional forests selected as sample for this study in Turkey as presented previously. According to this, it is very crucial to find out which tree species will be more adapted to survive and continue to produce forest ecological services for future generations. Different existing and tolerant tree species have been tested and suitability maps have been obtained showing where the suitability will increase, decrease or be stable for the selected tree species using Habitat Suitability Model (HSM). HSM, will help forestry professionals in finding appropriated tree species in climate change adaptation for the next 50 years in their respective forest area.

In Germany and Turkey, direct questionnaire administration was used compared to Cameroon where the questionnaire was shares online and recorded the lowest rate of answers. But relatedly, the number of respondents believing in climate change in Germany is higher (98%) than in Turkey (88%) and Cameroon (77%). Furthermore, almost all the respondents in Germany had an idea on adaptation strategies while the respondents in Turkey and Cameroon were relatively new in this topic.

Table 31. List of tolerant tree species cited by respondents in Germany

No.	Scientific name	Common name	Citation count
		Conifers	
1	*Pseudotsuga menziesii*	Douglas fir	121
2	*Abies alba*	Silver fir	59
3	*Cedrus libani*	Cedar of Lebanon	42
4	*Abies grandis*	Grand fir	31
3	*Pinus nigra*	Black pine	30
6	*Larix decidua*	European Larch	21
		Broadleaves	
7	*Fagus sylvatica*	European beech	140
8	*Quercus petraea*	Sessile oak	120
9	*Quercus rubra*	Red oak	71
10	*Quercus cerris*	Turkey oak	50
11	*Castanea sativa*	Sweet chestnut	42
12	*Corylus colurna*	Turkish hazel	22
13	*Carpinus betulus*	Common hornbean	21
14	*Juglans sp.*	Walnut	20
15	*Juglans nigra*	Black walnut	18
16	*Juglans regia*	English walnut	18
17	*Prunus avium*	Wild cherry	18
18	*Sorbus torminalis*	Wild service tree	18
19	*Acer platanoides*	Norway maple	15
20	*Liriodendron tulipifera*	Tulip tree or poplar	13
23	*Sorbus domestica*	Service tree	13
24	*Acer pseudoplatanus*	Sycamore maple	12
25	*Platanus occidentalis*	Occidental plane	9
26	*Mary asp.*	Mary cultural tree	5
		Other species	
27	*Neophytae*	Malayan owl	2
28	*Archeophytae*	Vascular plants	2

Table 32: List of some tolerant tree species cited by the respondents in Turkey (Fosso and Karahalil, 2021)

No.	Scientific name	Common Name
	Conifers	
1	*Pinus pinaster aiton*	Maritima pine
2	*Pinus brutia Ten.*	Calibrean pine
3	*Pinus sylvestris*	Scots pine
4	*Pinus nigra Arnold.*	Crimean pine
5	*Abies spp.*	Fir
6	*Cedrus libani A. Rich.*	Lebanon cedar
7	*Juniperus spp.*	Juniper
8	*Cupressus spp. L.*	Cypress
9	*Pinus pinea L.*	Stone pine
	Broadleaves	
10	*Fagus sp. L.*	Beech
11	*Quercus cerris*	Turkey oak
12	*Quercus spp.*	Oak

Table 33. List of adapted tree species cited by the respondents in Cameroon (Fosso, 2018)

No.	Scientific name	Common Name
	Broadleaves	
1	*Baillonnella toxisperma*	Moabi
2	*Irvingia gabonensis*	Andok
3	*Ricinodendron heudelotii*	Djansang
4	*Trichoscypha arborea*	Amvout
5	*Afromomum sp*	Jujube
6	*Entandrophragma cylindricum*	Sapeli
7	*Triplochiton scleroxylon*	Ayous
8	*Terminalia superba*	Fraké

Table 34. Summary of the respondent's characteristics

ITEM	UNIT	COUNTRY		
		Germany	**Turkey**	**Cameroon**
Number of Questionnaire	(%)	35	44	21
Believing in climate change	(%)	97.1	87.6	76.9
Perception of C.C. impacts	(%)	98	79	67
Reaction to climate change	(%)	93	55.4	40

4. DISCUSSION

4.1. Discussion on Habitat Suitability Modelling Results

The results of habitat suitability modelling in Trabzon and Antalya for selected tree species show that 5 over 7 selected species in Trabzon (*Picea orientalis, Quercus spp., Alnus glutinosa, Pinus sylvestris and Carpinus orientalis)* and 4 over the 5 selected species in Antalya (*Pinus nigra, Quercus spp, Cedrus libani* and *Abies cilicica*) are well adapted to climate change. Moreover, 2 species in Trabzon (*Fagus orientalis* and *Abies nordmanniana*) and one species in Antalya (*Pinus brutia*) have been identified as less adapted, and are very susceptible to increase the vulnerability of the respective forests to the effects of climate change. Furthermore, *Fagus orientalis* in Trabzon and *Pinus brutia* in Antalya are the most important species found in these forests whether they are native in the forest, or have been planted during forest management activities. In addition, these are economically significant species and are considered as an indicator of environmental integrity and play a crucial role in the restoration of degraded ecosystem, and hence, their conservation is of the highest significance in the context of future predicted warming climate in Turkey (GDF, 2019).

Similar studies have been carried out by Özdemir et al., (2020), who have predicted the habitat suitability of *Juniper excelsa* (Crimean juniper) in Antalya region using Maxent. As results, they found that it is possible to reveal possible changes in the distribution of *Juniper excelsa* that may occur under climate change using only bioclimatic parameters and presence data of the specie (Özdemir et al., 2020). As presented in the results of this study, habitat suitability of *Quercus spp* in Trabzon regional forest and in Antalya regional forest will have a tendency to increase according to climate change scenarios. As well, *Picea orientalis*, *Alnus glutinosa* and *Carpinus orientalis* show a relatively increasing habitat suitabilility in Trabzon regional forest from 2020 to 2050, then from 2050 to 2080. Furthermore, in Antalya regional forest, habitat suitability of *Pinus nigra*, *Cedrus libani*, and *Abies cilicica* will increase. These species are well adapted to future climate conditions in the respective areas as well as *Quercus spp*. for the case of *Abies nordmaniana* that will decrease in Trabzon regional forest in the north of Turkey, and increase in Antalya regional forest in the south of Turkey. That is a concreate case of tree migration, or habitat suitability migration for many other tree species. In fact, using Maximum Entropy modelling technic for ecological niche modelling help as a significant first stage in the development of strategies and policies to manage and use the important forest species. Many other studies like Mert et al., (2016), Mert and Kıraç, 2017, and Koç et al., (2018), have studied the distribution of individual species in the Mediterranean areas. But it is rare to find studies where many tree species distribution have been modelled to simulate real forest situation. Furthermore, the Mediterranean region where Antalya is located, is one of the regions in Turkey where forest fires frequency and drought are increasing at an alarming rhythm.

As well, in our study, the habitat suitability of *Pinus brutia* in Antalya region will decrease considerably from 2020 to 2050 where it will lose 42,4% of it suitable area, and from 2020 to 2080 where it will lose 62,2% of its suitable area. These results are similar to those of the General Directorate of Forestry in Turkey project results carried by Zeydanlı et al., (2010) in the Seyhan basin in Antalya, Adana and Mersin (Seyhan watershed) in 2010 intitulated: Climate change and Forestry: modelling application. In that project, they used bioclimatic parameters to model the distribution of four major species, namely: *Pinus brutia*, *Pinus nigra*, *Abies cilicica* and *Cedrus libani*. From that study, the results present a urge reduction of suitable habitat for *Pinus brutia*, whose not suitable area will increase from 45,2% in 2020 to 56,2% in 2050, then 80,9% in 2080, meaning that the east Mediterranean forest basin will not be appropriated to grow *Pinus brutia* due to the reduction of its habitat suitability.

In our study, *Pinus nigra* suitable area will decrease from 2020 to 2050 up to 33%, then increase from 2020 to 2080 more than 3 times, increasing from 12.052 ha in 2020 to 37.518 ha in 2080 under climate change scenario RCP8.5. this means that suitable *Pinus nigra* is highly suitable to replace *Pinus brutia* in the Cerle PU forest as a sample, and in the hole Antalya region to help the forest to adapt to future climate change. This result is similar to those of GDF Seyhan basin project results, where *Pinus nigra* unsuitable area will increase from 2020 (53,4%) to 2050 (68,5%), then decrease to 49,2% in 2080. Furthermore according to the results of this project, the appropriate area to plant *Pinus nigra* in the Seyhan basin will increase considerably from 2020 to 2080 under climate change (GDF, 2010b). Climate modelling of the entire selected tree species distribution has shown that future global climate change will have important effects on forest ecosystems (Wang et al. 2011). Discrepancies exist between varying climate modelling but the strategy still acts as a significant study tool to assess and predict future changes in the distribution of species (Iverson and McKenzie 2013).

Our models achieved AUC values range from 0.872 to 0.952 which for models to be considered strong are within the acceptable range. This is in accordance with Swet (1988), Elith (2000), and Pearce and Ferrier (2000) who stated that AUC values above 0.75 might be helpful and appropriated in evaluating the performance of a niche model. After removing auto-correlated parameters, MaxEnt stated that three factors of precipitation (Bio17, Bio18, and Bio19), slope, and one of temperature (Bio3) had more contribution (91.3%) to the current distribution many of the selected species. This is the same as in Zhong et al., (2010) who stated that the main role in determining the potential distribution habitats of selected species is played by temperature and precipitation.

In our study, in Trabzon regional forest, the bioclimatic factor affecting the most tree species distribution is mainly precipitation parameters bio17 (that is precipitation of the driest quarter), bio18 (that is precipitation of the warmest quarter) and bio19 (that is precipitation of the coldest quarter). This means that the increasing temperature will affect precipitation distribution in Trabzon regional forest, that will disturb the habitat suitability of tree species. At contrary, in Antalya regional forest, the bioclimate parameter affecting the most tree species distribution are temperature parameters bio1 (that is annual mean temperature), bio9 (that is mean temperature of the driest quarter) and bio10 (that is mean temperature of the warmest quarter). This means that the increasing temperature will increase drough and warmer seasons in Antalya region, that will disturb the habitat suitability of species.

In our study, it can be mentioned that the habitat suitability of *Abies cilicica* will increase progressively from 2020 to 2050, then from 2050 to 2080 in Antalya regional forest, under climate change scenarios RCP4.5 and RCP8.5. this increasing scame will be 4 or 5 times more suitable areas. Similarly the habitat suitability of *Cedrus libani* will increase slightly from 2020 to 2050, then doublely from 2050 to 2080 under climate change scenarios RCP4.5 and RCP8.5. these results are totally different from the findings of GDF (2010b) in the Seyhan basin, where the unsuitable area of *Abies cilicica* will increase slightly from 2020 to 2050 from 79.5% to 85.7%, then extremely from 2050 to 2080 with about 96% of unsuitable area. As well *Cedrus libani* habitat suitability will reduce drastically from 2020 to 2050 of about 86.4% of unsuitable area in 2020 to 93.1% in 2050, then 97.2% in 2080 (GDF, 2010b).

There are uncertainties in the modelling of the distribution of species, primarily due to several basic assumptions of the model and gaps in potential changes in greenhouse gases (GHG) emissions. It should be observed that while Maxent is efficient in modelling species habitat niche with small occurrence data and restricted ecological information, the climate factors used in this model may not adequately clarify the current and future distribution of species. Non-climatic factors such as bio-physical factors, biotic interaction, species dispersal mode and ability, potential land-cover changes, and other anthropogenic factors have not been used in the model that might influence the results, and this is a limitation of the research. Although these species distribution models have many assumptions and uncertainties, such species distribution models still remain a critical data source for future suitability prediction in order to evaluate scientific adaptation strategies for offsetting future warming impact on forests at species, community, and ecosystem levels (Wiens et al., 2009, Ackerly et al., 2010). For example, the bog wetland complex in the German Black forest has already recorded the lost of two important plant species which have gone extinct over the last 40 years due to rising temperature and longer dry period (Marthin-luther, 2020). As well, the population of 37 other plant species in the bog wetland of this forest have decrease by one third and it is projected to record the extinction of 10 other species in the next two decades. In contrast 46 different species displayed a positive trend in that same area over the same period, and future projections show their expansion in the area (Sperle and Bruelheide, 2020).

4.2. Discussion on Future Ecosytem Services Modelling Results

According to the results presented on future forest ecosystem services prediction using linear programming, it has been found that climate change will influence abundantly the different forest ecosystem services such as timber production, carbon storage, soil loss and water production. Ecosystem services have always been predicted using linear programming as stated in Vatandaşlar et al., (2019) where linear programming has been used to determine the best planning strategy for maximum wood production over 50 years planning horizon. In this thesis, the main interest is to determine if climate change will have a significant impact on forest ecosystem and how it can be managed. These results show that planting identified adapted tree species is the best strategy under climate change to maintain the production of forest ecosystem services, specially wood production and soil protection. It can be mentioned that the best strategies are those where adapted tree species are planted compare to strategies where non adapted tree species were continuously regenerated over the planning horizon. Many similar results have been found in previous linear modelling studies such as Gül, (1998), Mısır, (2001), Keleş et al., (2005), Zengin, (2009), Karahalil et al., (2009), Değermenci, (2018) and Hagr, (2019) in their studies, who found that reducing soil loss value will affect water production values, as well as increasing timber production will affect carbon storage, biomass, soil loss and water production. Furthermore, Lundholm et al., (2020), recognise the importance to evaluate the impact of future global climate change and bioeconomy scenarios on ecosystem services using a strategic forest management decision support system. According to their study, climate change will impact negatively ecosystem services by increasing natural hazards that will reduce the economical value of ecosystem services. Only taking good management decisions can help the forest to reduce their vulnerability like we did in this study. This will help forestry professionals in their decisions according to climate change impact management in forest management.

4.3. Discussion on Climate Change Perception by Forestry Professionals in Germany, Turkey and Cameroon

4.3.1. Perception of Climate Change by Forestry Professionals in Germany

Most of the German foresters believe in climate change and are willing to change the forest structure and composition to help their forest for adaptation to future climate change. About 3% of the respondents don’t believe in climate change. These results are similar to the study carried out by Yousefpour and Hanewinckel (2015). In that study, they found that none of the respondents denied the existence of climate change. However, a small group seemed to believe that the current climate change is not unique from a historical perspective, which is similar to the finding of Blennow and Persson (2009) where only 75% over thousands of respondents in Sweden believe that climate is changing to an extent that could affect forests. A small group of forest owners in their survey (19%) have, however, adapted their forest management strategies to take into account climate change. In this study, 93% of the respondents perceive that their forests are at risk from climate change and are taking some measures to help their forest in the adaptation process by planting tolerant tree species and building mix stocks with well adapted tree species to future climatic conditions.

Furthermore, adaptation is, in essence, about making the best possible decisions for the future, taking into account the implications of climate change (Keenan, 2015). It requires considerable knowledge, competence and commitment for adopting actions, but also embracing risk and uncertainty (Howlett, 2012). Accordingly, comparing options from available adaptation measures will be key to successfully adapting forest management to the challenges of climate change (Kolström et al., 2011). But, although much has been written about adaptation strategies in forestry (e.g. Lindner et al., 2010; Kolström et al., 2011; Keenan, 2015), and a number of recent guidance manuals to assist forest managers have been developed (e.g. Lindner et al., 2008; Peterson et al., 2011; FAO, 2013), there is still a major knowledge deficit among forest stakeholders. The study of Silva et al. (2016) highlighted the lack of information and technical knowledge to undertake climate change adaptation actions as the main constraints of foresters in Belgium to implement adaptation actions. Furthermore, the minor importance given to the lack of interest when compared to the other constraints indicated that it is not lack of willingness which prevents forest stakeholders from implementing these actions, whereas the lack of conviction in its importance is very likely linked to their lack of knowledge (Silva et al., 2016). And in Germany, 3% of the respondents do not believe in climate change and 7% of the respondents are not willing to take any action to help the forest to adapt to future climate change conditions.

In this study, the degree of belief in climate change did not differ between the groups of respondents (private or public forest, large or small forest area) forestry professionals in Germany. Regarding the risk of susceptibility of their forest, 93% of the respondents are willing absolutely or probably to change the structure and composition of their forest for future adaptation. About 86% of the respondents stated to react in anticipation on future climate change by planting tolerant tree species and building mix stocks of many tree species in their forests. As well, in reaction 35% of the respondents said to share knowledge within groups or team of forestry professionals to develop adaptation strategies; 30% of the respondents said to have activities with experts in climate change adaptation and law implementation. Similar results have been found by Blennow et al., (2012) who found that different implementation of adaptation strategies by forestry stakeholders in Sweeden is related to their perception of climate change.

4.3.1.1 Adaptation Measure Taken by Forestry Professionals in Germany

The results of this study present a very high implication of group work and training offered by climate change experts to forestry professionals in Germany to help them understanding climate change issues and in designing and implementing adaptation measures. This may help to orient their vision on the adaptation of their forest. It can be mentioned that 28 tolerant tree species have been cited by the respondent in Germany as tree planted for the adaptation of the Black forest to actual impacts and future of climate change. These are some indicators that forestry professionals in Germany are taking measures to adapt the management of their forest to climate change. The same observation has been done by Silva et al. (2016), studying the adaptation of forest management to climate change as perceived by forest owners and managers in Belgium. They found that climate change presents significant risks for forests and challenges for forest managers. Therefore studying their perceptions on climate change effects may help to better assist them to effectively respond to climate change challenges and opportunities over the long term.

According to Seidl et al. (2016), the understanding of climate change and the threat it poses to forest should be adjusted to management plans and practices. This may explain why in Germany, 93% of the respondents are willing to change their forest structure and composition to adapt to future climatic conditions.

4.3.2. Perception of Climate Change by Forestry Professionals in Turkey

In this study, the perception of climate change signs and manifestations in the selected study areas are very high with 88.3% of respondents identifying climate change as a reality and having an impact on their forests (Fosso and Karahalil, 2021). This is higher compare to the (83%) of forestry professionals who perceived climate change as a reality, human-caused and is a significant risk for forest in the study carried out by Yousefpour and Hanewinkel (2015) in south east Germany. According to climate change experts, there is an increasing temperature tendency affecting season’s occurrences which are increasing, precipitation tendencies are decreasing and water availability to soil is decreasing and will continue to decrease over the next decades in Turkey (IPCC, 2014c). These are well perceived by respondents in the selected study areas with an average of 72.6% of them giving the parallel answers according to IPCC reports. Similar observations have been found by Korkmaz (2018) who stated that 80% of the respondent in his study about public awareness and perception of climate change in Turkey had a very high level of awareness about climate change manifestation and risk. This is relatively the same with the study carried out by Yousefpour and Hanewinkel (2015), where 80% of forestry professionals perceived that climate change has evident effects on their forest.

Scientists stated that due to the increasing frequency of drought in Mediterranean regions, the growth rates of trees will be slowed and the risks and exposures to other natural hazards will be higher (Capstick and Pidgeon, 2014; Korkmaz, 2018). All these climate change impacts on forests have been well identified by the respondents. The majority of respondents have identified that storm tendency (47.1%), insect's attacks (71.9%), forest fires (65.9%), drought tendency (74.3%) and tree mortality (57.7%) are more frequent (Fosso and Karahalil, 2021). Besides, growth rate of trees is decreasing as a consequence of climate change (51.2%). There was a public opinion that growth rates of trees will increase due to the increased vegetation period. On the other hand, the perception on the growing rate of trees displayed different results in this study. For instance, Antalya is located in the Mediterranean region of Turkey and the majority of respondents (62.5%) think that climate change is the main cause of increasing drough that impacts the growth rate of trees. According to them, trees are growing slower now comparing to the past. As well, a minority of respondents in İstanbul (46.8%) and Trabzon (44.4%) perceive that trees are growing slower (Fosso and Karahalil, 2021). At the contrary of this group, some respondents are thinking that growth rate of trees will increase due to the increase of rainy days per years and increase of precipitation such as in İstanbul (23.4%), but this perception is wrong. This is well explained by FAO (2013), stating that due to climate change impacts on forests, the tendencies of trees dying in forests as result of natural mortality will increase around the world. As well the consequences for certain species will differ by geographic location and the extent of climatic change.

While some species will respond positively with an increasing growth rates, an increased chance of survival and reproductive potential, other species, however, will respond negatively with a decreasing growth rate and reduced fecundity (Lindsey et al., 2012). As well the frequency of insects, pest outbreaks and the spore formation and colonization success of fungal pathogens will increase in Turkey forests with climate change according to Tüfekçioğlu et al. (2005). There will also be an increasing rate of death wood due to drier climate conditions leading to the venue of wood decomposers such as fungi according to Ceylan et al. (2009). Furthermore, a study carried out by Fosso and Karahalil (2020) in Cerle PU in Antalya found that increasing temperature of 1.9ºC from 1960 to 2010 and of 3.85 ºC by 2050, a slightly reduction of precipitations and humidity with the shift of season sequence have contributed to the increasing forest fire frequency in the forest leading to salvage cutting and the development of *Pinus nigra* which seems to be well adapted to the changing climatic conditions in Antalya.

The impacts of climate change on forest ecosystems vary from one region to another. This may explain the difference in the perception of the impact of climate change on forests in different selected study regions of this study. For example, 84.8% of respondents perceive more frequent forest fire in Antalya and only 46.7% in Trabzon. This may be due to the different climatic conditions in Antalya that is warmer (92.0% of respondent perceived increasing temperatures) than Trabzon (80.5% of respondents perceived increasing temperatures). The same observation have been made by (Lenart and Jones, 2014) who stated that the geographical location of respondents in USA had an influence on their perception of climate change due to climate variability from one region to another. So in Antalya, respondents are more prepared for risk management (92%) than İstanbul (76.7%) and Trabzon (65%) due to the higher frequency of forest fires in their region and the technical preparation to fight forest fires.

Considering the reaction in case of extreme climatic conditions, forest managers generally try to increase the forest area managed for ecological values without taking into account the effects of climate change. In this study, only 39.1% of respondent stated to plant tolerant species or building mix stocks. Similar observations have been made by Yousefpour and Hanewinkel (2015), who stated that forest decision-makers must be aware of the nature and implications of climate change in order to develop management strategies that may help to reduce adverse effects and sustain productive forest. On the other hand, more efforts should be made especially during the forest management planning process, responsible for the determination of forestry activities such as regeneration, thinning or planting via forest management plans. Therefore, there is a strong need to integrate the climate change issue to those practices since global climate change is causing an increase in the frequency of forest fires in Mediterranean forest like in Antalya and temperate coniferous areas like in Trabzon.

As stated by the results of this research on adaptation strategies elaborated, the majority of respondents in this study are trying to implement forest law or work with an expert in climate change to face the impacts on their forest. This goes in strait line with FAO (2013) climate change guidelines for forest managers and policy-makers, stating that there is a need to integrate climate change concerns into new or existing forest policies and national forest programs in order to assist forest managers to better assess and respond to climate change challenges and opportunities at the forest management level. There is no need to wait for the venue of climate change adverse before trying to adapt to them. Therefore, forest managers need to put in place an adaptation system that should monitor the disturbance according to regional and local realities to improve the adaptation capacities of the society in case of active adaptation strategies. Spittlehouse and Stewart (2003) noted that adapting to climate change in the face of the uncertain timing of impacts requires planning for changes so that a range of options are available whenever needed. As well 25.1% of the respondents in this survey said to implement passive adaptation strategies by observing the change without any reaction. This group and the foresters having no idea need to be trained since they play a key role in the success of the adaptation strategy process in forest ecosystems (Yousefpour and Hanewinckel, 2015).

In this study, the willingness to change forest structure and composition for future adaptation has recorded 55.4% of respondent favourable and 25.1% against, while 19.5% of respondents stated to have no idea about it. This is highly related to the perception of climate change by the respondents ($r=0.83$; $p=0.000$). This result is similar to Lenart and Jones (2014), who found that the willingness to adopt an innovative adaptation practice by forestry professionals in USA depend on their perception of climate change. The justifications about their willingness to change the structure and composition of their forest for future adaptation are that adapted species will be more appropriated to continue to produce forest ecosystem’s goods and services sustainably while dealing with climate change impacts on forests.

4.3.3. Understanding Climate Change and Actions, as Perceived by Forestry Professionals in Cameroon and Comparaison to Germany and Turkey

The Chi-square statistic test is significant when we compare answers of respondents in Germany, Turkey and Cameroon, meaning that the answers of respondents vary according to their location, their education level, their age, gender and their professional occupation. Furthermore, the analysis between the believing in climate change and the willingness to change the forest structure and composition is significant for the study in

Turkey (Fosso and Karahalil, 2021), meaning that believing in climate change is related to the willingness to take action for forest's adaptation. These results are nearly similar to the study carried out by Blennow et al. (2012) and Yousefpour and Hanewinkel (2015), who found that believing in climate change is highly correlated to the willingness to elaborate adaptation strategies.

Furthermore, in Cameroon, 76% of the respondents believe that climate change is real, 67% of them are willing to take actions to help the forest to adapt, but only 40% of them have been able to identify real and effective actions for adaptation through planting adapted trees species in their forests (Fosso, 2018). This means that the willingness to take action must be converted into practical knowledge in order to identify adapted tree species to take effective action. So more research must be carried out in the selected areas, especially in Cameroon to help forestry professionals to find appropriated adaptation strategies and identify adapted tree species to plant in their forests. As well, training programs on the integration of climate change to forest management practices must be elaborated for cameroonian forestry professionals taking into account local realities for their implementation.

In this study, 93% of the respondents in Germany, 55.4% in Turkey and 66.7% in Cameroon, have understood that their forests are at risk from climate change and are taking some measures to help their forest in the adaptation process by planting tolerant tree species and building mixed stocks with well adapted tree species to future climatic conditions. Climate change adaptation is a new challenge for forest managers in addition to current economic, social and political challenges. The best way to implement adaptive practices is to share the knowledge at hand among the plurality of foresters (Keenan, 2015). For example to conserve forest structures, it is assume that low adverse impacts of climate change and high stand resistance to climatic stress, whereas passive adaptation means stopping all management interventions and relying on spontaneous adaptation processes. For many intensively managed forests in Europe, active adaptation is recommended to cope with marked climate change e.g., introducing new tree species or genetically better adapted provenances of existing species, and changing the rotation time or the thinning regime (Bredahl-Jacobsen and Nick, 2004).

Moreover, risk perception differs from one respondent to another, but taking the best decision for adaptation should be a concensual between forest managers. But they need knowledge and practical experience to implement these adaptation practices. This is why on the 66.7% of respondents willing to help forest to adapt in Cameroon, only 40% have the effective knowledge to implement adaptation in their forests. Accordingly, comparing options from available adaptation measures will be the key to successfully adapting forest management to the challenges of climate change (Kolström et al., 2011). But, although much has been written about adaptation strategies in forestry (e.g. Lindner et al., 2010; Kolström et al., 2011; Blennow et al., 2012; Yousefpour and Hanewinkel, 2015; Keenan 2015), and a number of recent guidance manuals to assist forest managers have been developed (e.g. Lindner et al., 2008; Peterson et al., 2011; FAO, 2013), there is still a major knowledge deficit among forest stakeholders.

The study of Silva et al. (2016) highlighted the lack of information and technical knowledge to undertake climate change adaptation actions as the main constraints of foresters in Belgium to implement adaptation actions. This was the case for forestry professionals in Turkey and Cameroon who are largely willing to take action, but lack technical knowledge to operationally implement their willingness. As well German respondents are well equipped both technically and scientifically. This may explain the significant differences in the statistics of answers per countries. Furthermore, the minor importance is given to the lack of interest when compared to the other constraints. This indicates that it is not the lack of willingness which prevents respondent's forestry professionals from implementing these actions, but the lack of conviction in the importance of climate change adaptation is very likely linked to their lack of knowledge (Silva et al., 2016). Similar study carried out by Soucy et al., (2020) on understanding characteristics forest professionals stated that climate change risk perception and management is a factor of believing in climate change. Then 3% of the respondents in Germany do not believe in climate change due to ignorence and 7% of them are not willing to take any action to help the forest to adapt to future climate change conditions due to lack of knowledge.

The majority of respondents in Turkey and Cameroon didn't state adapted tree species in their areas. Only 12 adapted tree species have been cited by respondents in Turkey and 8 ones by respondents in Cameroon. This may explain the requirement of a large program of research and communication on adapted tree species to plant in their areas as well as workshops and training to upgrade their knowledge on the management of this phenomenon. Some on-going sylvicultural research have been carried out to investigate the potential tree species that will be well adapted to future climatic conditions in the Black Forest and the results have been shared to forestry professionals working in and around this area. This will help in the future to adapt the Black Forest to future climatic conditions. It is stated that *Picea abies* is not adapted to future climate conditions in the Black Forest and *Pseudotsyuga menziesii* and *Pinus sylvestris* are well adapted to drought and other future climatic conditions (Bindewald et al., 2021). Doubts have arisen that *Pinus sp*. is as drought tolerant as it has been regarded in earlier years (Sohn et al., 2016). As well, the availability of informations on adaptation techniques, financial capital and human capacities improvement are the needs to increase forest manager's adaptation capacities (Soucy et al., 2020). Moreover, risk perception index is related to cognitive factor (education), experimental processing (self experience), socio-cultural influences and socio-demographic parameters and therefore, based on these parameters, climate change risk perception model has been elaborated as presented in Figure 69 (Van der Linden, 2015; Van Eck et al., 2020).

4.4. Elaboration of a Simplified Model to Help Forestry Professionals to Identify Adapted Tree Species in Their Forest

According to the CCRPM+ model, the cognitive dimention is the most important part of climate change risk perception and understanding. But it is related to experiental processing such as emotion and personal experience of extreme weather events by the respondent. As well it is also related to socio-cultural factors such as social norms and value orientations like egoistic, socio-altruistic and biospheric values. Nevertheless, trust in sources of information should be considered in climate change risk perception analysis and management (Van Eck et al., 2020).

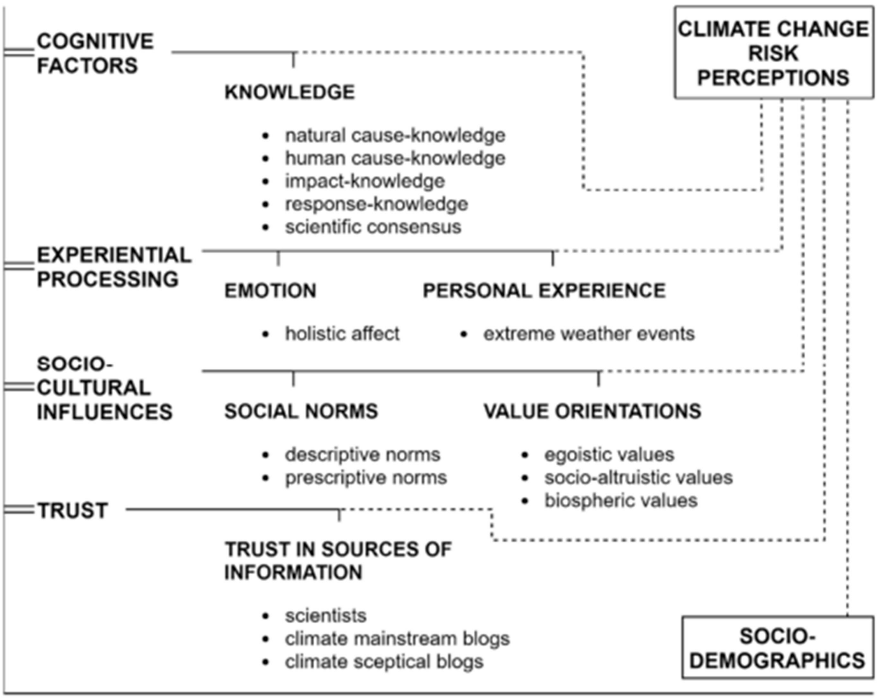


Figure 70. Climate change risk perception model (CCRPM+) (Van Eck et al., 2020)

It can be stated from Figure 70 that, to explain and predict adaptation to climate change, the constraints limiting forest management adaptation to climate change must be considered and addressed to make adaptation successful. In particular, there is a need to continue the training of forestry professionals in Germany, Turkey and specially Cameroon in order to develop information tools they need to make decisions on their forest management options to address climate change. This should be the case for silvicultural regeneration of forest with adapted tree species in existing identified threaten areas, such that in case climate change will have negative impact on them, adapted species will interact with non adapted species to reduce their vulnerability (Huss et al., 2020). Nevertheless, some of the respondents in the 3 selected countries perceive climate change as too uncertain to undertake actions, while others who believe in climate change are not willing to take actions to change the structure of their forest for future adaptation. These are most often related to the lack of knowledge on climate change adaptation strategies in forest management activities specific to each country.

According to all these, the following model has been elaborated as a synthesis to implement the integration of climate change to forest management practices:

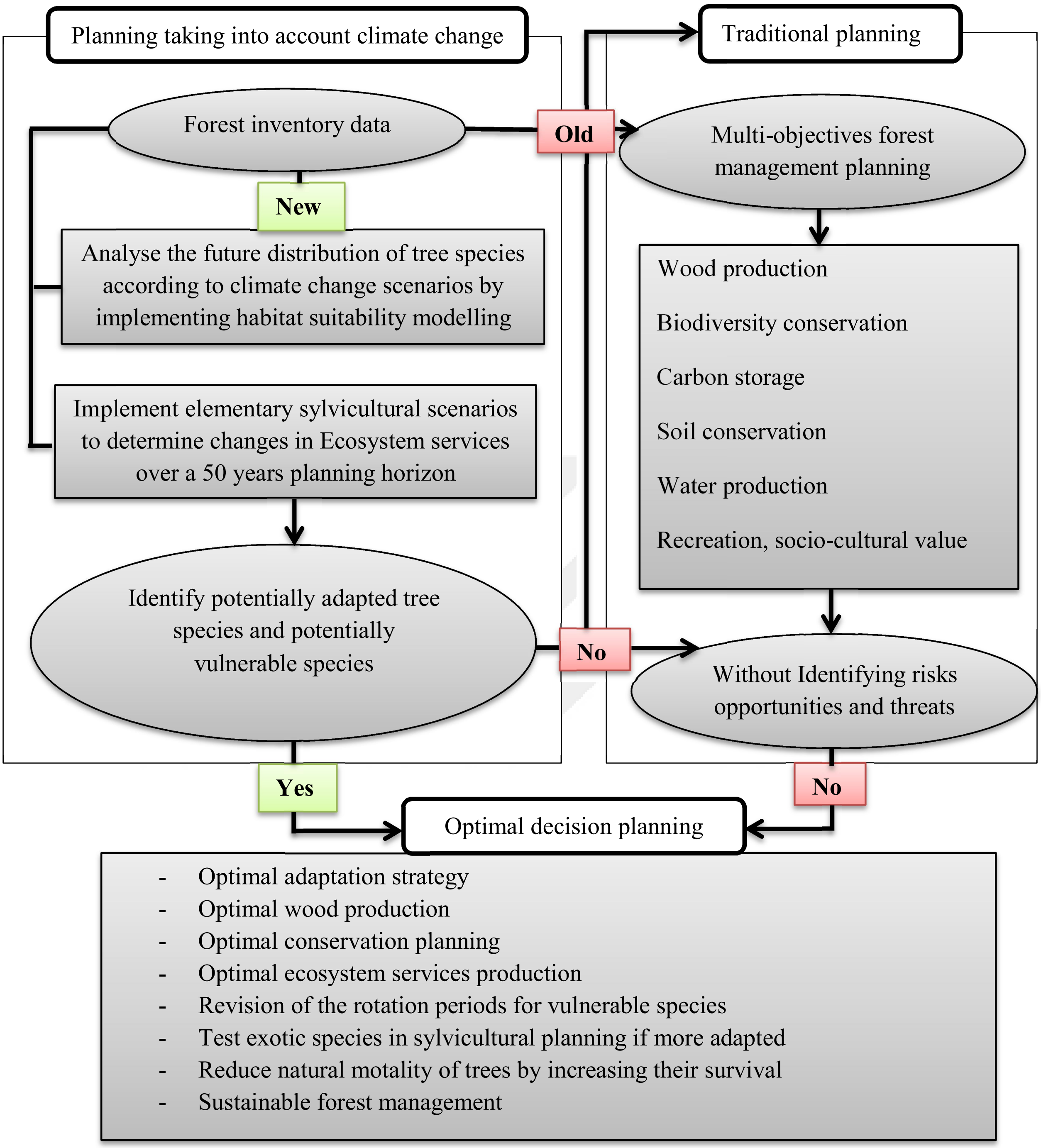


Figure 71. Model for integrating climate change to forest management planning

As mentionned in Figure 71, forest inventory data collection is the first step of forest management planning. In the traditional planning system, multiple objectives forest planning is established directly after forest inventory in order to manage sustainably forest resources while satisfying the needs in wood production, biodiversity conservation, carbon storage, soil conservation, water production, recreation, socio-cultural values, etc. That is an old system that Is being implemented without identifying the risks, opportunities and threats caused by climate change on the current and future distribution of forest tree species and ecosystem services related. The new approach that may help forest managers to make an optimal decision in forest management planning should be done by analysing the future tree distribution and sylvicutural simulations according to climate change scenarios in order to identify adapted tree species as well as potentially vulnerable species as a new forest planning model. As well, sylvicultural scenarios help to determine the change in ecosystem services according to future climates scenarios. This will help to identify adapted tree species that should be integrated in future management plans, and vulnerable species that must go under conservation management. If this is implemented, it can help to archieve optimal decison planning with an optimal adaptation strategy.

5. CONCLUSIONS

The aim of this thesis was firstly to evaluate the consequences of climate change on the geographical distributions and habitat suitability of selected tree species in Trabzon and Antalya using maximum entropy modelling technic. The results of the study revealed that the selected tree species, namely *Picea orientalis*, *Fagus orientalis*, *Quercus spp.*, *Alnus glutinosa*, *Pinus sylvestris*, *Carpinus orientalis* and *Abies nordmanniana* in Trabzon, and *Pinus brutia*, *Pinus nigra*, *Quercus spp*., *Cedrus libani* and *Abies cilicica* in Antalya, distributions are largely determined by bioclimatic variables (bio1-bio19). The Maxent models performance was evaluated using ROC AUC which confirmed that the models generated were well calibrated. AUC values generated by Maxent models for the selected tree species range from 0.872 to 0.952 which is higher than 0.5 of a random model. However, the performance of Maxent models could still be improved by avoiding the generalization of the parameters and variables to be used for modelling of multiple species. Furthermore, it does not necessarily mean that bioclimatic variables are the only parameters that should be taken in to account to predict the potential future distribution of tree species that are mainly dependent on biophysical parameters spatially and temporally auto correlated with bioclimatic parameters.

Tree species mixture suitability change has been observed in the two selected regions, with the expansion of suitable area for *Quercus spp*. and *Pinus sylvestris* in Trabzon region, while the reduction of suitable area for *Pinus brutia* and the expansion of *Cedrus libani* and *Quercus sp.* in Antalya region have been observed. It can be mentioned that according to the results presented in this study, *Quercus spp*. and *Pinus nigra* are the tree species presenting good adaptation potentialities in Antalya regional forest according to habitat suitability predictions. As well, *Pinus brutia* has been identified as a vulnerable tree species as well as other possible tree species whose habitat alterations by future climate was shown. This call for appropriate adaptation strategies in order to maintain the quality of forest in those areas.

Secondly, we have been able to achieve the goals of identifiying the change in terms of ecosystem services related to the change in climatic conditions leading to forest structure and composition change. With the help of linear programming, four forest values (timber production, carbon storage, soil loss and water production) were integrated into a single plan using different strategies. Each strategy was compared (for 5 periods) as well as a comparison of planning strategies each other. The most appropriated strategies have been identified (STR9 and STR10), for maximum wood production while minimizing soil loss. These strategies consist of planting adapted tree species under climate change impact in order to maintain forest ecosystem services production at a sustainable level. The results of this study are consistent with previous studies and emphasize modeling ability to optimize forest management plans because of their ability to provide alternatives to planning and thus help to make an appropriate decision, which would maintain a balanced supply of ecosystem resources. It can be more interesting to evaluate the change in terms of forest ecosystem services in economical values. This can contribute to increase the awareness of forestry professionnals about climate change impacts on their forests and the necessity to take action for adaptation by planting adapted tree species. This modeling approach should be included in forest management plans in Turkey and in other countries in the world, because it can help to establish clear management objectives and integrate climate change as one constraint in forest regeneration, afforestation activities and wood production activities as well as other ecosystem services production. This method of integrating climate change to forest management can also help forestry professionals to anticipate on the future economic, social and cultural impacts of climate change on their forest. By this way, multi-objective forest management can be perforemed easily.

Thirdly, the perception of climate change and adaptation strategies elaborated by forestry professionals in Germany, Turkey and Cameroon have been analyzed. As results, it can be stated that perceptions on increasing temperature and reducing precipitation tendency in Germany are well identified as climate change signs and manifestations in that area by 97% of the respondents in the south of Germany. Merely all 93% of forestry professionals in this region are aware of potential strategies for helping forests to adapt to the negative impact of climate change including focusing on adapted species and provenance selection. Converting forest structure from pure to mixed stands and changing thinning regimes by planting adapted tree species have been stated as actions to help forest in the active adaptation process in Germany. About 28 different tolerant tree species have been cited by respondents as having real adaptation potentialities. However, only 3% of the respondents said they were not willing to take action to help their forest to adapt to future climate change impacts in the Black forest. Furthermore, respondents in Germany are well prepared to help their forest to adapt to future climate change events, by implementing active adaptation strategies comparing to respondents in Turkey, where 88.3% of the respondents perceive well the phenomenon and only 55.4% of them are willing to take actions for adaptation, and comparing to Cameroon where 76.2% of the respondents believe that climate change is real, 67% of them are willing to take actions to help the forest to adapt, but only 40% of them are taking effective actions. Our findings about respondents understanding on climate change and the need to have adaptation measures can inform the general public about the good level of preparation of German forestry professionals compared to Turkey and Cameroon, and the need of continuous training and research in each country.

Climate change phenomenon is real and evidence of climate change impacts on forest ecosystems are known as risks or certainties. However, the future of climate change is based on speculations, scenarios and theories such that every sectors must develop their own framework to consider future climate events. This is the case for future forest management practices that should adapt with the most advanced climate models. There is no need to wait for the venue of climate change adverse before trying to adapt to them. Prevision should be taken now and adaptive policies should be developed to adapt management strategies in response to improve their understanding of the impacts and observed forest responses to the changing environmental conditions. There is a need to put in place an adaptation system that should monitor the disturbance and integrate the international policies, national legislations, regional and local realities to improve the adaptation capacities of the society. Forest management practitioners plays a key role in the success of the adaptation strategy in forest ecosystems process, by implicating local peoples, forest owners and government.

In this study about 88.3% of the respondents in Turkey perceive climate change as a real phenomenon and this perception is depending on the region of respondents in Antalya (92.9%), İstanbul (90.9%) and Trabzon (81.1%). Even if the phenomenon is real and evidence of climate change impacts on forest ecosystems are certain, more than 25% of the respondents in Turkey said to perceive less effects of climate change on forests, and are not willing to take any adaptation measure to help the forest to adapt to future climatic conditions. The future outputs of the ecosystem services can be handled using decision support systems under different climate scenarios and forest managers can be informed in order to increase their willingness to adopt climate change adaptation measures.

This study reveals that in Turkey, forest managers should improve climate change risk management practices and adjust afforestation techniques, while controlling the fuel uploading and stand structure modification to reduce fire risk and insect or pest propagation in and around their forests. As well, the selection of adapted tree species for silvicultural operation is a must to integrate climate change to forest management practices.

To conclude, understanding climate change signs and manifestations and adaptation strategies elaborated are very crucial to analyze in the current intensive discussion on climate change and sustainable forest management. Forest administrations of the different Federal States in Germany have started to design adaptation strategies to climate change, with some distinct differences in their assessments of needs and strategies. This should be done in every country and region of the world in order to take in account local specificities and realities of each forests, ecoregions and microclimate change. Since forestry professionals play an important role in the implementation of these strategies in every country in the world, their perceptions and their level of understanding of climate change and potential adaptation strategies are decisive for the successful application of the adaptation strategies.

6. RECOMMENDATIONS

It is recommended to:

- Carry out specific studies in different forest ecosystems in order to observe the different impacts of climate change on forests and the possible specific management activities that can be scheduled to reduce the future impacts of climate change on forests in any other country around the world.
- Continuously training forest managers on how to implement adaptation strategies in Germany, Turkey and Cameroon as well as in other countries in the world to help the forest to maintain sustainably its productive capacities for the well-being of future generations.
- Integrate climate change management strategies in forest policies and management plans in Turkey, create a platform to continuously inform and train the foresters about potential management strategies of climate change risks and impacts in their forest, continuous research on climate change potentially adapted tree species that could be planted in the forest area where the vulnerability is highly evident.
- For future studies, the inclusion of forestry working areas of the respondents in the questionnaire is also suggested, to display the relationships between their perceptions and working areas.
- Modeling approach should be included in forest management plans in Turkey and in other countries in the world, because it can help to establish clear management objectives and integrate climate change as one constraint in forest regeneration, afforestation activities and wood production activities as well as other ecosystem services production. This method of integration climate change to forest management can also help forestry professionals to anticipate on the future economic, social and cultural impacts of climate change on their forest. By this way, multi-objective forest management can be perforemed easily.
- More studies should be conducted throughout the country. Future distribution of other basic species should be estimated.

- Demand and supply for the future and other future ecosystem services was not taken into account in this study. So future scenarios on demand to other ecosystem services should also be access.
- In this study, Worldclim data was used to produce habitat suitability distribution of the species. But localy collected climate data could provide more details and more precise predictions.
- Ecosystem services shoud be displayed in a more detailed way, with economic evaluation, because the net present value can be estimated and the change in that economic value could be more interesting to present to decisioners.
- Future land used/land cover change should be estimated in the selected study area and evaluated with such single results. Therefore, actual and future spatial distribution of the future forests can be displayed.

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ANNEXES

Annex 1: Questionnaire

Questionnaire: Climate change perceptions by forest managers and adaptation strategies elaborated

Area Code ☐ Respondent Code ☐ Interviewer Number ☐ (**not to be filled by the respondent**)

Q1. Identification of the respondent You are the forest Manager of a:

Type: 1. Private forest ☐ 2. Community forest ☐ 3. Public forest ☐ 4. Other ☐

Forest area ……… Your age ……. Your Level of educatio

1. University ☐
2 High school. ☐
3.Self-Training ☐
4.Others ☐

Gende

1. Male ☐
2. Female ☐

1. Climate change perception: Signs of climate change.

Q2. What do you think about **climate tendency** actually comparing to the past 30 years**?**
1. Seasons are warmer ☐ 2. Seasons are cooler ☐ 3. Seasons are the same ☐ 4. No idea ☐

Q3. What do you think about **season's (spring/autumn) occurrence** tendency comparing to the past 30 years?
1.Earlier than before ☐ 2. Later than before ☐ 3. Always occur at the same time ☐ 4. No idea ☐

Q4. What do you think about **temperature tendencies** in your region considering the past 30 years?
1- Increasing ☐ 2. Decreasing ☐ 3. Not changing since decades ☐ 4. No idea ☐

Q5. How do you think **precipitation tendency** has evolved comparing to the past 30 years**?**
1. Higher precipitation ☐ 2. Less precipitation ☐ 3. Still the same ☐
4. More snow in winter ☐ 5. Less snow in winters ☐ 6. No idea ☐

Q6. What do you think about **water availability** tendency comparing to the past 30 years?
1. More water available ☐ 2. Less water available ☐ 3. Still the same ☐ 4. No idea ☐

Q7. Do you think **climate change** is real or an utopia?
1. Real ☐ 2. Utopia ☐ 3. No idea ☐

Q8. Do you think the **climate is changing** to such an extent that **it will affect the forests** in this region?
1. Yes, absolutely ☐ 2. Yes, probably ☐ 3. No, probably not ☐
4. No, absolutely not ☐ 5. No idea ☐

2. Climate change manifestation and impacts on forestry activities during past 30 years.

Q9. What do you think about the **tendency of storms** in the region comparing to the past 30 years**?**
1. More frequent ☐ 2. Less frequent ☐ 3. Not changing since 30 years ☐ 4. No idea ☐

Q10. What do you think about **insect's attacks tendency** on trees in the forest in this region?
1. More frequent ☐ 2. Less frequent ☐ 3. Not changing since 30 years ☐ 4. No idea ☐

Q11. What is the tendency of **forest fires occurrence** in this region?
1. More frequent ☐ 2. Less frequent ☐ 3. Not changing since 30 years ☐ 4. No idea ☐

Q12. What is the tendency of **drought occurrence** in this region?
1. More frequent ☐ 2. Less frequent ☐ 3. Not changing since 30 years ☐ 4. No idea ☐

Q13. What is the tendency of **trees dying by natural mortality** without any explanation?
1. More frequent ☐ 2. Less frequent ☐ 3. Not changing since 30 years ☐ 4. No idea ☐

Q14. What is the **main hazard causing tree mortality** in the forests of this region?
1. Increasing storm frequencies ☐ 2. Increasing insects attacks ☐ 3. Increasing forest fires ☐
4. Extended drought period ☐ 5. All these factors combined ☐ 6. Other causes ☐ 7. No idea ☐

Q15. What do you think about the **growth rate of trees** in the forest of this region actually?
1. Trees are growing faster ☐ 2. Trees are growing slower ☐ 3. Not changing ☐ 4. No idea ☐

Q16. Do you think that these **natural hazards** are caused by long term global climate change?
1. Yes, absolutely ☐ 2. Yes, probably ☐ 3. No, probably not ☐
4. No, absolutely not ☐ 5. No idea ☐

3. Reactions of forest managers in case of extreme events due to climate change.

Q17. How do you **react in case** of the occurrence of **extreme climatic events** in your forests?
1. I do nothing ☐ 2. I try to handle the risk ☐ 3. I try to find help from an expert ☐
4. I reduce harvesting intensity ☐ 5. I increase thinning operations ☐ 6. I try to build mix stocks ☐
7. I plant more tolerant tree species ☐
which one do you plant? ……………………………………………

4. Adaptation strategies elaborated: depending on the willingness to change.

Q18. How do you **adapt to extreme climatic events occurrence** in your forest? (After they occur: Curative)
1. I try to implement prescriptions of our forest laws and governance in case of extreme events ☐
2. I try to read, understand and implement new prescriptions from experts ☐
3. I try to develop my own damage prevention program based on my previous experience ☐
4. I reduce the annual harvesting volumes ☐
5. I subscribe for a natural hazards risk insurance ☐
6. I work with a risk management team ☐ 7. I do nothing ☐

Q19. Are you willing to change the forest stands structure and composition in the future for adaptation to climate change in the future? (As a Prevention in advanced of **extreme climatic events occurrences)**
1. Yes, absolutely ☐ 2. Yes, probably ☐ 3. No, probably not ☐
4. No, absolutely not ☐ 5. No idea ☐

Q20. If Yes, Why?
…………………………………………………………………………………...................

If No, Why?
…………………………………………………………………………………………..

THANK YOU VERY MUCH FOR YOUR ANSWERS.

CURRICULUM VITAE

He completed his primary school and secondary school at the green city school of Yaoundé, where he almost performed as one of the best students of his batch. He got a baccalaureat in Natural Sciences (Biology, Mathematics, Physics and Chemistry) with a Good grade, then he was admitted at the Faculty of Agronomy and Agricultural Sciences of the University of Dschang in Cameroon where he completed his Bachelor degree in Forestry after 3 years, his professional Master in Forest Engineering degree after 5 years, then his Master of Sciences degree in Natural Resources Management the 6th year of studies at FASA. Thereafter, he got got the chance to be admitted for a PhD program in Forest engineering at Karadeniz Technical University, in Trabzon, Turkey, under the Turkish Governement Scholarship Program. Therefore, Erasmus+ program at the University of Freiburg in Germany. During his academic carreer, he has worked as a civil servant in Cameroon as an Agriculture and Forestry works engineer, at the Ministry of Agriculture and Rural Development in Cameroon from 2011 to 2015. He has also worked as a Biology teacher at Intelligentsia Corporation in Cameroon. He is actualy working in a project of the Marmara Forest Reseach Institute, where he provides expertise on Habitat suitability modeling of tree species in Turkey.

Due to his origin, Lionel constantin FOSSO speaks fluently French, English and his mother language that is NGUEMBA (a Bantou language). He also has a very fluent Turkish Language spoken, as well as German that he learned in Cameroon and Germany. Within the scope of his thesis, he participated to many conferences on climate change and forestry in İstanbul, Antalya and Trabzon in Turkey, Freiburg, Koblenz-Landau, Anwieler in Germany, strassbourg in France and Bruxells in Belgium. He did a presentation on a part of his results in French at the University of Strassbourg in September 2018, in English at the 3MT competition organized by the University of Queensland in Australia but for the German universities in Freiburg, and took part to the Congo Basin Forest Partnership meeting in Bruxells, where he was a participant. He is the author of one book and 5 articles, within which 3 have been published as part of the results of this study and there are more to be published.

As motivation, he always remember a citation of his primary school teacher who told them that: “**School will only do good, to those who will do it well**.”

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