POTENTIAL DISTRIBUTION OF TREE SPECIES IN PRESENT AND FUTURE CLIMATE SCENARIOS FOR AFFORESTATION PROJECTS IN KP, PAKISTAN

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A thesis submitted in partial fulfillment of the requirement for the degree of Master of Science in Environmental Science

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Approval Certificate

Certified that the contents and form of the thesis entitled
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Dedication

I dedicate this thesis to my late father, who worked hard all his life to provide me the best opportunities

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Abstract

Because of the growing frequency of extreme weather events, climate change has progressively become a serious concern. Climate change has posed a threat to more than a quarter of all plant species. Climate change is projected to cause substantial shift in the potential distribution of tree species throughout the planet. *Cedrus deodara, Dalbergia sissoo, Juglans regia, Pinus wallichiana,* Eucalyptus, *Senegalia Modesta, Populus ciliata,* and *Vachellia Nilotica* used in afforestation projects of Khyber Pakhtunkhwa (KP), Pakistan, were studied in this perspective. 19 bioclimatic variables, as well as soil, irrigation, and elevation were used to predict current and future potential distributions under moderate and extreme scenarios for mid and end of the century, by using Maxent model. Furthermore, it was investigated that if the recent tree plantation sites of respective eight tree species fall inside the projected potential distributions. Each tree species responded independently in terms of its potential habitat to future climatic conditions. *Cedrus deodara* showed increase in potential suitable area towards northern parts in present and future climate scenarios. *Dalbergia sissoo* showed the least potential suitable area in KP. *Pinus wallichiana, Juglans regia and Vachellia nilotica* showed decline in habitat in future climate scenarios. The results predicted expansion in suitability area for *Eucalyptus* in future with eastward shift under SSP5-8.5. *Senegalia modesta* showed increase in suitability area in the middle of the century but declined at the end of the century for both SSPs. *Populus ciliata* is predicted to occupy habitat at higher altitude to the north of KP. Results of the test AUC mean values of 0.9 for *Cedrus deodara*, 0.9 for *Dalbergia sissoo*, 0.9 for *Juglans regia*, 0.9 for *Eucalyptus*, and 0.9 for *Vachellia nilotica* indicated that the model performed better, while values of 0.705 for *Pinus wallichiana*, 0.676 for *Senegalia modesta*, and 0.637 for *Populus ciliata* demonstrated that the model performed satisfactory. These research outcomes are useful in understanding the geo-ecological features of these species, as well as providing regional projections under present and future climate change scenarios for afforestation and conservation projects.

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List of Abbreviations

AMF	Arbuscular Mycorrhizal Fungi
AUC	Area Under the Curve
BTAP	Billion Trees Afforestation Project
CMIP6	Coupled Model Intercomparison Project 6
DEM	Digital Elevation Model
GBIF	Global Biodiversity Information Facility
GCM	Global Climate Models
HIV	Human Immunovirus
HPV	Human Papillomavirus
HSV	Herpes Simplex viruse
IPCC	Intergovernmental Panel on Climate Change
KP	Khyber Pakhtunkhwa
MaxEnt	Maximum Entropy
ROC	Receiver Operating Characteristics
SDM	Species Distribution Modeling
SSPs	Shared Socioeconomic Pathways

Chapter 1

INTRODUCTION

1.1 Climate Change

Climate change has gradually become one of the major concerns throughout the world due to the increased severe weather events. Since the industrial era, global mean surface temperatures have increased to 1.07°C, and are anticipated to rise by 3.3°C to 5.7°C by the end of the century under the a high emissions/business-as-usual scenario (IPCC, 2021). Climate change has long-term consequences for forest species, necessitating immediate climate change mitigation and adaptation efforts by governments and civil society around the world (Altvater et al., 2012; IPCC, 2018).

1.2 The Effects of Climate Change on Plant Distribution

The physiological research shows that the increasing hotter temperatures are having a negative effect on the annual growth of younger plants of subalpine and alpine species (Vittoz et al., 2008). Research carried out over the ecosystem of mountains has revealed relocation of species towards a higher level and towards North Pole as a result of climate change (Sproull et al., 2015). The studies carried out on European mountain ranges also revealed shift of species to higher levels from lower latitude. The studies also showed an overall decrease in the tropical plants of at the lower elevations (Pauli et al., 2012). According to the Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report, nearly a quarter of all plant species are considered endangered (IPCC, 2013). The geographical spread of plants, notably woody plants, is heavily influenced by climatic variations. The woody species seem to be more susceptible towards temperature than herbaceous vegetation in general, and temperature controls their altitudinal and latitudinal limits (D'Odorico et al., 2013). As a result, several studies (Mong & Vetaas, 2006; Kullman, 2008; Vitasse et al., 2012) have observed changes in the range restrictions and progressively skewed distributions of species along elevation gradients, revealing that plant distributions are moving upslope due to climate change.

In a rapidly changing environment, forest tree populations can have three potential scenarios: persistence through migrating to follow different habitats regionally, survival through adapting to new circumstances in existing places, or eventual extinction. As climate change is expected to happen considerably rapidly than tree species' natural ability to adapt and relocate (Savolainen et al., 2007; Aitken et al., 2008). Large-scale afforestation in China's dry and semiarid regions has undervalued terrain, climate, and irrigation, all of which can affect tree survival. All restoration attempts will be harmed by climate change, which is presently shifting species ranges and will continue to do so at a faster rate in the future. To meet the needs of current and future landscape concerns, restoration methods must use modern scientific techniques such as Species Distribution Models (SDMs) and Nature Based Solutions (Beatty et al., 2018).

1.3 Species Distribution Modeling (SDM)

To predict the possible distribution of species of plants, viruses and animals, the Species Distribution Modeling (SDM) is substantially used. The modeling is also a helpful instrument to tackle with the problems related to conservation and ecology of different species (Pearson et al., 2007). The most ideal habitats for a selected species and/or a community are indicated in the SDM’s result with spatial projections (maps). The connection between the likelihood that a given species will come about and the given environmental variables is examined in the habitat suitability modeling (Hirzel & Lay, 2008). In the scenario where a limited observational data is available on the selected specie, the habitat suitability modeling helps to predict the occurrence of specific species (Pearson et al., 2007). However, limited available data of the selected specie’s occurrence specifies areas that have similar characteristics to those where the selected species naturally occurs; it does not bound the range of specie’s habitat. To model species geographic distributions, Phillips et al. (2004) put forward the application of maximum entropy method. Maximum entropy modeling (MaxEnt) uses techniques developed from machine learning, allowing empirical data to be used to predict the probability of finding something under certain conditions distributed in space. The maximum entropy model, a commonly used SDM normally combines observations of the species occurrence with environmental information to predict the geographic distributions of animal or plant species.

SDMs can be quite useful tools to design entire afforestation projects by projecting potential suitable areas for species under different climate change pathways (Hidalgo et al., 2008). Afforestation projects even in deserted areas of the world has been reported as successful, however, climatic factors such as climate extremes and seasonality factors and species selection play a vital role in success of any afforestation project (Majumder et al., 2013; Li et al., 2016; Cuong et al., 2019). High temperatures, drought stress, disease, and low soil nutrient levels have played a key role in extensive dieback and mortality of many tree species (Allen et al., 2010; Ji et al., 2020; Colangelo et al., 2018;). Many afforestation projects are being carried out all around the globe, without considering niche dynamics of planted species. Due to this negligence a lot of species were introduced in their non-native zones (Li et al., 2018).

1.4 Shared Socioeconomic Pathways (SSPs)

Shared Socioeconomic Pathways (SSPs) is a series of five narratives about prospective social growth and global environmental change trajectories in the 21st century. (Fig 1.1). The SSPs contain one of most complete collection of environmental and sustainable development scenarios ever created. Each SSP includes a narration about upcoming socioeconomic growth as well as quantitative information validating the narratives from state-of-the-art demographic, economic, and incorporated evaluation algorithms. Projections on a variety of subjects are included, including size of the population, urbanization trends, incomes, energy consumption and production, agricultural production and land use, emissions, and climate change. Shared Socioeconomic Pathways (SSPs) are scenarios of projected socioeconomic global changes up to 2100. SSP 2-4.5 is an updated RCP 4.5 scenario that uses a moderate path of development and signifies an intermediate level of greenhouse emissions and a nominal 4.5 Wm^2 radioactive forcing amount by 2100; SSP 5-8.5 is an updated RCP 8.5 scenario that uses a path of development controlled by fossil fuels and signifies a high rate of greenhouse emissions as well as a nominal 8.5 Wm^2 radioactive forcing amount by 2100. According to a modelled study by Nepal et al. (2019) global forest area is projected to increase by 7% as of 2100 relative to 2015 levels in SSP3, which predicts a future with the lowest rate of economic growth, and by 36% in SSP5, which is a future with the highest rate of economic growth and greater economic equality across countries. Global demand of industrial round wood is 20% lower in SSP3 as compared to SSP2. With certain variations and geographic inequalities in environmental conservation, SSP2 largely matches existing trends. SSP5 is defined by a carbon-based economic growth paradigm in which an increased land demands for agricultural production, combined with insufficient global coordination leads to deforestation, though at a steady rate than SSP 3 (Estoque et al., 2019).

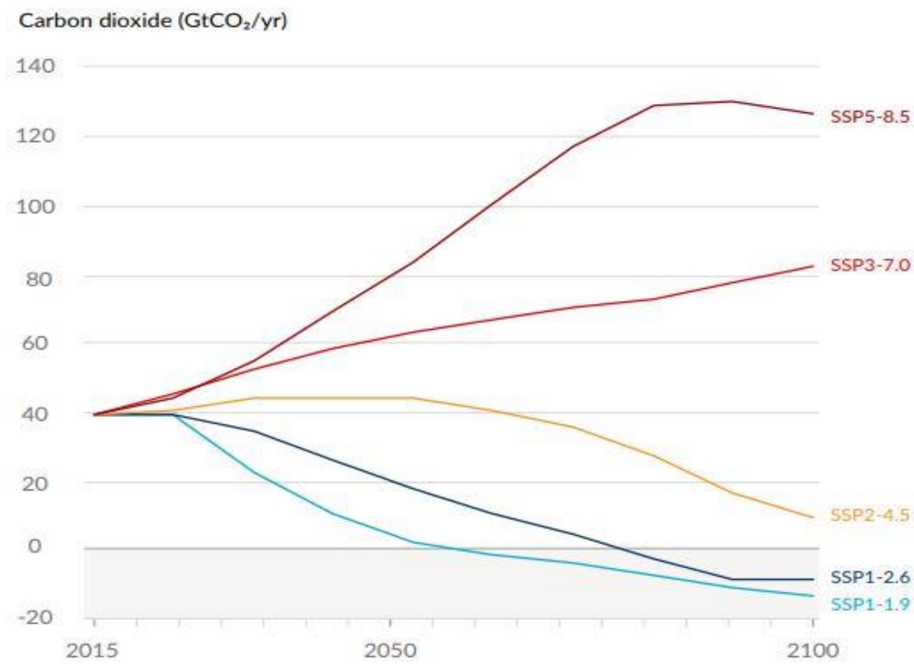

Figure 1.1. Shared Socioeconomic Pathways (SSPs) (Source: IPCC 2021)

1.5 Billion Tree Afforestation Project (BTAP)

The Billion Trees Afforestation Project (BTAP) was established by the provincial government of Khyber Pakhtunkhwa Province (KP) in 2014. In terms of governmental funding, territorial extent, and the %age of indigenous communities impacted, the BTAP is considered one among Pakistan's greatest afforestation initiatives. The BTAP is divided into 28 forest and watershed divisions across KP's three forest areas (Southern Forest (region 1), Northern Forest (region 2), and Malakand forest (region 3). 593,232 hectares of appropriate grassland and barren terrain have been restored with various tree species. 263,153 hectares were set aside for afforestation, 306,983 hectares for natural regeneration by prohibiting logging and grazing, and 23,096 hectares for sowing and aerial seeding., according to the World-Wide Fund's third-party monitoring report (WWF, 2017).

1.6 Significance of the study

Pakistan is highly vulnerable to climate change, ranked 5th most affected by climate change from 1999 to 2018 (Global Climate Risk Index 2020). Government of Pakistan is preferring to mitigate this crisis through increasing the forest cover. Many studies have predicted potential shifts in the tree line, changes in distribution of tree species, variations in forest type borders, and interspecific competition under different climate scenarios (Boisvert-Marsh et al., 2014; Zhu et al., 2018; Iverson et al., 2019, Boisvert-Marsh et al., 2019; Meng et al., 2021). Taking these into account, it is evident that climatic factors and species suitability are important factors for afforestation projects. However, little is known about the criteria for site selection and species selection for afforestation project BTAP for KP, Pakistan (Sabir et al., 2020). Therefore, in the present research, our goal is to determine the distribution characteristics of the habitat for afforested species in present and future climate scenarios used for afforestation project BTAP in KP, Pakistan through ecological niche modelling.

Chapter 2

LITERATURE REVIEW

The purpose of this chapter is to review the literature related to the research. Additionally, theory of Maxent and prediction of the habitat suitability of tree species used in afforestation projects through maxent is discussed using examples from relevant literature.

2.1 Maxent Theory

To create a distribution model of a given species in connection with a number of environmental variables, the maximum entropy theory is utilized in the Maxent program (Phillips et al., 2008) To produce distribution model, maximum entropy theory utilizes limited information, presence only data that best complies with a set of restraints, environmental variables without taking into account other restraints (Phillips et al., 2004). The Maxent program, created by Phillips, Dudik, and Schapire in 2004, consists of a machine learning process that utilizes a number of replications to train the model into creating a sustainable model. In order to bring the average of the outputs to an acceptable result, a number of replicates of the model must be run due to the random nature of the process (Kemp et al., 2012). The method of maximum entropy for modeling species distribution consists of utilizing a collection of known species data as sample combined with the relevant environmental variables to model the distribution of the species in the proximity of known geographic area (Phillips et al.,2004). Phillips et al. (2005) explains the operation and testing of the Maxent program as an extensively utilized maximum entropy modeling toolkit to represent species geographic distributions utilizing habitat suitability, and presence-only data. To speculate the distribution of species from a combination of records and environmental predictors, Maxent has become an often-used species distribution modeling (SDM) instrument utilized by conservationist. Nevertheless, the data records of the occurrence of specie utilized to train the model are usually biased due to differing sampling efforts in the study and research area (Fourcade at al., 2014). The Maxent program has been exemplified as particularly efficient to tackle the difficult interplay between speculative variables, response and to be slightly reactive to small sample sizes but it outperformed all other algorithms on smaller sample size (Fig 2.1) (Wisz et al., 2008).

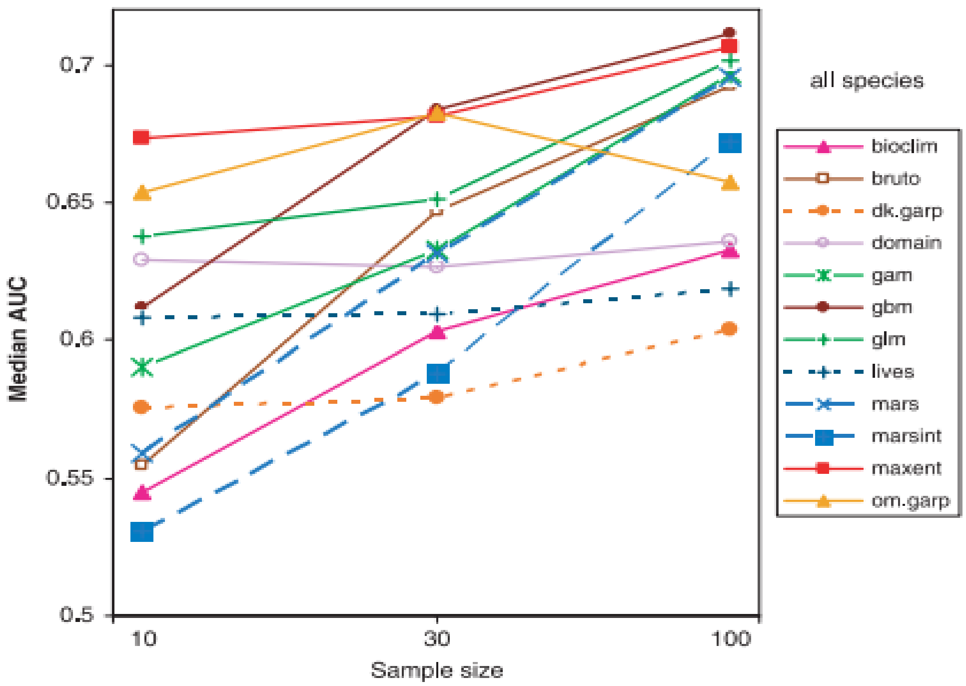

Figure 2.1. Performance Graph of All Models considered in Wisz et al., (2008) study.

The Maxent program has become the most extensively utilized algorithm due to its simplicity of usage. The SDM and Maxent modeling by and large has become the center of conservation-oriented studies and research (Elith et al., 2006). Further, the latest availability of global data records is facilitated by regional and continent-wide studies. The World Climate project developed global climate variables, such as, environmental layers which put forward continuous description of very large areas. In similar fashion, the open biodiversity databases development expands numerous spatial coverages of groundwork observation that could have been gathered by a single project (Global Biodiversity Information Facility, GBIF, http: //www.gbif. Org). These data records generally give presence only record that modeling methods like Maxent can handle (Denis et al., 2000). After being introduced in 2004, the Maxent program has been used widely for modeling species distributions. Many biosecurity, evolutionary, conservation and ecological applications cover diverse aims in published examples such as locating corresponding specie occurrences, discovering existing distributions, and speculating to current times and places. Different government and non-government organizations have also made Maxent operational for large-scale, actual-world biodiversity discovering applications that includes the Point Reyes Bird Observatory online application (http://www.prbo.org/) and the Atlas of Living Australia (http://www.ala.org.au/). The need for an ecologically accessible explanation of Maxent was identified due to the involvement of JE and SJP's in such programs (Elith et al., 2011).

2.2 Significance of Maxent in Ecological Restoration Projects

Many Afforestation project are carried out all around the globe, without considering niche dynamics of planted species due to this negligence a lot of specie were introduced in their non-native zones (Li et al., 2018). In ecological and forestry research, determining the niche dynamics of tree species is not yet a general target as compared to invasive species (Vetaas et al., 2002). Both Invasive and afforestation species spread their native area in an identical method via Humans or birds but their effects on ecology are different (Richardson et al., 2011). Spain started massive afforestation projects under the financial aid of European Economic community's agricultural reforestation directives from 1993 till 2006 irrespective of future climatic scenarios, these regions now have to deal with extreme climatic conditions (Duque-Lazo et al., 2018). Total 46 species were initially selected considering ecological characteristics such as frequency, land cover and run a PCA model on it to extract the 10 most potential suitable species with respect to desired ecological characteristics for ecological restoration, then the response of these species with current climate scenario were calculated by applying A2 climate scenario, using Maxent. The most potential suitable species are recommended for ecological restoration projects in central Mexico (Gelviz-Gelvez et al., 2015). In another study by (Linlin Zhang et al. (2016) assessed the potential suitable habitat of *Scutellaria baicalensis* through Maxent model in China to conserve the deteriorating habitat of this endangered plant used in Chinese traditional medicines. Currently habitat of this species is disappearing due to environmental factors. Objectives of this study were to identify new cultivation areas of this important species and to investigate that which major environmental factors are affecting. In this study they found six environmental factors (alt, prec7, prec1, bio4, bio1 and tph) as a reason out of 16 environmental factors taken from Worldclim. Total 419,857 Km^2 was identified as a potential suitable area for *Scutellaria baicalensis* in the eastern, central and western area of northern china.

2.3 Relevant Maxent Studies

Antúnez et al. (2018) predicted 13 tree species potential distribution in Mexican state Durango, considering three periods (i) Most recent glaciation period (21,000 years ago), (ii) current period (iii) the future period 2080-2100. *Pinus durangensis*, *Pinus teocote* and *Quercus crassifolia* were the species that showed no major changes. Rather, the models projected a minor decrease, shift or disintegration in the potential area of *Pinus arizonica, P. cembroides, P. engelmanni, P. leiophylla, Quercus arizonica, Q. magnolifolia* and *Q.sideroxila* in the future period.

Carvalho et al. (2017) modelled the relationship between environmental variables and four species of trees (*Casearia sylvestris, Copaifera langsdorffii, Croton floribundus and Tapirira guianensis*), extensively used for reforestation in the state of Minas Gerais, Brazil. Species widely occurring in the state of Minas Gerais are *Casearia sylvestris, Copaifera langsdorffii and Tapirira guianensis*, including a broad range of environmental variables. Restricted occurrence was observed in the southern state shown by *Croton floribundus*, with narrow environmental variation.

Garcia et al. (2013) defined the geographic distribution of 14 threatened forest trees species under future and current climatic scenarios in Philippines. The threatened species presence record, bioclimatic variables and bio-physical variables were encoded into Maxent to predict the current and future potential distributions. Seven species *(Afzelia rhomboidea; Koordersiodendron pinnatum; Mangifera altissima; Shorea contorta; Shorea palosapis; Shorea polysperma; Vitex parviflora)* showed satisfactory results under future conditions while seven species *(Agathis philippinensis; Celtis luzonica; Dipterocarpus grandiflorus; Shorea guiso; Shorea negrosensis; Toona calantas; Vatica mangachapoi)* showed decline in suitability.

Akyol et al. (2019) studied the habitat suitability of the most commonly used tree *Pinus pinea L*. in afforestation projects of Turkey, conducted through Maxent modelling, with high resolution Environmental data. They collected 13 occurrence points from field-based surveys and considered 19 climatic variables for the identification of potential distribution of *P.pinea L.* under current, moderate and extreme climatic models. According to the results Min Temperature of Coldest Month, Annual Precipitation, and Precipitation of Wettest Quarter were found as a most influential environmental variables for *P.Pinea L.*, Future models shown Habitat loss and the shift in habitat form north to higher altitudes.

Naudiyal et al. (2021) used maximum entropy modelling to predict the potential distribution of ecologically important tree species, Abies, Picea, and Juniperus, at the eastern edge of the Tibetan Plateau in China. Precipitation of wettest month, seasonality, temperature annual range, and soil type made the most significant contribution to model outputs. projections of habitat suitability under current climate scenario projected onto future climate change scenarios for all concentration pathways in 2050s and 2070s, showed a clear decline in potentially potential suitable habitats for all three species.

Li et al. (2016) looked at the potential distribution of the most widespread species *Pinus tabulaeformis* of China, which is mostly used for afforestation projects. According to this study, it is essential to identify the geological and ecological dynamics of any species for sustainable horticulture and preservation of species. Potential suitable afforestation areas of *Pinus tabulaeformis* was detected through Maxent, formulated on 13 climatic variables and globe cover 2009 data. Northern Shaanxi, Southern Ningxia and central area of Liaoning and Gansu Provinces were predicted as the most potential suitable areas in china for afforestation under current and future climate. Precipitation of Wettest Month, Min Temperature of Coldest Month, Annual Mean Temperature were found most influential climatic variables for *Pinus tabulaeformis.*

2.4 Relevant Maxent Studies Conducted in Pakistan.

Gilani et al. (2020) predicted potential distribution of six tree species *Abies pindrow, Betula utilis*, *Cedrus deodara*, *Picea smithiana*, *Pinus wallichiana*, and *Quercus ilex* in Gilgit Baltistan with respect to (2015-2016) current climate scenario as well as RCP4.5 and RCP8.5 climate-change scenarios by 2050. It was observed that overall elevation, precipitation, and temperature were the main contributing variables towards species distribution. The results of the MaxEnt model for each tree species were satisfactory.

Ashraf et al. (2016) predicted the potential distribution of *Olea ferruginea* (Olives) in Pakistan under climate change by using Maxent Model. They found the relationship of *Olea ferruginea* with reference to bioclimatic variables, elevation, and slope. They also predicted the current and future potential distribution of *O. ferruginea* in Pakistan through recent bioclimatic and topographic data. Their results showed that there is a notable impact under future scenario There is a major decrease in the overall distribution of *O. ferruginea* under current scenario due to habitat loss.

2.5 Species Used in the Current Research

Following are the eight tree species considered for this research.

2.5.1 Cedrus deodara

Cedrus deodara is Pakistan's national tree, long-lived woody tree that can live for 500 to 700 years and can be found between 2000 and 3000 metres in elevation (Moinuddin et al., 2009; Khan et al., 2013). *Cedrus deodara*, often known as Himalayan cedar or deodar, is a coniferous evergreen tree that grows 45-60 metres tall and has a thickness of 0.8 to 1.1 metres. (Sheikh, 1993). It is found in abundance throughout the country's dry temperate forest. Deodar trees could be observed in Murree, Hazara, Abbotabad, Swat, Azad Kashmir, Kaghan valley, Kohistan Chillas, Dir, and Chitral, among several other places. It is predominantly a dry temperate species; however scattered stands of this species can be found in moist temperate areas (Champion et al., 1965) and sub alpine areas (Ahmed et al., 2006). According to Hussain & Illahi (1991), majority of such forests are found in the transitional zone between dry and moist temperate zones, with no clear differentiation between two. *Cedrus deodara* is a medicinal and economic conifer tree species belonging to the Pinaceae family. *Cedrus deodara* has a good, outstanding, and durable wood quality that is used for building works and interiors. Its root oil is used to treat ulcers and skin diseases in camels and goats. The bark is an astringent that can be used to treat fevers, diarrhoea, and dysentery. The oil has a diaphoretic effect, making it effective in the treatment of skin illnesses and ulcers (Sajadand Ahmed, 2021).

2.5.2 Dalbergia Sissoo

Dalbergia sissoo belongs to subfamily Papilionoideae of the Leguminosae family. Upon Swedish botanist Nicholas Dalberg, the genus Dalbergia was named. Dalbergia sissoo is found in the sub-Himalayan region of India, Pakistan, and Nepal, where it grows between 900 and 1500 meters above sea level. The tree's natural temperature range is 12-22 degrees Celsius, but it can withstand temperatures as high as 50 degrees Celsius. Rainfall of 300-2000mm is required on average (Singh et al., 2011, Adenusi and Odaibo, 2009). In the Indo-Pakistan subcontinent, there are 27 Dalbergia species, 15 of which are native. Shisham (*Dalbergia sissoo Roxburgi*) is a well-known and well-established forest species in Pakistan (Mukhtar et al.,2015). The significance of the sissoo tree can be explained by the fact that it is a fast-growing multipurpose tree. *Dalbergia*

Sissoo is a useful tree species that is frequently proposed for reforesting and agroforestry programs in dry land conserving zones (Joshi et al., 2021). It's simple to grow, has a good economic return, and can fix nitrogen. It is an extremely demanding tree species. Because it is used as a medicinal tree to treat a variety of diseases, this versatile tree is commercially significant (Naqvi et al., 2019).

2.5.3 Juglans regia

The Juglans genus, namely the Juglandaceae family, contains many species that are widespread all over the globe. Its most well-known member, the Persian, English, common walnut or *Juglans regia L.* (*J. regia L.*), consists of substantial types of deciduous trees found primarily in temperate zones and economically grown in Asia, the United States, central and southern Europe. (McGranahan, & Leslie,1991). Walnut is a huge arbor tree with a trunk up to 2 meters in diameter and a height of 25–35 meters. It is historically grown for its precious wood and fruit (Zhang et al., 2015). Walnut is mostly grown in the northern mountainous highlands of Khyber Pakhtunkhwa, with an annual production of 11.5 thousand tones, however productivity has decreased in recent years (Khan et al., 2020). It is planted in most areas in Pakistan between 925- and 3000-meters height, and it is also widely grown. Walnut trees grow wild in mixed deciduous and coniferous woods at elevations varying from 1550 to 3000 meters. In the Kaghan Valley, wild walnuts can be found. Walnut trees can develop to be gigantic in some areas. The largest, which is found in the Bumborait Valley (Chitral), has a diameter of 6.8 meters. The tallest trees are between 40 and 50 meters tall (Khan et al., 2010)

2.5.4 Pinus wallichiana

Pinus wallichiana is a Pinus species native to the Himalayan ranges, Karakoram range, and Hindu Kush Mountain ranges. With an altitude ranging from 1800 m to 4300 m, this plant's broad and luxuriant growth can be found all over the Himalayan ranges, beginning in eastern Afghanistan and extending across Pakistan, Bhutan, India, Myanmar, Nepal and China (Ghimire et al., 2010). *Pinus wallichiana* grows best in colder climates and can be found in pure or mixed forests at high altitudes with limited rainfall or low altitudes with considerable rainfall (Rahman et al., 2017). In glacial forelands, *Pinus wallichiana* may emerge as a pioneer species or in temperate regions, it could represent the dominant species in old age mixed forests alongside *Cedrus deodara, Picea smithiana*, and *Abies pindrow*. In elevations above 3000 meters near the tree line, it may be paired with *Betula utilis* and *Juniperus macropoda* (Shah et al., 2009). It can grow on loamy sandy clay or well drained sandy clayish soil but most potential suitable soil for *Pinus wallichiana* is deep moist (Rahman et al., 2018). *Pinus wallichiana* is mostly utilized for lumber and is commercially important alongside deodar (Bhat et al., 2015). Furthermore, the tree is used to extract oleoresins, which are useful in the preparation of turpentine oil, needles oil, and camphor (Aslam et al., 2011). The tree is also extremely valuable to various ethnic people residing in the Himalayan region (Khan et al., 2007).

2.5.5 Eucalyptus

In the late 1990s, 40 species of Eucalyptus were introduced into Pakistan to fulfill the wood consuming demands of a growing population, to improve forest cover, and to sustain wood-dependent industries (Bilal et al., 2014). The most often cultivated tree species in government plantations, community programmes, and household woodlots is Eucalyptus. This tree species grows quite well on every kind of soil and faster than other indigenous tree species. Small holders have a special affinity for Eucalyptus trees, which may be used to make farm implements as well as to build dwellings and fencing (Mengist et al., 2011). Furthermore, the trade of Eucalyptus trees and byproducts has the ability to increase farmers' income, decrease poverty, and improve food security. Because farmers, especially small farmers in tropics and subtropics locations, frequently prefer to grow eucalyptus, it provides greater and numerous advantages compare to several other tree species (Ketsela 2012). However, by depleting water supplies, it has a negative impact for the environment and ecology; it increases soil erosion, reduces undergrowth, deprives soil minerals, and allopathically impacts neighboring agricultural crops.

2.5.6 Senegalia modesta

Senegalia modesta is a deciduous, thorny tree that could grow 10 meters high with 100 cm wide in mature trees (Garad et al., 2015). Currently, this species is the primary source of gum Arabic consumed in the food, pharmaceutical, cosmetic, and textile sectors. It is planted in India for its gum, and it is also grown in Pakistan for wind protection (Khan,2017). *Senegalia modesta* is a favorable species for subtropical and warm temperate countries ranging from Afghanistan to India, in which it can withstand temperatures as low as -5°C and as high as 40°C (Giulio et al., 2018). It flourishes in regions in which the total annual precipitation is between 250 and 1,300mm.

S. Modesta is used medicinally as well as timber wood. An aqueous preparation of the fresh leaves is used for treating sore eyes and cataract (Bukhari et al., 2010). It is usually cultivated in India, Pakistan and Nigeria. Gum Arabic trees grow at an optimum annual rainfall of 380 to 2280 mm, and annual mean temperatures between 16.2°C and 27.8°C (Abdellah, Z. O. I. 2019). It is intolerable of frost but is particularly tolerant of drought. It can survive in places where drought lasts for 11 months. It thrives on rocky slopes and sandy soils, but also on clay plains and cotton soils with a pH ranging from 5 to 8 (Heuzé et al., 2016).

2.5.7 Populus ciliata

Populus ciliata is an important native species of Pakistan that has inhibited a huge area of our ecological zones. It grows best at an altitude between 5000-10,000 ft. The longitudinal and latitudinal growth preference lies between 70 - 75 E and 33 – 36 N respectively. The other hybrid poplar is prone to insects and are more likely to get infected but P. Ciliata showed good resistance to borers. In Pakistan it has been widely used as a fast-growing specie and it can also be planted on eroded soils (Siddiqui et al., 1986). *Populus ciliata* (Himalayan poplar) is one of the few forest species that is most potential suitable for agroforestry. It is a large deciduous tree with sexually differentiated male and female plants common in temperate and sub-temperate regions of the Himalayas at elevations of 1200-3500 m. It has exceptional qualities of high-capacity vegetative propagation and fast growth rate, due to which it has been extensively used in the pulp and paper industries, for reforestation of degraded lands, and in phytoremediation of contaminated soil. (Aggarwal et al., 2015).

2.5.8 Vachellia modesta

Vachellia Nilotica, commonly known as *Acacia Nilotica* is native to Indian and African subcontinent. It has very high medicinal value in both sub continents, it is extensively used to treat many disorders like sexually transmitted disorders. Many studies have been conducted to ensure the effectivity against microbial/viral activities (Ali et al., 2015). One of them was to explore the ethnomedical use of *V. nilotica* to treat genital lesions against Human Immunovirus (HIV), Herpes Simplex Virus (HSV) Human Papillomavirus (HPV) (Donalisio et al., 2018). *Vachellia Nilotica* grows well at arid and semi-arid condition and contribute in the rural economy of the nation. Required annual precipitation to flourish is of 125–1300 mm. It can withstand a moderate level of salinity. In Pakistan, it is found in Sindh, Punjab, Balochistan and NWFP on farmlands and in block plantations. *A. nilotica* is considered one of the highly demanded hardwood timber species in Pakistan. Almost every part of the tree has some use, it is used in furniture industry as well as for medicinal purposes (Siddiqui et al., 2010). It is an invasive species in certain parts of world and usually spread through livestock. It was introduced in Australia around mid-1800s as a shade and fodder tree but it has been so widespread since then that it has become a significance weed now that infects over 7 million hectares of Queensland (Taylor & Dhileepan, 2019). It is highly versatile tree that is not only used medicinally but also useful to rural populations, is often used to restore Senegalese salt-affected soils due to its salt-tolerance probably related to Arbuscular Mycorrhizal Fungi (AMF) symbiosis (Samba et al., 2020).

2.6 Significance of the study

Pakistan is considered to be highly vulnerable to climate change. Government of Pakistan is taking measures to mitigate effects of climate change through increasing forest cover. One provincial government took initiative and started the billion trees tsunami afforestation project, which got international admirations. Government of Pakistan is now considering to extend the afforestation project nationwide Therefore, it is important to assess the significant change in the potential distribution of tree species of above-mentioned species and map the areas that may not remain favorable for afforestation in future under different climate change scenarios for KP. This purposed study will provide basis for further studies for policies maker and decision makers to shortlist the most potential suitable species for afforestation projects for other provinces.

2.7 Objectives of the Research

I. To identify significant change in the potential distribution of eight tree species of KP, Pakistan, used in afforestation project as a function of 19 climatic variables as well as Soil, Irrigation and Elevation.

II. To identify species with risks of decreasing their potential distribution area in the future climate under SSP2-4.5 and SSP5-8.5 climate change for years 2041-2060 and 2081-2100

Chapter 3

METHODOLOGY

3.1 Study Area

The study region for this research is Khyber Pakhtunkhwa (KP), which stretches from 31°4' 0.48" to 36° 53' 23.28" latitude and 69° 14' 19.6080" to 74° 7' 35.3640" longitude in Pakistan's northwestern corner (Fig 3.1). It is Pakistan's smallest province in terms of land area, covering 101,741 Km^2. The province's vast altitudinal differences result in a variety of natural climates, ranging from 250 metres above sea level in the south to 7,708 meters above sea level in the north. The temperature varies from -14 degrees Celsius in the north to 51 degrees Celsius in the south. Annual rainfall varies from 130mm in the south to 3200mm in the north (Ali et al., 2020). *Cedrus deodara*, *Pinus wallichiana*, and *Pinus gerardiana* are the primary species found in Himalayan dry temperate forests between 1525 and 3350 metres above sea level, predominantly in the inner Himalayas of North KP outside the monsoon region. *Pinus wallichiana*, *Abies webiana*, and *Picea smithiana* are the principal tree species in Himalayan moist temperate forests, which are found between 1,375 and 3,050 meters above sea level in the outer Himalayas, well within the monsoon rainfall range. At altitudes of 900 to 1 700 meters, sub-tropical chir pine forests can be found in the lower Himalayas. KP is home to 63.6% of these forests. Scrub woods can be found on the lower slopes of the Himalayas in KP, between 400 and 1000 meters above sea level. Scrub forest species include *Olea ferruginea* and *Acacia modesta*. At 400 meters above sea level, tropical thorn woods can be found in plain parts of KP. These forests are inhabiting *Acacia nilotica* and *Acacia Senegal*. Oak woods can be found in moist and dry temperate zones in KP, ranging in altitude from 1200 to 1500 meters (Forestry Sector Review, 2019).

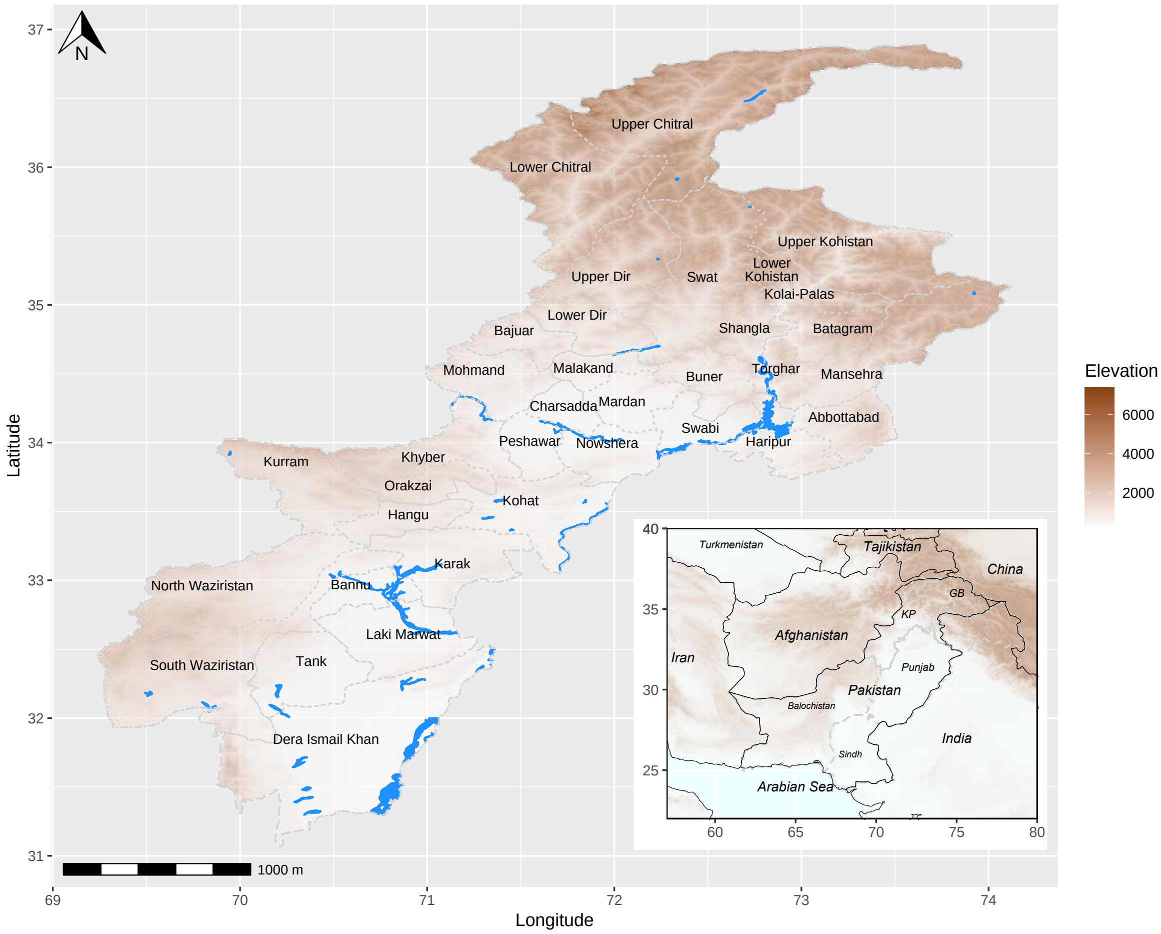

Figure 3.1. Study area.

3.2 Occurrence Data

Cedrus deodaraa, *Pinus wallichiana*, *Dalbergia sissoo*, *Eucalyptus*, *Populus ciliata*, *Juglans regia*, *Senegalia modesta*, and *Vachellia nilotica* occurrence data were acquired from open database (Global Biodiversity Information Facility, GBIF, http: //www.gbif. Org). These data records often include only a presence record, which can be processed through modelling approaches such as Maxent (Dennis & Thomas, 2000. Field trips and relevant literature were used to acquire additional information. The BTAP Office in Peshawar, KP provided information on the KP afforestation project.

Table 3.1. Number of occurrence points used for each species

S. No	**Species**	**No of Occurrences**
1	*Cedrus deodara*	50
2	*Dalbergia Sissoo*	15
3	*Juglans regia*	32
4	*Pinus wallichiana*	15
5	Eucalyptus	15
6	*Senegalia modesta*	16
7	*Populus ciliata*	30
8	*Vachellia nilotica*	15

3.3 Bioclimatic Data

Bioclimatic data containing 19 variables was retrieved at 2.5 minutes spatial resolution from the WorldClim database version 2.1 (www.worldclim.org) (Fick & Hijmans,2017). WorldClim contains 9 Global Climate Models (GCMs) and four Shared Socio-economic Pathways for the years 2021-2040, 2041-2060, 2061-2080, and 2081-2100 (SSPs). GCM, IPSL-CM6A-LR from Coupled Model Intercomparison Project 6 (CMIP6), and two 'Shared Socioeconomic Pathways' were used. (O'Neill et al., 2017) to compare the different patterns of conceivable and diverse climate projections: SSP2-4.5 (ambitious) and SSP5-85 (realistic). Two timeframes were used in both SSPs to estimate the climate change impact by the middle and end of the twenty-first century (2041- 2060; 2081-2100). The model also included other factors including Digital Elevation Model (DEM), irrigation, and soil types. Several variables, such as irrigation and soil type, were gathered from the Food and Agriculture Organization of the United Nations (www.FAO.org) and Elevation data was obtained from (www.worldclim.org) at similar resolution.

Table 3.2. Bioclim Variables

Code	Names
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (×100)
BIO4	Temperature Seasonality (standard deviation ×100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

3.4 Maxent Model

The bioclimatic data was downscaled to KP extent for current and future scenarios. Model input included occurrence data, elevation DEM, irrigation, and soil type (Fig. 3.2). DEM and irrigation were treated as continuous variables, while soil type was treated as a categorical variable. The occurrence data was divided into two groups: training data and testing data, with each group accounting for 80% and 20% of the total. Each record was given a fair and randomized chance to be treated as a testing record using five K-folds. The Area Under the Curve (AUC) and Receiver Operating Characteristics (ROC) of each K-fold were calculated and averaged (ROC). Maxent has two major parameters: the regularization multiplier and feature classes. The regularization multiplier determines how well the output distribution is matched in terms of centered and precision. A value lower than 1.0 would result in a very restricted output distribution that fits the specified presence data. A forecast with a higher regularization multiplier would be more spread out and less localized. The "regularization multiplier" option was set to 1 for this study. A "feature class" refers to a broader set of changes made to the initial variables. This limits the probability distribution that can be determined. A few of the features includes linear, quadratic, product, threshold, and hinge. The feature class selection is determined by the number of species occurrence points. If there are fewer data points available, the algorithm defaults to limiting the model to fundamental features. The model typically employs linear feature, but when there are at least 10 samples, the quadratic feature is used; when there are at least 15 samples, the hinge is used; and when there are at least 80 samples, the threshold and product are used. (Li et al., 2020; Phillips, 2017). Because of the herbarium dataset, Maxent was run on auto feature; auto feature models work much better, and models trained using a small number of herbarium datasets produce better predictions than those calibrated using a huge but skewed survey dataset (Syfert et al., 2013). After the Maxent model was simulated, comparable maps for the current and two future scenarios were created. Maps were created for two alternative timescales for the two future scenarios (2041-2061 & 2081-2100). In order to evaluate the model's efficiency, the area under the curve (AUC) values from the receiver operating characteristics (ROC) were assessed. AUC determines the model's performance using all available parameters. The model outperforms a random prediction if the AUC is greater than 0.5. Five thresholds have been chosen for the distribution region to produce prospective distribution maps: 0-0.2 shows not potential suitable, 0.2-0.4 shows not really potential suitable, 0.4-0.6 indicates pretty acceptable, 0.6–0.8 shows potential suitable, and 0.8–1 suggests highly potential suitable. Each uniform terrain utilized in the aggregated projection was converted into a binary projection by adopting a probability threshold (0.8) that reflected optimum specificity at optimum sensitivity. The resulting binary projection set to a value of 1 or 0 to each 1 Km^2 pixel, indicating whether it was appropriate or not. In addition, BTAP afforestation site coordinates were used for species and plotted those coordinates on binary projections to see if the afforested sites fall inside the acceptable region in all situations. To simulate and analyze the data, the Maxent model in R (R Core Team, 2020) was utilized.

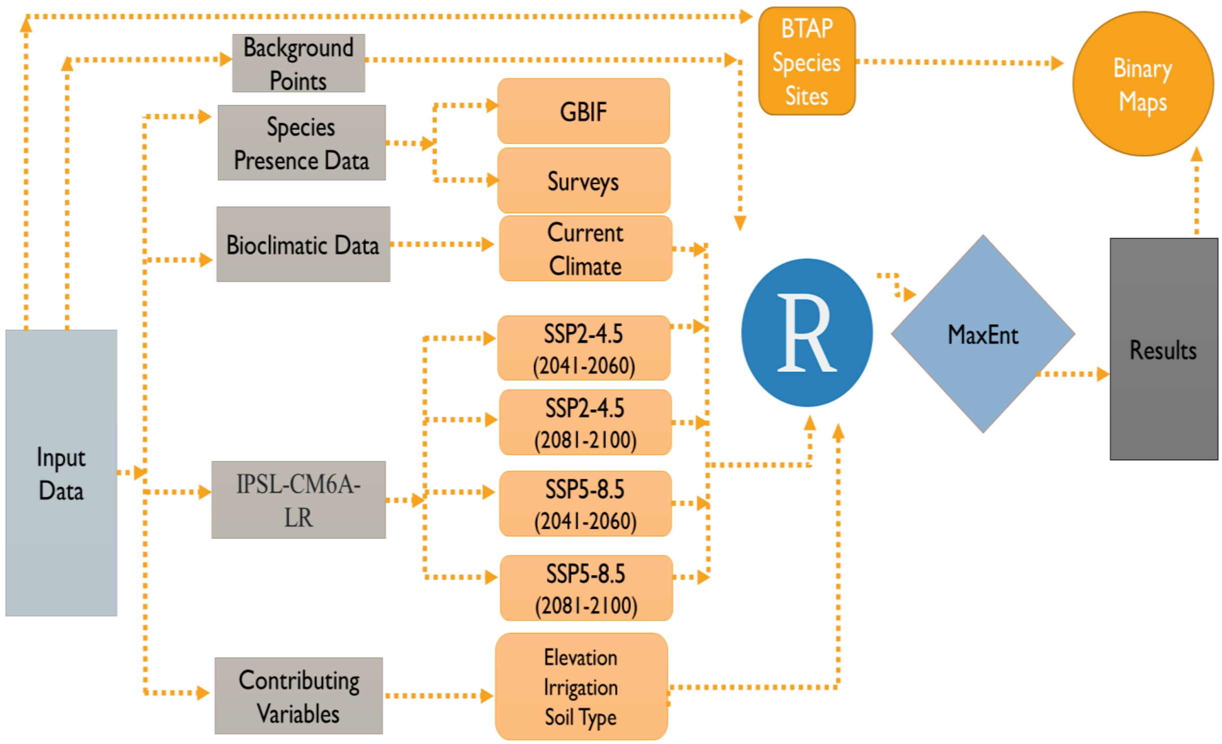

Figure 3.2. Research Design

3.5 Variable Importance for Current Climate Distribution

The Jackknife test was performed to determine the relevance of various factors in the study. With the aid of this test, a large number of models are created. The core idea behind this test is to eliminate one variable and create a model using all of remaining variables. Then, utilizing each variable separately, a model is formed. furthermore, as before, a model is generated using all variables (Song et al., 2012) Pink and blue bars indicate the relevance of the variables.

Chapter 4

RESULTS

4.1 *Cedrus deodara*

The majority of *Cedrus deodara's* potential suitable habitat shown in the current projection was in the north of KP at higher altitudes (Fig 4.1a). Upper Chitral, Lower Chitral, Upper Dir, Lower Dir, Northern Swat, Kohistan, Mansehra, Abbottabad, and Kurram agency are among the potential suitable districts. *Cedrus deodara* had potential suitable area in similar districts in binary projections (Fig. 4.2a). The Upper Chitral region of KP, between 2300 and 2600 meters above sea level and surrounded by glaciers and barren mountains, is unsuitable for vegetation. There is a vast potential suitable area predicted in binary projections in Lower Chitral, Upper Dir, Lower Dir, and Northern Swat. A belt of potential suitable land stretching from west to east, near Parachinar, is projected in the west of KP along the region of Kurram. Afforested sites shown in (Fig. 4.2a) of *Cedrus deodara* cover only a small proportion of the potential suitable area. However, the bulk of afforested sites are located between the range of 0.2-0.4 on the raw projection map (Fig. 4.1a), revealing a non-suitable area.

Similar districts fall under extremely potential suitable areas in the future SSP2-4.5(2041-2060) scenario (Fig. 4.1b), except in the north of KP, the Upper Chitral region, where suitability decreases significantly. Similarly, Upper Chitral is anticipated to be non-suitable for Cedrus deodara in binary projections (Fig. 4.2b). In (Fig. 4.2b) one afforestation site in Manshera district and few afforestation sites in Malakand were added in potential suitable afforested sites of current scenario.

More potential suitable regions in North Waziristan have appeared for the SSP2-4.5 (2081-2100) scenario (Fig. 4.1c). Other places, such as Shangla, Kohistan, Southern Chitral, and Mansehra, have seen an increase in binary projection (Fig. 4.2c). However, in the KP districts of Malakand, Abbottabad, and Battagram, there was a decrease inpotential suitable areas as compared to (Fig. 4.2b), with a modest shift to the north east in Mansehra. As a result of the decreasing potential suitable area in Malakand, a few afforestation sites that were earlier forecasted aspotential suitable (Fig. 4.2b) are now projected as non-suitable.

The most potential suitable regions are anticipated in the north of KP in SSP5-future 8.5's scenario (2041-2060) (Fig. 4.1d). Some highly potential suitable regions of Lower Chitral and Upper Dir are shifting to somewhat potential suitable areas, according to a binary projection (Fig. 4.2d). However, when compared to the current scenario (Fig. 4.2a), the projections are very similar, with the exception of several locations in Chitral.

Cedrus deodara's suitability is increased in the future SSP5-8.5 (2081-2100) scenario (Fig. 4.1e), specifically in Lower Chitral and Upper Dir. Furthermore, in binary projection (Fig. 4.2e) potential suitable area of Southern Chitral and Upper Dir restored again as compare to mid of century under extreme scenario (Fig. 4.2d). Several areas in Mansehra have been added, and there is a comparable slight shift to the north.

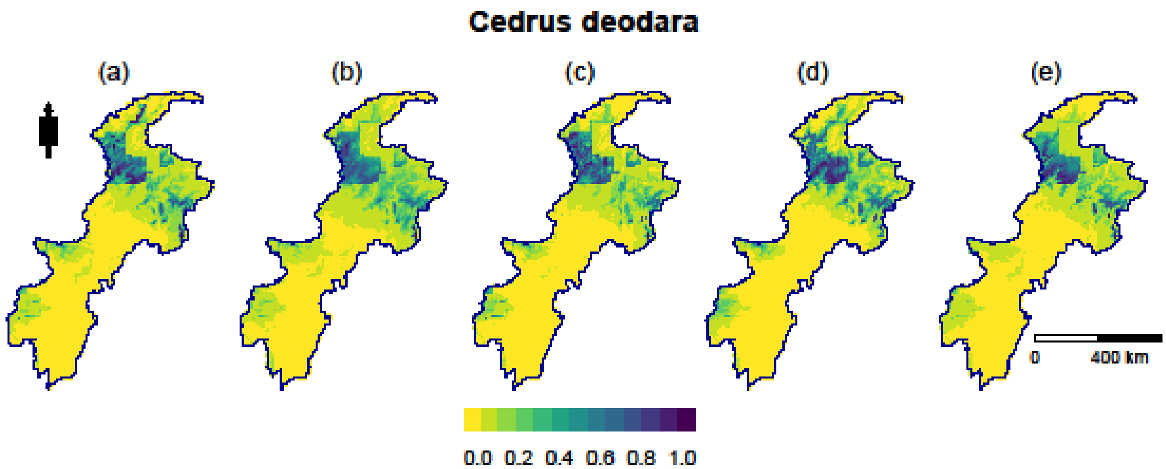

Figure 4.1. Raw-value maps derived from Maxent exponential output. (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5(2081-2100).

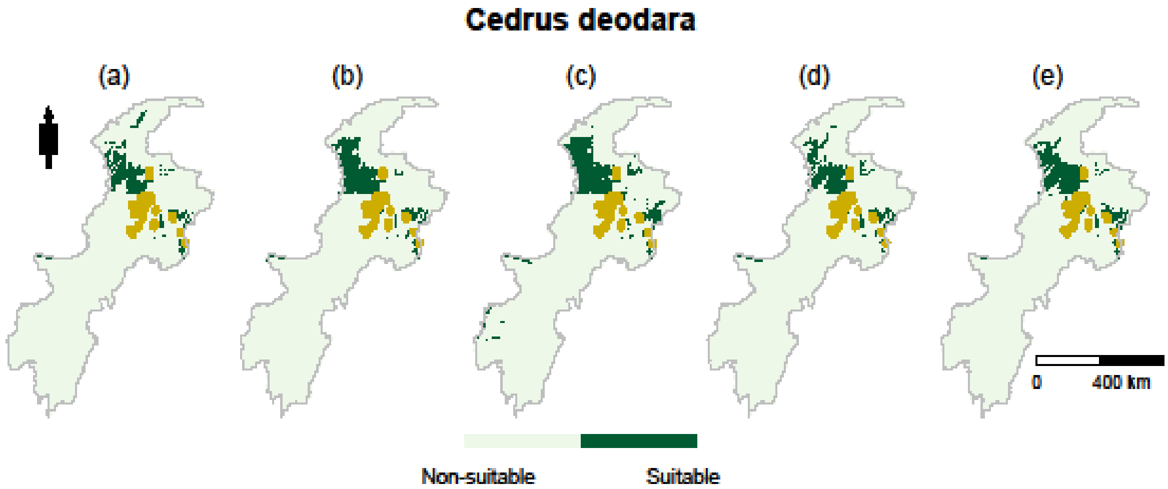

Figure 4.2. Binary maps (threshold value 0.8). (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5 (2081-2100). Yellow dots are recent afforestation sites for *Cedrus Deodara*.

4.1.1 Evaluation of Model Accuracy

The accuracy of the model prediction is validated by ROC Curve (Fig. 4.3). The model's AUC mean score, obtained using 5-fold cross-validation, is 0.891, showing excellent performance (AUC score > 0.80).

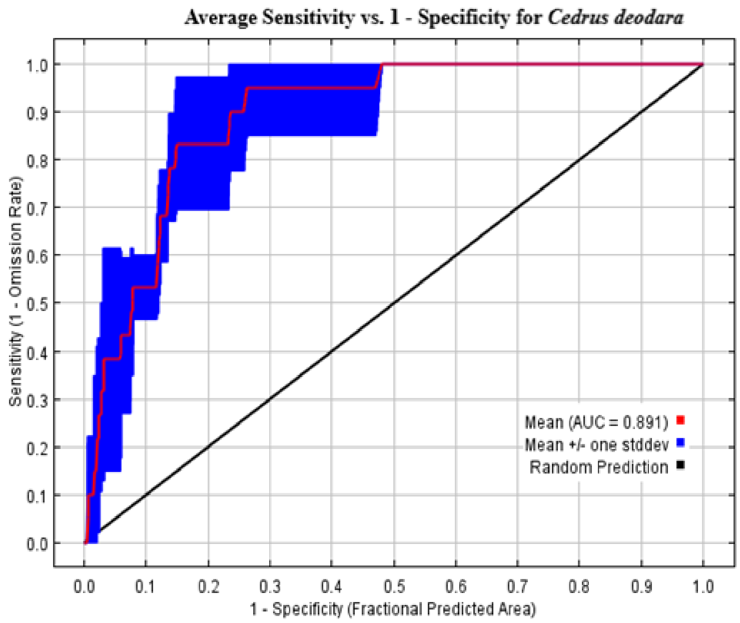

Figure 4.3. Receiver Operating Characteristic (ROC). The black straight line indicates a random prediction, while the red curve indicates the model prediction for the species. The AUC of this ROC plot is 0.891 ± 0.016.

4.1.2 Jackknife test for *Cedrus deodara*

The jackknife test verified that Annual Mean Temperature, Mean Temperature of Coldest Quarter, Mean Temperature of Driest Quarter and Elevation are the most important variables in the current climatic condition for *Cedrus deodara* habitat suitability.

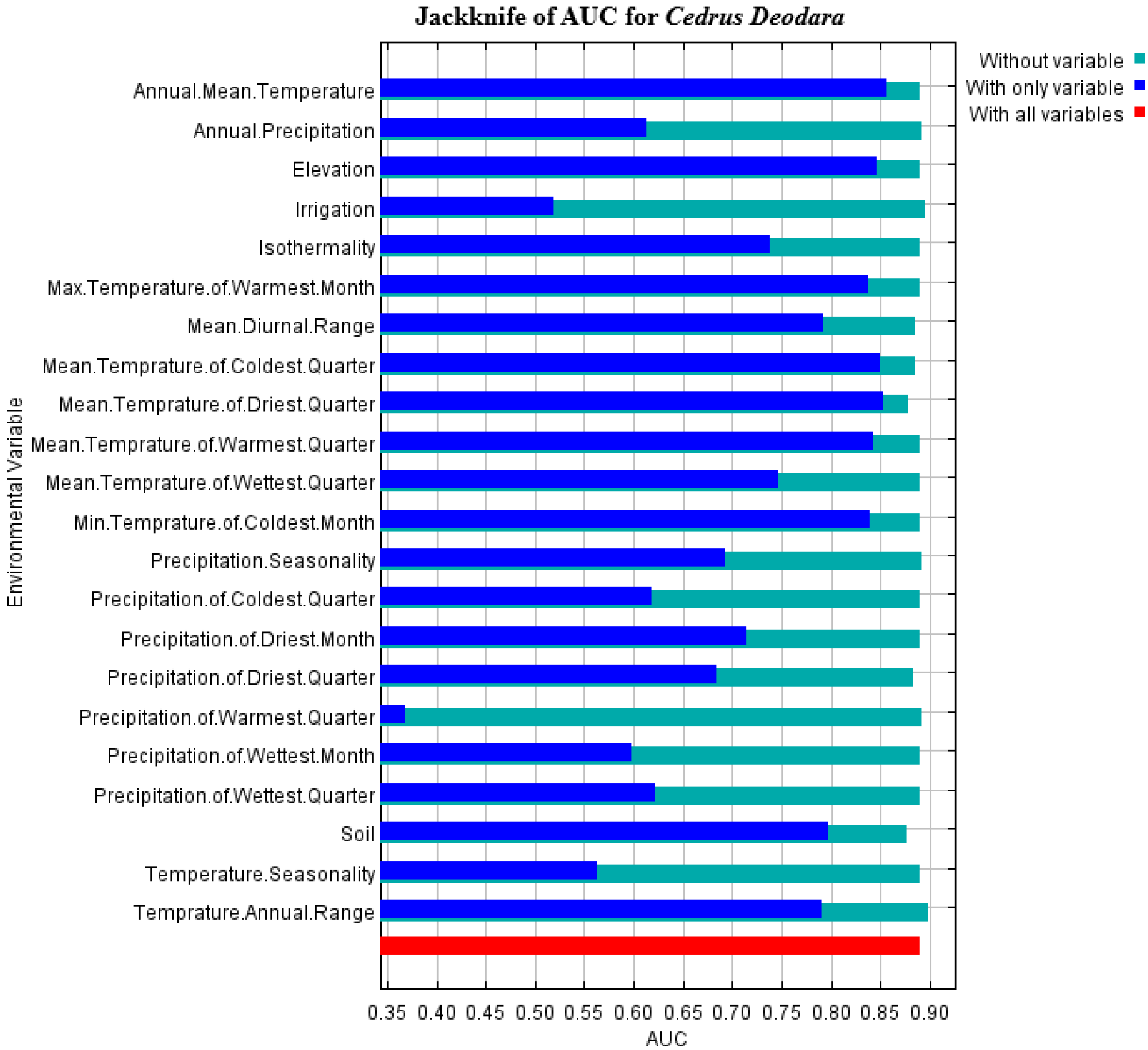

Figure 4.4. Jackknife test for *Cedrus deodara*. The value considering just one of the climate indicators is shown by the length of the blue bar; the longer the bar, the more important the climatic variable is. The score of a model generated using the remaining indices is represented by the length of the sea green bar.

4.2 *Dalbergia sissoo*

Dalbergia sissoo habitat suitability may be found in three places in the current scenario (Fig. 4.5a) Peshawar, Bannu-Karak, and Dera Ismail Khan. A uniform declining trend can be noticed around certain centres. Peshawar, Charsadda, and the eastern edge of Mohmand Agency are all in the 0.4-0.6 range of acceptable areas. Lakki marwat, Tank, and Karak districts, on the other hand, have a 0.6-0.8 threshold, indicating a potential suitable area. In addition, the Dera Ismail Khan District has a range of 0.6 to 1, indicating highly potential suitable areas in the east and leastpotential suitable areas in the west of Southern Waziristan. However, the binary map (Fig. 6a) implies that *Dalbergia sissoo* will be found in places with very low suitability. Extremely potential suitable areas are predicted only for Bannu and for eastern side of Dera Ismail Khan. Present afforested sites (Fig. 4.6a), particularly in north of Peshawar region fall in non-suitable area while few of afforestation sites near Bannu and Dera Ismail Khan lie somewhat within potential suitable areas.

Similar suitability areas are identified in the SSP2-4.5 (2041-2060) scenario (Fig. 4.5b) as in the current scenario (Fig. 4.5a). The binary projection (Fig. 4.6b) shows a significant surge in exceptionally potential suitable sites in Bannu and its environs, as well as close Peshawar and Tank, however a few areas in eastern Dera Ismail Khan are lost. More afforested areas in Bannu, Lakki Marwat, and Dera Ismail Khan are expected to be potential suitable. Peshawar, Bannu, Lakki Marwat, and Tank districts exhibit a reduction from (0.8 – 1) threshold to (0.8 – 1) threshold in the SSP2-4.5(2081-2100) scenario (Fig. 4.5c) (0.6-0.8). These regions aren't incorporated to highly potential suitable areas in the binary projections map (Fig. 4.6c). Sites that are afforested, do not fall within the estimated potential suitable region.A similar pattern may be seen in the SSP5-8.5 (2041-2060) scenario (Fig. 4.5d) as it is in the current scenario (Fig. 4.5a). However, in Binary projections (Fig. 4.6d), a slight increase in the East of Dera Ismail Khan, which results in a 17% increase in appropriate area in comparison to current climate estimates (Fig. 4.6a).

In the SSP5-8.5 (2081-2100) projections (Fig. 4.5e), there is a loss of suitability east of Dera Ismail Khan, however certain sections of the Peshawar region resurface as potential suitable habitat. The binary projection (Fig. 4.6e) reveals a reduction in the area of Dera Ismail Khan and an increase in the area of Peshawar. The majority of afforested areas are in unsuitable areas.

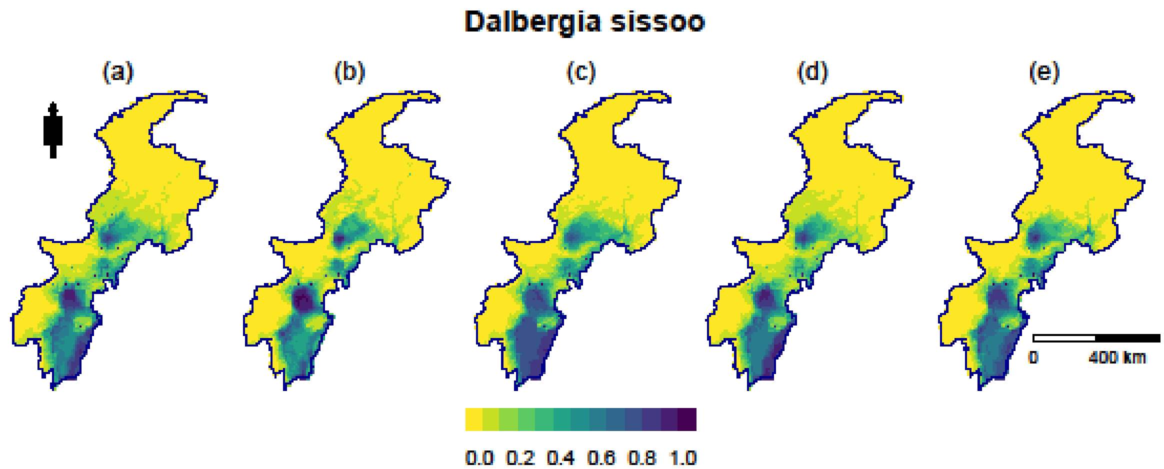

Figure 4.5. Raw-value maps derived from Maxent exponential output. (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5(2081-2100).

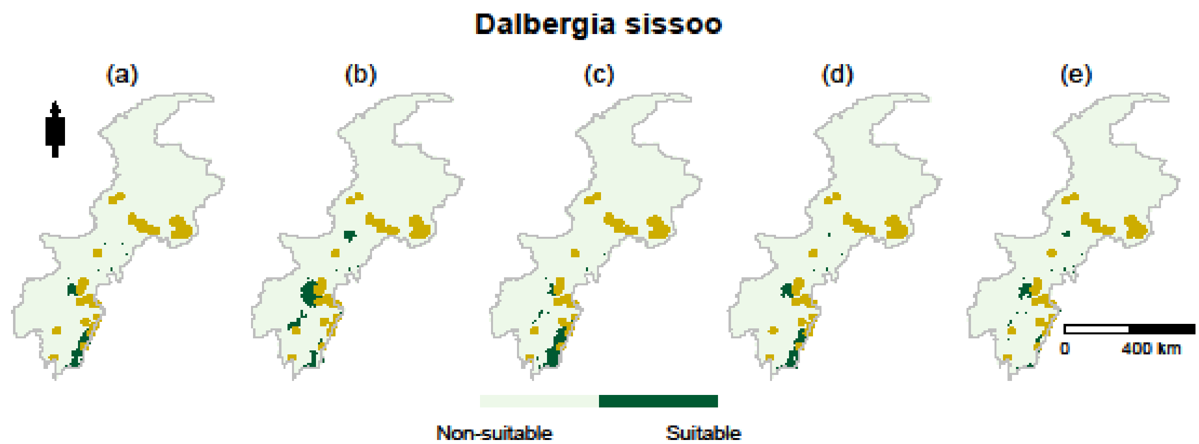

Figure 4.6. Binary maps (threshold value 0.8). (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5 (2081-2100). Yellow dots are recent afforestation sites for *Dalbergia sissoo*.

4.2.1 Evaluation of Model Accuracy

The accuracy of the model prediction is validated by ROC Curve (Fig 4.7). The model's AUC mean score, obtained using 5-fold cross-validation, is 0.856, showing excellent performance (AUC score > 0.80).

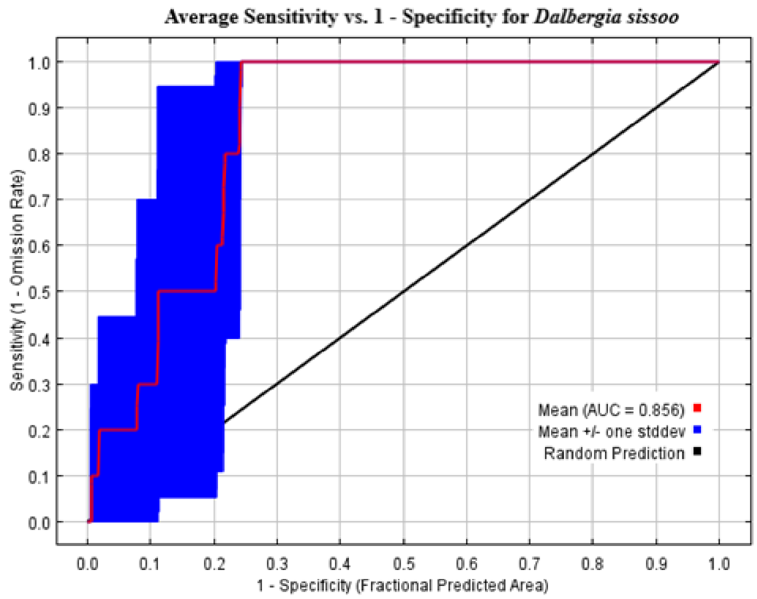

Figure 4.7. Receiver Operating Characteristic (ROC). The black straight line indicates a random prediction, while the red curve indicates the model prediction for the species. The AUC of this ROC plot is 0.856 ± 0.016.

4.2.2 Jackknife test for *Dalbergia sissoo*

The jackknife test verified that minimum temperature of coldest month, mean temperature of warmest quarter and maximum temperature of warmest month are the most important variables in the current climatic condition for *Dalbergia sissoo* habitat suitability.

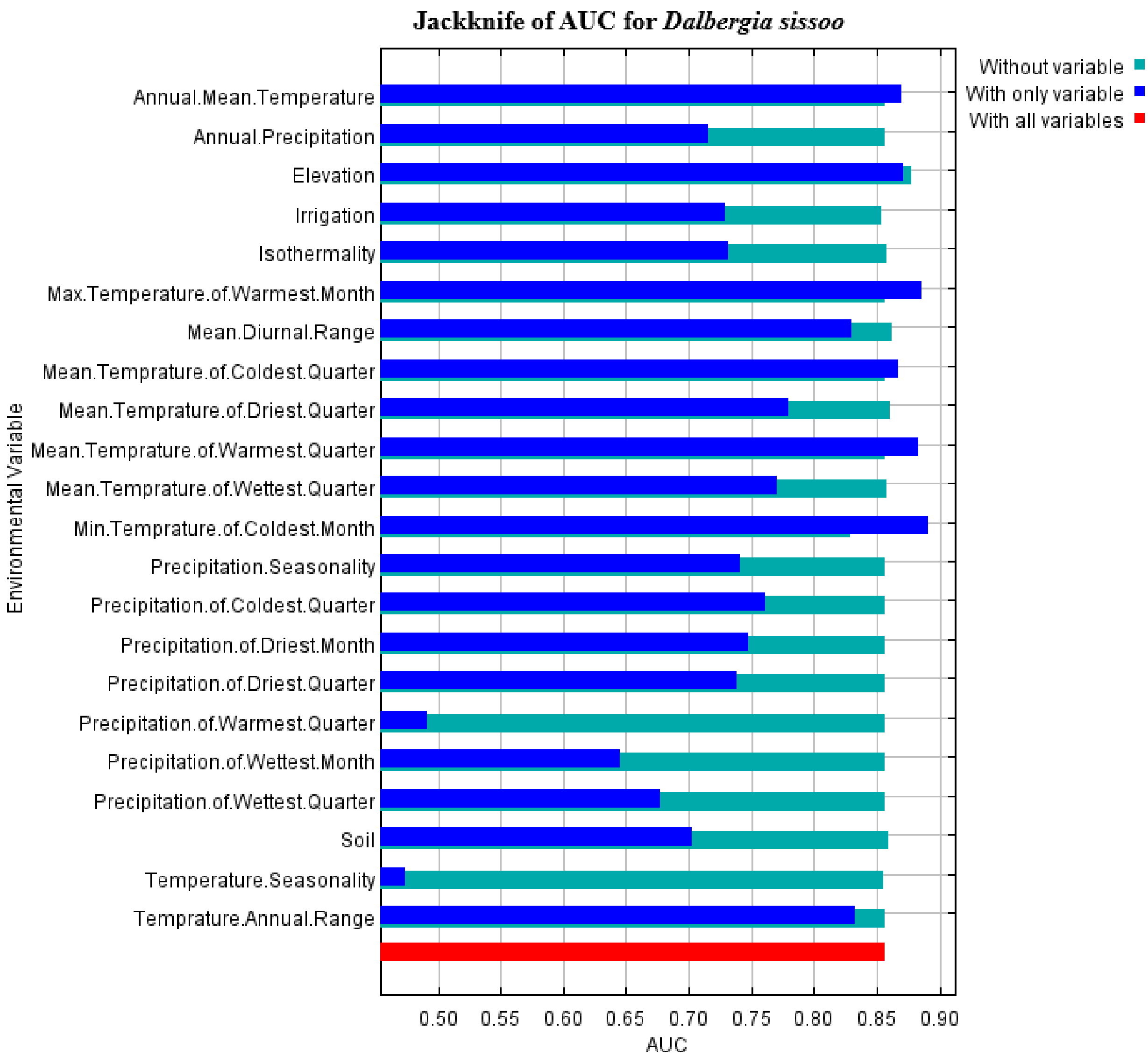

Figure 4.8. Jackknife test for *Dalbergia sissoo*. The value considering just one of the climate indicators is shown by the length of the blue bar; the longer the bar, the more important the climatic variable is. The score of a model generated using the remaining indices is represented by the length of the sea green bar.

4.3 *Juglans regia*

Juglans regia covers practically the entire region of KP under current climatic, with a suitability gradient stretching from northern Chitral to south of Dir (Fig. 4.9a). From Kohistan to Buner is the territory in the north east. Kurram and Khyber Agency in the west demonstrate suitability. It is predicted to be present in South Waziristan and Mansehra and Abbottabad districts in the south and east, respectively. Lower Chitral, Upper Dir, Lower Dir, Swat, Shangla, Upper Kohistan, Lower Kohistan, Kolai Palas, and a few regions of Mansehra, Battagram, Northern Chitral, Malakand, and Abbottabad are particularly potential suitable areas of *Juglans regia*. In addition, two other exceptionally potential suitable areas are proposed, one from Kurram to Khyber agency, and the other in South and North Waziristan. The *Juglans regia* afforestation site (Fig. 4.10a) is not an exceedingly potential suitable site; but, in raw projection (Fig. 4.9a), it falls within the 0.4-0.6 threshold, indicating an acceptable region for the tree species.

Extremely potential suitable areas under current climate were turned into fairly potential suitable areas, such as Shangla, Swat, Battagram, Mansehra, Abbottabad, Khyber Agency, Kurram Agency, and South and North Waziristan districts. (Fig 4.9a) Binary projection (Fig 4.10b) predicted that extremely potential suitable areas are in Waziristan, Khyber Agency, Kurram Agency, and Abbottabad. A decrease in suitability were predicted in districts like Swat, Battagram, Mansehra, Shangla, Malakand, Lower Dir, Upper Dir, Kohistan, Kolai Palas and Lower Chitral.

For SSP2-4.5 reduction in potential suitable areas for *Juglans regia* were predicted (Fig. 4.9c). The binary projection (Fig. 4.10c) projected a key loss of extremely potential suitable area in Shangla, Mansehra, Malakand, Battagram, and Kolai Palas. The suitability areas expanded from 0.4-0.6 to 0.6-0.8 thresholds in the future SSP5-8.5 (2041-2060) scenario (Fig. 4.9d), but there were fewer places in the 0.8-1 threshold range. When comparing binary projection of the current scenario with the future SSP5-8.5 (2041-2060) scenario (Fig. 4.10a, d), it can be seen that the highly potential suitable areas in Battagram, Upper Chitral, Kolai Palas, Shangla, Kurram Agency, Abbottabad, Buner, Khyber Agency, and Waziristan are disappeared. Extremely potential suitable locations in Mansehra, Swat, and Malakand have also decreased.

Those regions that increased from 0.4-0.6 to 0.6-0.8 thresholds in SSP5-8.5 (2041-2060) scenario reduced to (0.2-0.4) threshold in SSP5-8.5 (2081-2100) future scenario (Fig. 4.9e). Additional reductions were observed in potential suitable areas under Binary projection (Fig. 4.10e). Afforested locations were inside the range of moderately potential suitable areas. The models were trained with 12 occurrence records.

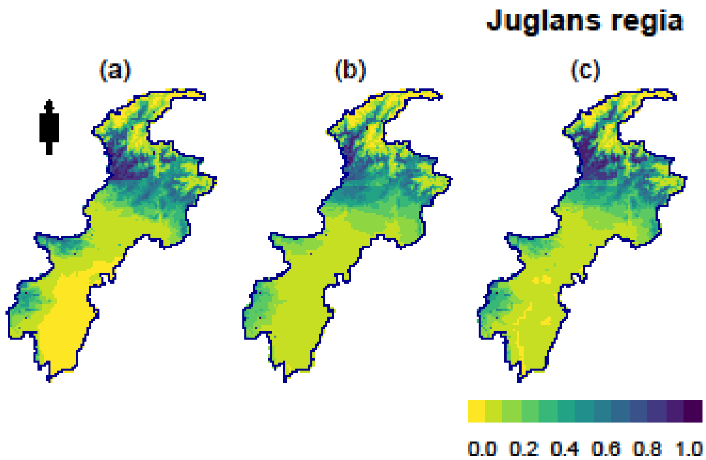

Figure 4.9. Raw-value maps derived from Maxent exponential output. (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5(2081-2100).

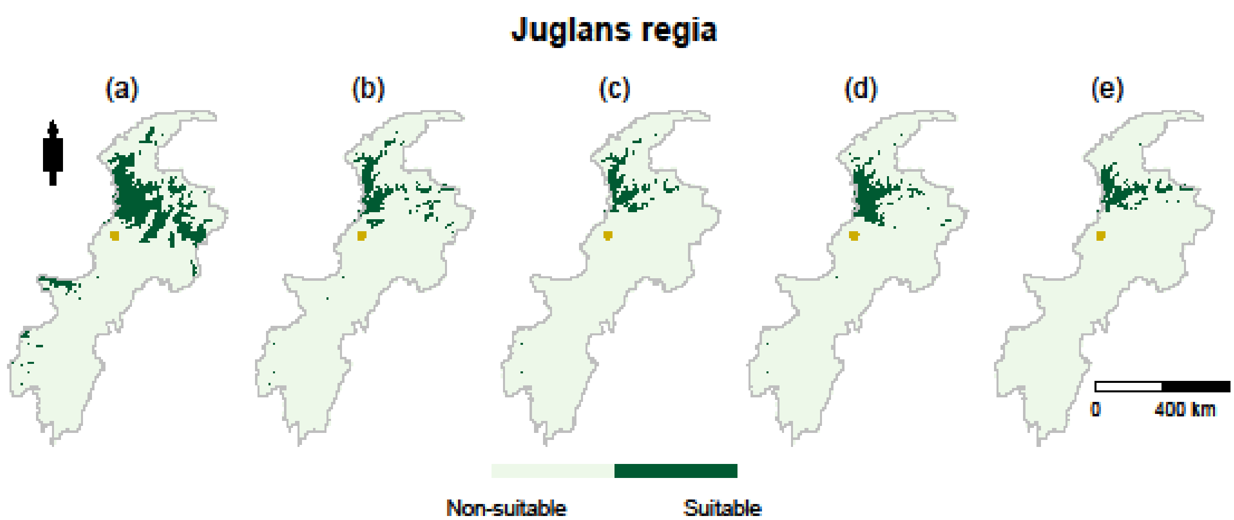

Figure 4.10. Binary maps (threshold value 0.8). (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5 (2081-2100). Yellow dots are recent afforestation sites for *Juglans regia*.

4.3.1 Evaluation of Model Accuracy

The accuracy of the model prediction is validated by ROC Curve (Fig 4.11). The model's AUC mean score, obtained by using 5-fold cross-validation, is 0.847, which showed excellent performance (AUC score > 0.80). The analyses also indicated that the model is fairly good at predicting *Juglans regia* habitat suitability.

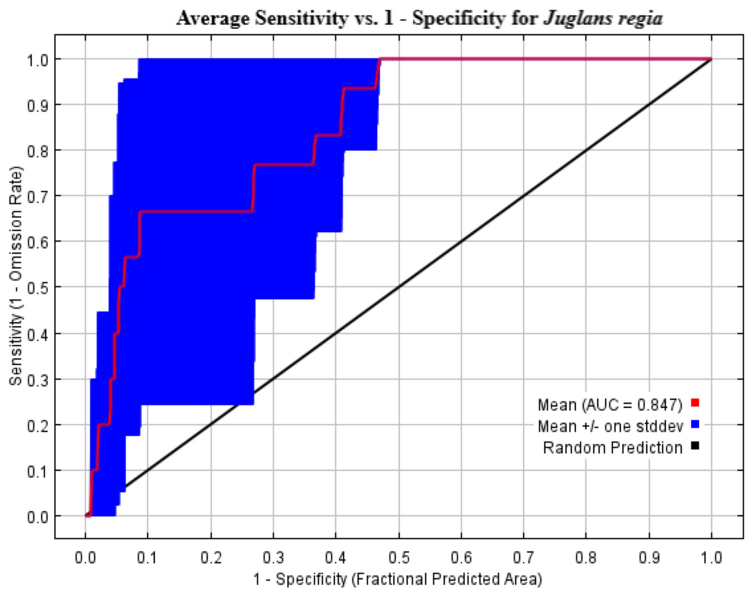

Figure 4.11. Receiver Operating Characteristic (ROC). The black straight line indicates a random prediction, while the red curve indicates the model prediction for the species. The AUC of this ROC plot is 0.847 ± 0.016.

4.3.2 Jackknife test for *Juglans regia*

The jackknife test verified that Irrigation, Isothermality, and Precipitation of Warmest Quarter are the most important variables in the current climatic condition for *Juglans regia* habitat suitability.

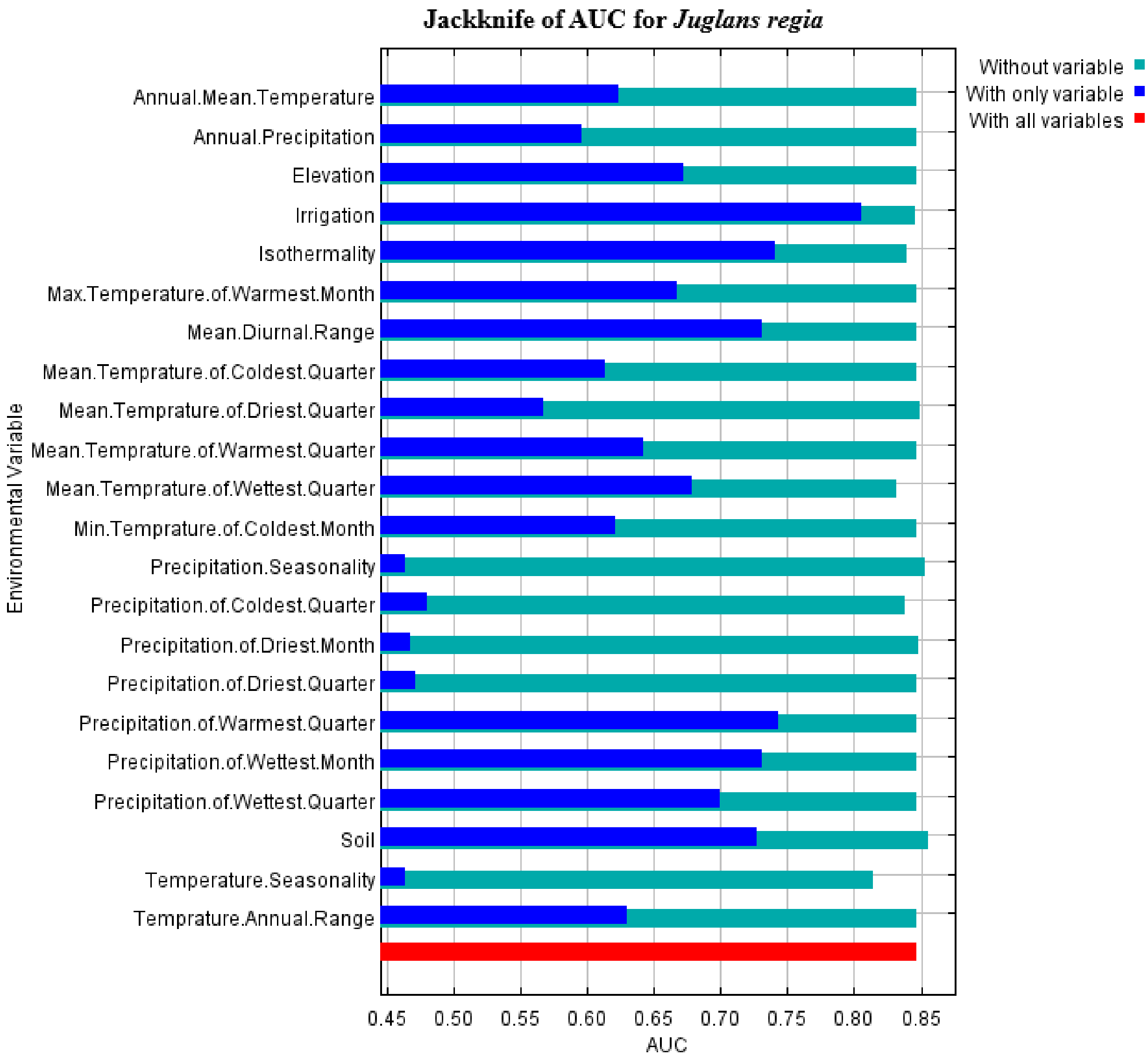

Figure 4.12. Jackknife test for *Juglans regia*. The value considering just one of the climate indicators is shown by the length of the blue bar; the longer the bar, the more important the climatic variable is. The score of a model generated using the remaining indices is represented by the length of the sea green bar.

4.4 *Pinus wallichiana*

In the current climate scenario (Fig. 4.13a), *Pinus wallichiana* is nearly potential suitable throughout KP. In the north, extremely potential suitable area was projected, extending from Upper Chitral to the Bajaur agency. Upper Kohistan and Buner were projected as potential suitable areas in the north east. Hangu, Orakzai, Kurram, and Khyber Agency are projected to be ideal areas in the west. North and South Waziristan are projected to have potential suitable conditions in the south, while Mansehra, Battagram, Torgarh, Haripur, Kolai Palas, and Abbottabad were predicted to have potential suitable conditions in the east. According to binary map (Fig. 4.14a) demonstrates that areas in the north and east of KP are particularly suitable for *Pinus wallichiana*. Lower Dir, Upper Dir, Shangla, Swat, Upper Kohistan, Lower Kohistan, Mansehra, Kolai Palas, Battagram, Malakand, and Abbottabad are among them. Two other exceptionally potential suitable areas were also predicted, one of them is in Kurram agency, and second is in Waziristan. All Pinus wallichiana afforestation sites (Fig. 4.14a) are located within a potential suitable area.

Almost every area slipped below the (0.8-1) threshold in the SSP2-4.5 (2041-2060) scenario (Fig. 4.13b). The binary projection (Fig. 4.14b) demonstrated how much the appropriate region has shrunk in comparison to the existing situation. Lower Dir, Mansehra, Abbottabad, and Kurram Agency were all anticipated to be extremely appropriate. Although the raw projection map (Fig. 4.13b) shows that the afforestation sites are in Swat and Malakand with 0.4-0.6 threshold and Mansehra and Batagram with 0.6-0.8 threshold, all afforested sites are expected to be in the range of non-suitable region (Fig. 4.14b).

A similar pattern was observed in the SSP2-4.5 (2081-2100) scenario (Fig.4.13c), even though the binary map (Fig. 4.14c) shows that Swat Kurram and Khyber agencies had lower suitability regions, while Abbottabad and Upper Chitral had increased suitability areas. Two afforested sites in Malakand and Swat were estimated to be in unsuitable areas (Fig. 4.14c), despite being inside the 0.4-0.6 criterion on the raw projection map (Fig. 4.13c).

Quite few locations in Upper Dir, Swat, Mansehra, Battagram, and Kurram Agency fall under the (0.8-1) threshold in the future SSP5-8.5 (2041-2060) scenario (Fig. 4.13d). However, in the binary map (Fig. 4.14d), a decrease in potential suitable area is expected as compared to the current condition. In binary projection, afforested sites in Malakand, Swat, and Shangla were projected in non-suitable terrain (Fig. 4.14d), but they remained in the 0.6-0.8 threshold area in raw projection (Fig. 4.13d).

More potential suitable areas in the Swat region are expected in the SSP5-8.5 (2081-2100) scenario (Fig. 4.13e). The binary map (Fig. 4.14e) confirms a rise in the Central Swat region and

Upper Dir, but a slight decrease in Mansehra, Battagram, and Abbottabad. Almost majority of the afforested plots are expected to be in unsuitable regions (Fig. 4.14e).

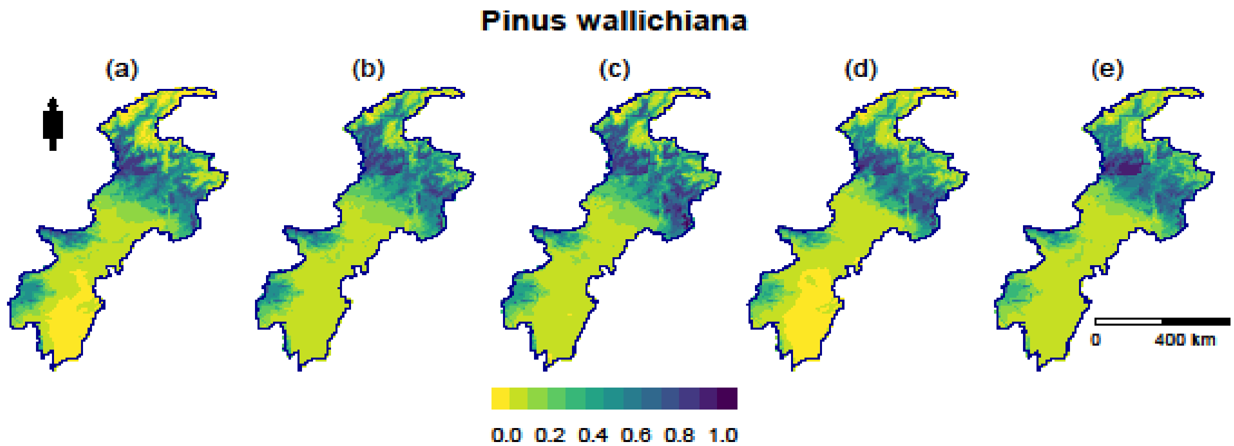

Figure 4.13. Raw-value maps derived from Maxent exponential output. (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5(2081-2100).

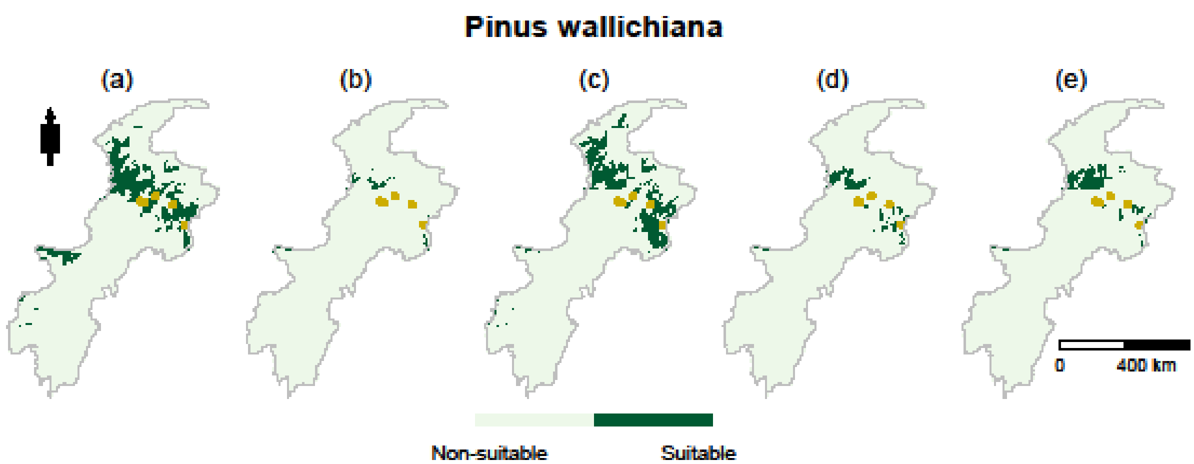

Figure 4.14. Binary maps (threshold value 0.8). (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5 (2081-2100). Yellow dots are recent afforestation sites for *Pinus Wallichiana*.

4.4.1 Evaluation of Model Accuracy

The accuracy of the model prediction is validated by ROC Curve (Fig 4.15). The model's AUC mean score, obtained using 5-fold cross-validation, is 0.705, showing satisfactory performance (AUC score > 0.8). The analyses also indicated that the model is satisfactory at predicting *Pinus wallichiana* habitat suitability.

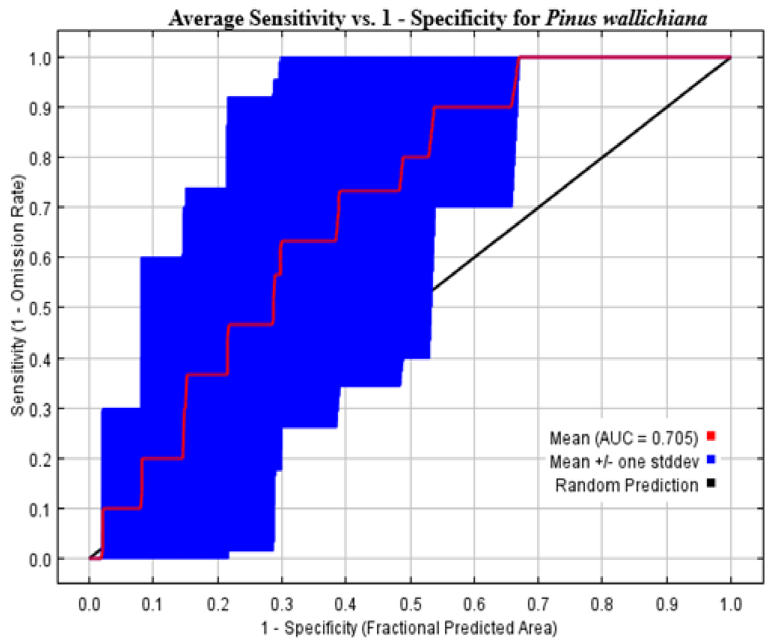

Figure 4.15. Receiver Operating Characteristic (ROC). The black linear line represents a random forecast, whereas the red curve represents the species' model prediction. This ROC plot's AUC is 0.705 ± 0.016.

4.4.2 Jackknife test for *Pinus wallichiana*

The jackknife test verified that Temperature Annual Range, Precipitation of Driest Quarter, and Precipitation of Driest Month are the most important variables in the current climatic condition for *Pinus wallichiana* habitat suitability.

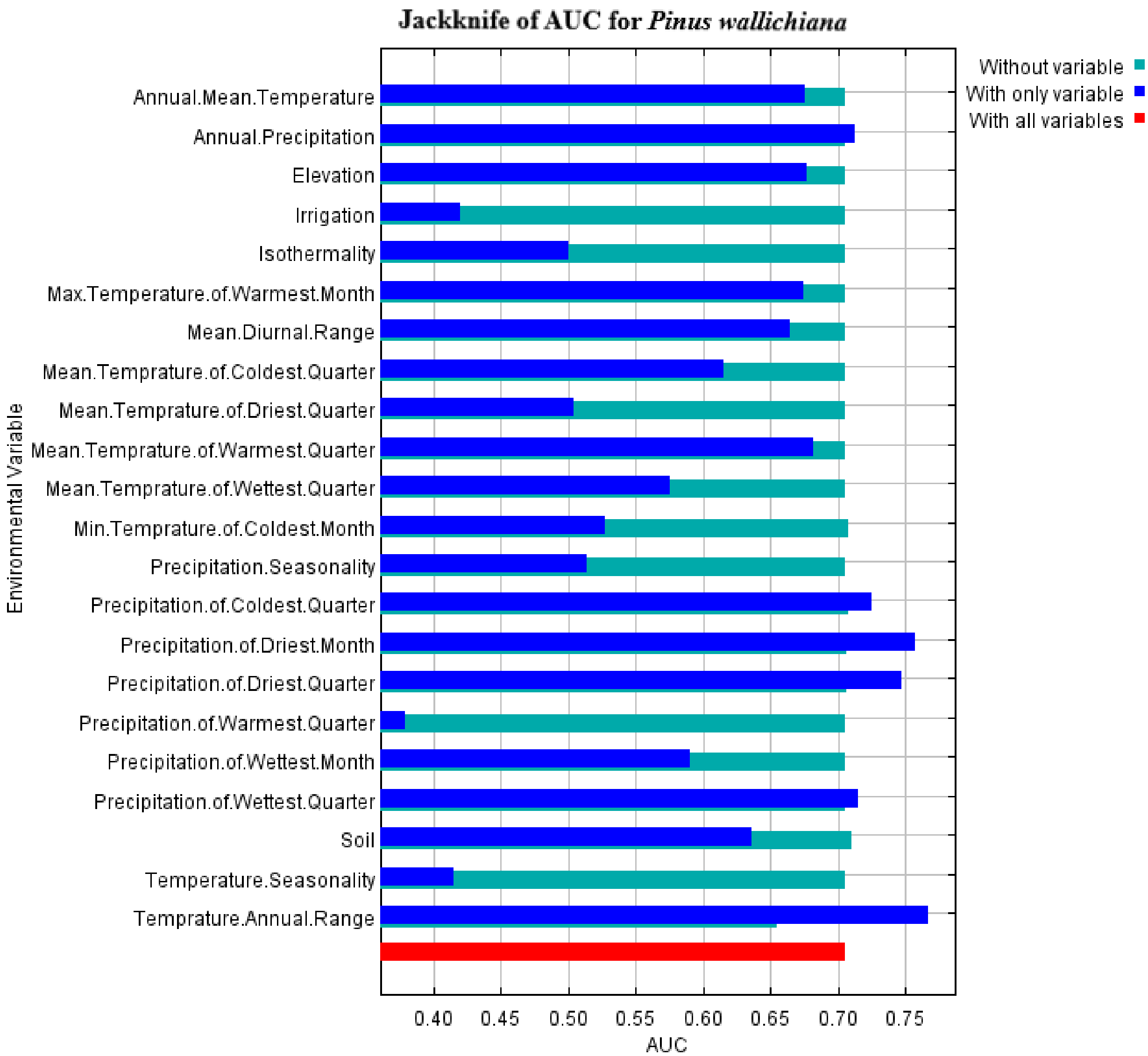

Figure 4.16. Jackknife test for *Pinus wallichiana*. The value considering just one of the climate indicators is shown by the length of the blue bar; the longer the bar, the more important the climatic variable is. The score of a model generated using the remaining indices is represented by the length of the sea green bar.

4.5 Eucalyptus

Initially, current climatic circumstances predict that a few locations in KP are potentially suitable for Eucalyptus cultivation (Fig. 4.17a), especially Bajaur, the Swat-Upper Dir border, Lower Dir Malakand, Mardan, Swabi, Charsadda, and Nowshera. As per binary projection (Fig.

4.18a), potential suitable sites identified in the aforementioned KP districts, as well as in areas of Haripur, Mansehra, Buner, and Peshawar.

Numerous Eucalyptus species were utilized for afforestation in KP (Fig. 4.18a), particularly afforested sites in Bajuar, Lower Dir, Swat, Malakand, Mardan, Buner, and Swabi, all of which are projected to be ideal regions. Non-suitable regions include afforested sites in Kohat, Dera Ismail Khan, Bannu, Hangu, Karak, Haripur, and Abbottabad.

For the future SSP2-4.5 (2041-2060) scenario (Fig. 4.17b), similar areas were forecasted as in the current scenario (Fig. 4.17a), with a modest increase in area. Some additional zones are projected using binary projection (Fig. 4.18b), particularly in Swat, Peshawar, Malakand, Charsadda, and Bajaur. Afforested areas in Bajuar, Lower Dir, Malakand, Mardan, Buner, and Swabi are potential suitable areas, however afforested areas in Kohat, Dera Ismail Khan, Bannu, Hangu, Karak, Haripur, and Abbottabad are not suitable (Fig. 4.18b).

Similar areas were predicted as potentially suitable in the end of century under moderate scenario SSP2-4.5(2081-2100) (Fig. 4.17c) as in the SSP2-4.5 (2041-2060) scenario (Fig. 4.17b), however there is a modest shift in current potential suitable areas to the north-west. In comparison to SSP2-4.5, the binary projection map (Fig. 4.18c) shows that Swat, Shangla, and Mansehra have increased eligible areas (2041-2060). SSP2-4.5 anticipated afforestation sites remained unchanged (2041-2060).

The potential suitable areas in the western side of KP were significantly changed in the SSP5-8.5 (2041-2060) future scenario (Fig. 4.17d). In Bajuar, Upper Dir, Lower Dir, and Malakand, there was a sudden loss of potential suitable areas. Furthermore, in the Binary projection (Fig. 4.18d), the abovementioned regions saw a decline in potential suitable area for Eucalyptus, with a shifting of habitat towards the east. Bajaur Agency's and Lower Dir's forested locations are in an unsuitable zone.

Similar potential suitable regions are predicted in SSP5-8.5 (2081-2100) scenario (Fig. 4.17e) as in SSP5-8.5 (2041-2060). (Fig. 4.17d). The binary projection (Fig. 4.18e) revealed a small loss in area in the Buner region. Afforested sites are located in the same regions as SSP5-8.5(2041-2060). (Fig. 4.18d).

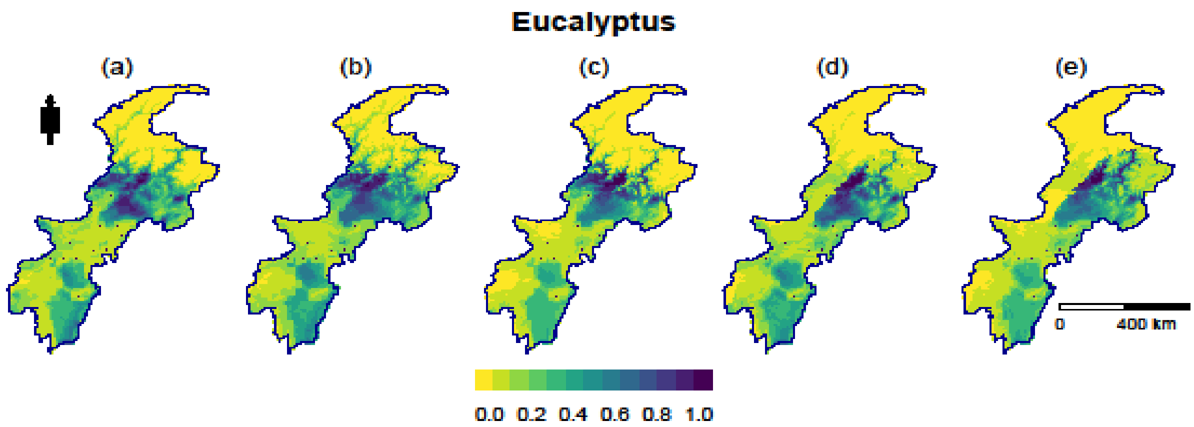

Figure 4.17. Raw-value maps derived from Maxent exponential output. (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5(2081-2100).

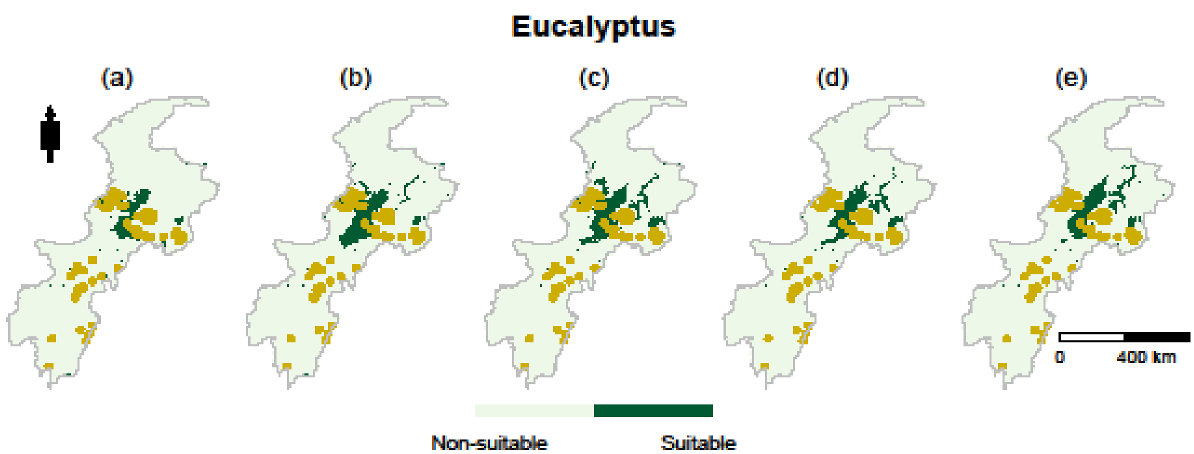

Figure 4.18. Binary maps (threshold value 0.8). (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5 (2081-2100). Yellow dots are recent afforestation sites for Eucalyptus.

4.5.1 Evaluation of Model Accuracy

The accuracy of the model prediction is validated by ROC Curve (Fig 4.19). The model AUC mean score, obtained using 5-fold cross-validation, is 0.874, showing excellent performance (AUC score > 0.80). The analyses also indicated that the model is quite good at predicting *Eucalyptus* habitat suitability.

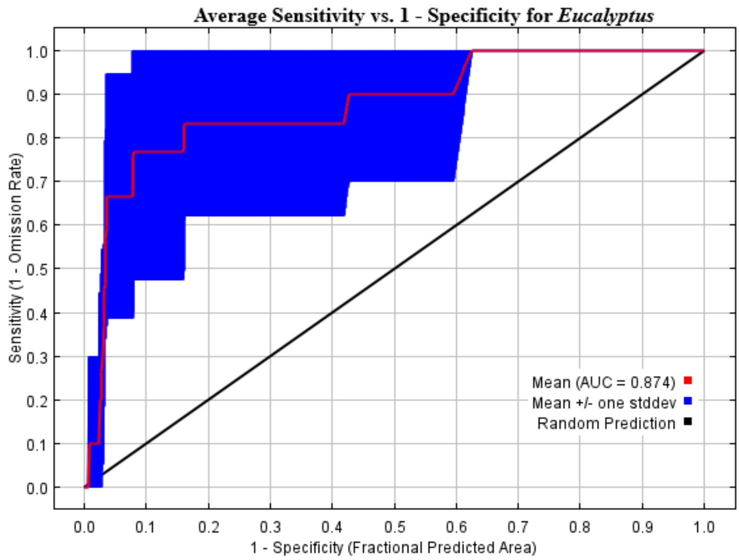

Figure 4.19. Receiver Operating Characteristic (ROC). The black linear line represents a random forecast, whereas the red curve represents the species' model prediction. This ROC plot's AUC is 0.705 ± 0.016.

4.5.2 Jackknife test for Eucalyptus

The jackknife test verified that Irrigation, Precipitation of Warmest Quarter, and Precipitation of Wettest Month are the most important variables in the current climatic condition for Eucalyptus habitat suitability.

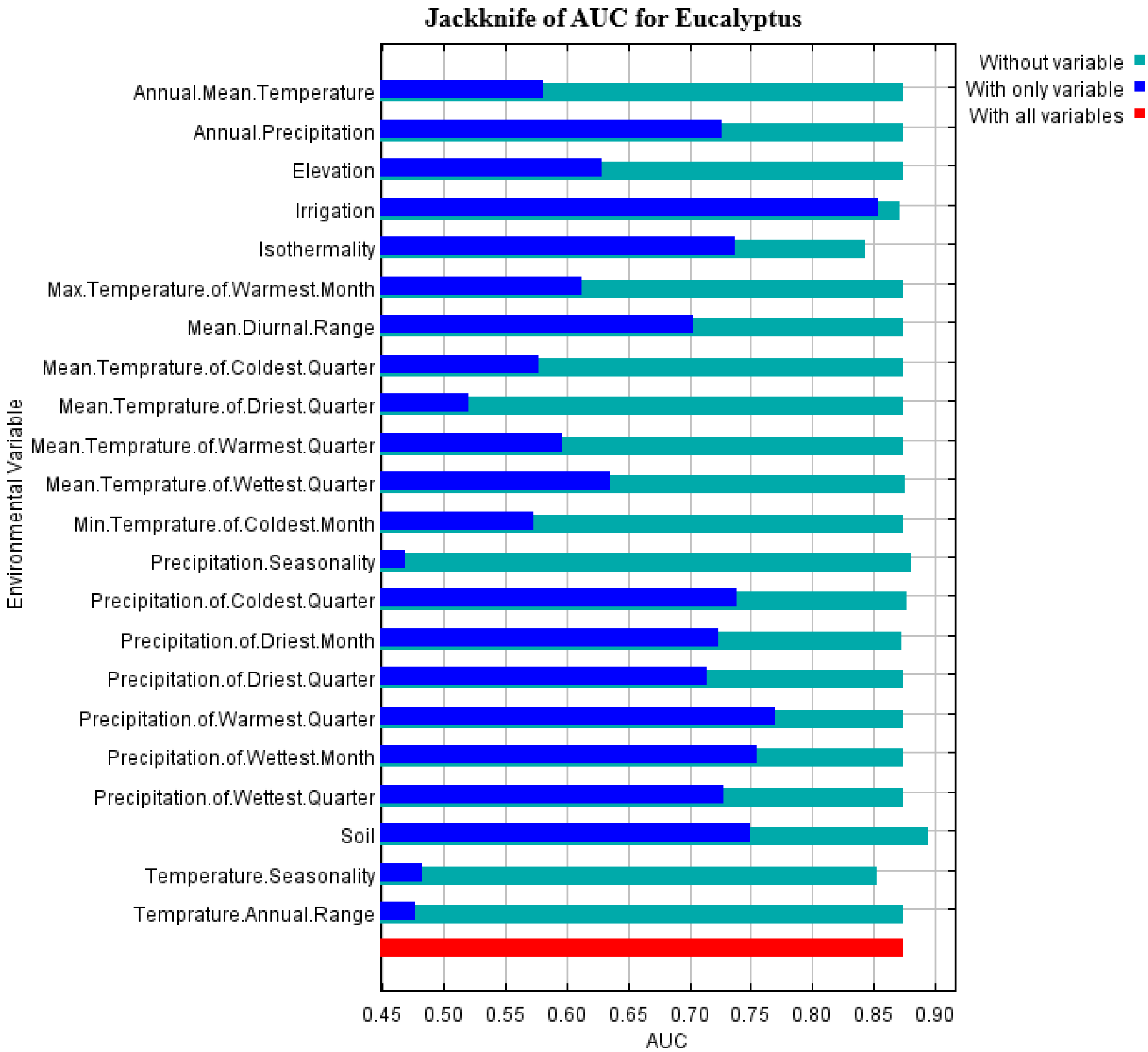

Figure 4.20. Jackknife test for Eucalyptus. The value considering just one of the climate indicators is shown by the length of the blue bar; the longer the bar, the more important the climatic variable is. The score of a model generated using the remaining indices is represented by the length of the sea green bar.

4.6 *Senegalia Modesta*

The current climate scenario (Fig. 4.21a) predicts a potential suitable habitat for *Senegalia Modesta* along the central parts of KP. *Senegalia modesta*'s niche suitability was demonstrated by binary projection (Fig. 4.22a) in Swat, Malakand, Shangla, Buner, Charsadda, Haripur, Abbottabad, Mansehra, Peshawar, Mardan, Kohat, Kurram Agency, Bannu, and the eastern side of Dera Ismail Khan. *Senegalia modesta* afforested sites were quite close to potential suitable regions. Furthermore, a raw projection map of Bajaur afforested areas (Fig. 4.21a) revealed that they are growing at the threshold levels of suitability with a (0.2-0.4).

For future scenario SSP2-4.5 (2041-2060) *Senegalia modesta* (Fig. 4.20b) has intermediate suitability as in current scenario however in binary projection (Fig. 4.21b) suitability area is predicted to increased. potential suitable areas include Peshawar, Kohat, Bannu Orakzai Agency, Hangu and Waziristan. Area has expanded from Buner and Haripur to Shangla and Kohistan.

The suitability area is decreased in the SSP2-4.5(2081-2100) scenario (Fig. 4.20c), particularly in Khurram Agency, Mansehra, Haripur, and Kohat. In comparison to SSP2-4.5(2041-2060), a significant drop is predicted in Abbottabad, Shangla, Swat, Mansehra, Kohat, Kurram Agency, Bannu, Waziristan, and the eastern part of Dera Ismail Khan in binary projection (Fig. 4.21c) (Fig. 4.21b). The afforested locations of Kohat, Hangu, and Karak in the south become unsuitable, and the Bajaur agency remains unsuitable, like all previous projections. Remaining locations of Mardan and Swabi remain potential suitable areas.

Future SSP5-8.5 (2041-2060) scenario (Fig. 4.20d) increased habitats suitability is observed. Further in binary projection (Fig. 4.21d), Kohistan and Waziristan districts were added in more potential suitable areas for *Senegalia modesta*. Some potential suitable areas improved in Dera Ismail Khan, Hangu, and Karak, but declined in Mansehra Abbottabad and Karak.

Some variations predicted in areas including such Dera Ismail Khan, Swabi, Haripur, and Mansehra in the SSP5-8.5 (2081-2100) scenario (Fig. 4.20e). In binary projection (Fig. 4.21e), a reduction in potential suitable area were projected for the Mardan, Haripur, Buner, Karak, Hangu, Bannu, Mansehra, Dera Ismail Khan, Waziristan, and Kurram agencies. However, in Swabi, the potential suitable area had totally disappeared as compared to the previous period of SSP5-8.5.

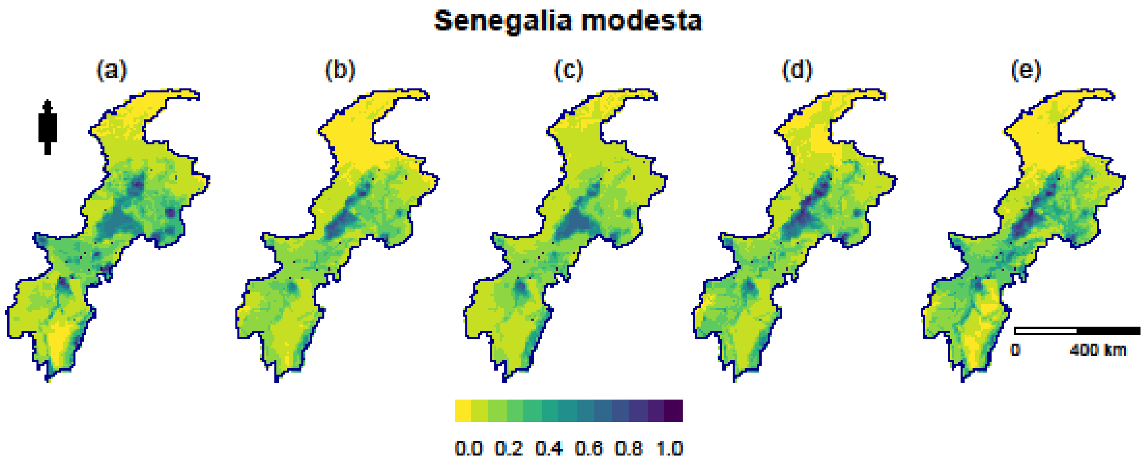

Figure 4.21. Raw-value maps derived from Maxent exponential output. (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5(2081-2100).

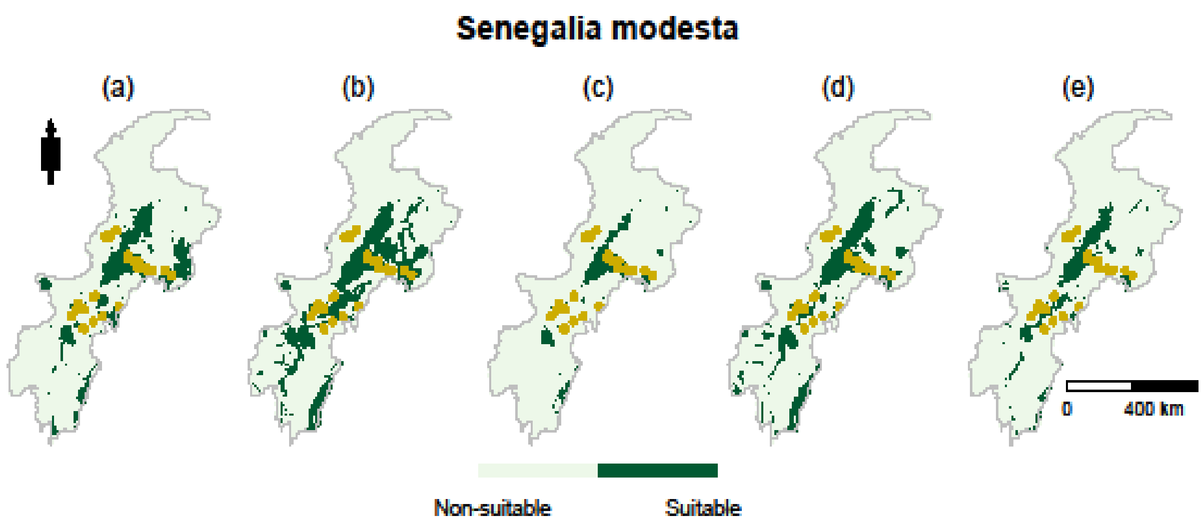

Figure 4.22. Binary maps (threshold value 0.8). (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5 (2081-2100). Yellow dots are recent afforestation sites for *Senegalia modesta*.

4.6.1 Evaluation of Model Accuracy

The accuracy of the model prediction is validated by ROC Curve (Fig.4.22). The model's AUC mean score, obtained using 5-fold cross-validation, is 0.68, showing satisfactory performance (AUC score > 0.60). The analyses also indicated that the model is satisfactory at predicting *Senegalia modesta* habita*t* suitability.

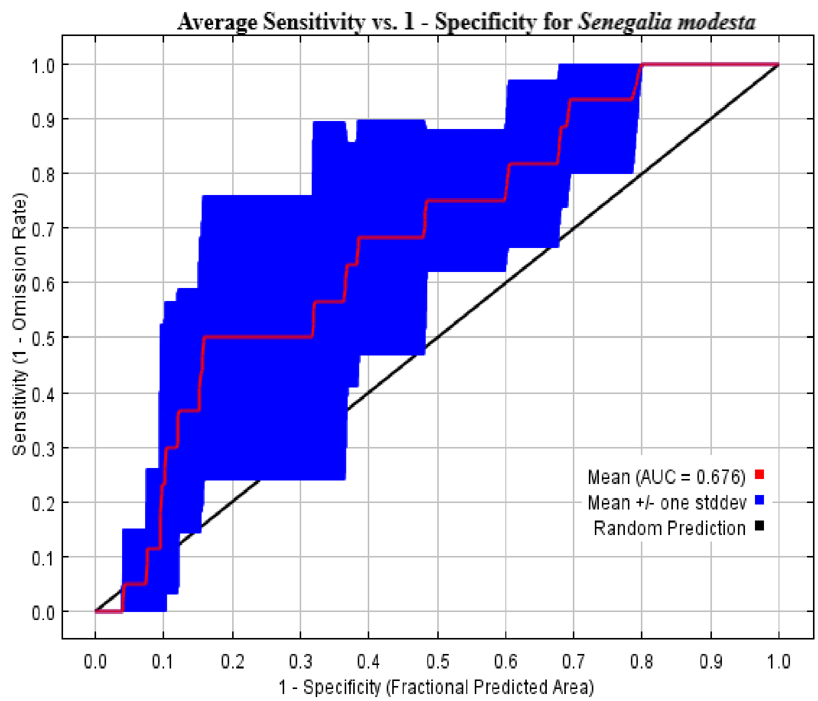

Figure 4.23. Receiver Operating Characteristic (ROC). The black linear line represents a random forecast, whereas the red curve represents the spec'es' model prediction. This ROC p'ot's AUC is 0.676 ± 0.016.

4.6.2 Jackknife test for *Senegalia modesta*

The jackknife test verified that Temperature Seasonality, Elevation, and Irrigation are the most important variables in the current climatic condition for *Senegalia modesta* habitat suitability. The value considering just one of the climate indicators is shown by the length of the blue bar; the longer the bar, the more important the climatic variable is. The score of a model generated using the remaining indices is represented by the length of the sea green bar.

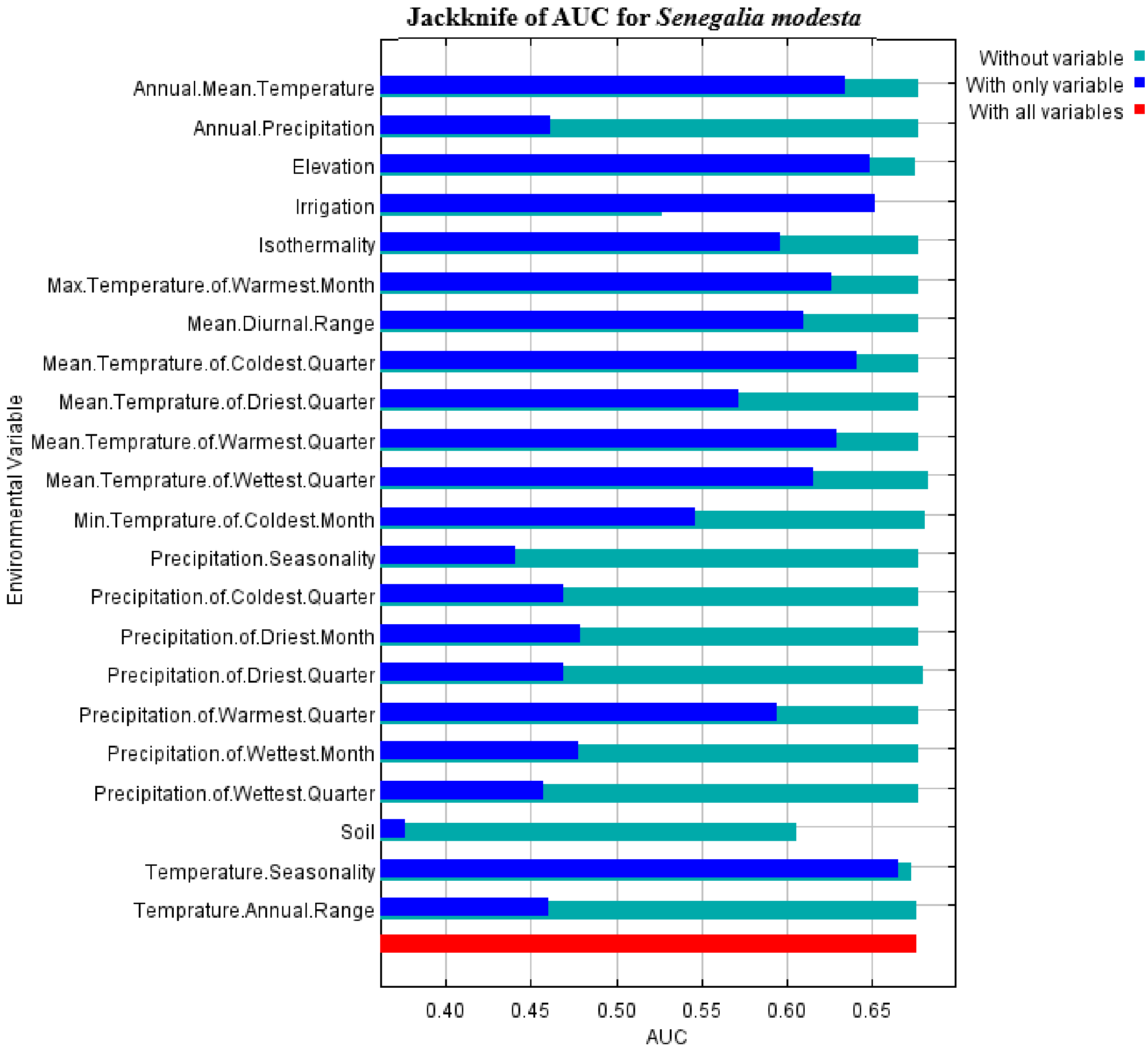

Figure 4.24. Jackknife test for *Senegalia modesta*. The value considering just one of the climate indicators is shown by the length of the blue bar; the longer the bar, the more important the climatic variable is. The score of a model generated using the remaining indices is represented by the length of the sea green bar.

4.7 *Populus ciliata*

For the current climate scenario, (Fig. 4.25a) potential suitable areas were projected in north of KP. In binary projection (Fig. 4.26a), potential suitable areas were projected in all northern districts of KP, namely Chitral, Upper Dir, Lower Dir, Swat, Shangla, Kohistan, Battagram, and

Mansehra. In the south, potential suitable areas were forecasted in Kurram Agency and Waziristan. Certain afforested sites in Shangla and Battagram are in potential suitable places, while others are in non-suitable areas (Fig. 4.26a).

For SSP2-4.5 (2041-2060) scenario (Fig. 4.25b), climate suitability for *Populus ciliata* falls in the northern sections, but increases in Chitral and Upper Swat. In binary projection (Fig. 4.26b), potential suitable areas remained dominant in northern districts such as Chitral, Swat, and Dir. When compared to the existing situation, potential suitable areas have increased in Battagram, Mansehra, Kurram, and Waziristan (Fig. 4.26a). Mansehra's two forested areas come inside the appropriate site.

Populus ciliata habitat suitability reduced in the SSP2-4.5 (2081-2100) scenario (Fig. 4.25c). A significant drop is predicted in Chitral, Swat, Kohistan, Shangla, and Mansehra in binary projection (Fig. 4.26c). Suitability reduced in the western part of KP in SSP5-8.5(2041-2060) (Fig. 4.25d). The binary projection (Fig. 4.26d) showed a significant increase in the potential suitable area for Kurram, Khyber, Waziristan, Chitral, and Hangu. A minor upward shift was observed in the northeast region.

The outcomes for SSP5-8.5 (2081-2100)) scenario (Fig. 4.25e) were nearly identical to the results of the preceding timeline SSP5-85(2041-2060). (Fig. 4.25d). In binary projection (Fig. 4.26e), a reduction in potential suitable area is shown in Kurram, Khyber, and Waziristan in the south of KP, whereas a reduction was projected in Chitral and Swat in the north.

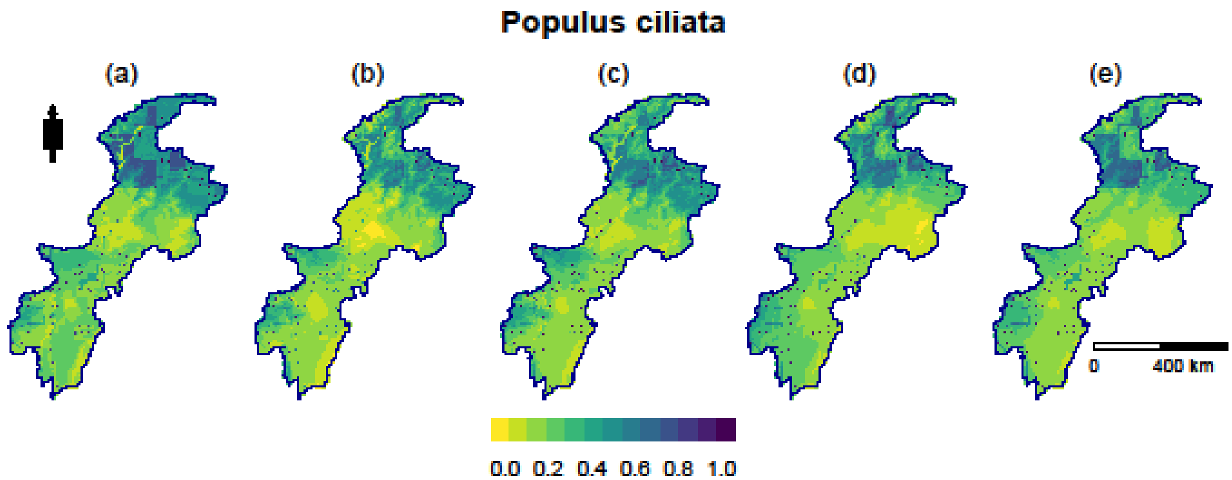

Figure 4.25. Raw-value maps derived from Maxent exponential output. (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5(2081-2100).

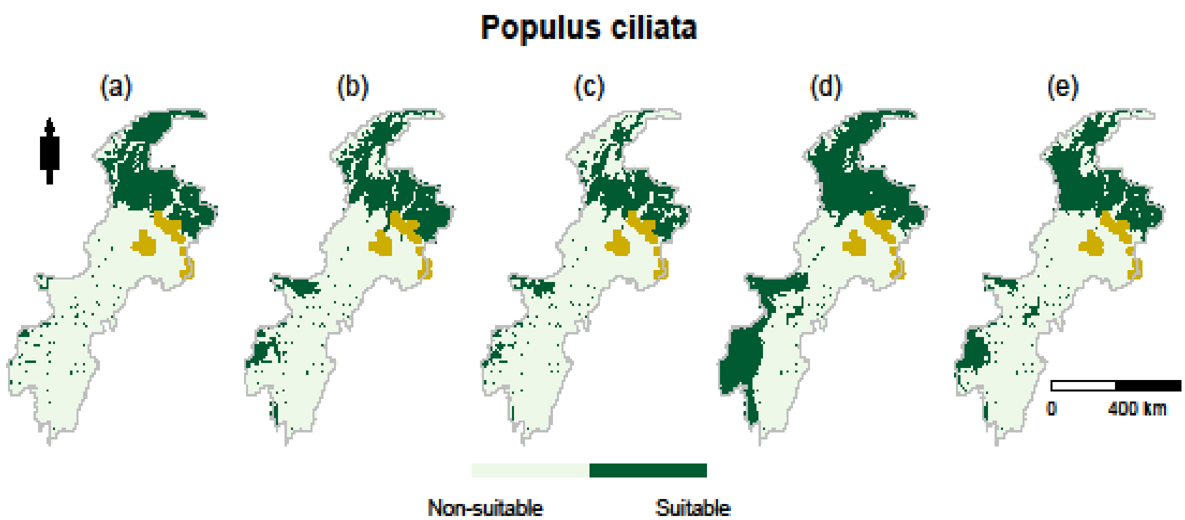

Figure 4.26. Binary maps (threshold value 0.8). (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5 (2081-2100). Yellow dots are recent afforestation sites for *Populus ciliata*.

4.7.1 Evaluation of Model Accuracy

The accuracy of the model prediction is validated by ROC Curve (Fig 4.26). The model's AUC mean score, obtained using 5-fold cross-validation, is 0.637, showing satisfactory performance (AUC score > 0.60). The analyses also indicated that the model is satisfactory at predicting *Populus ciliata* habitat suitability.

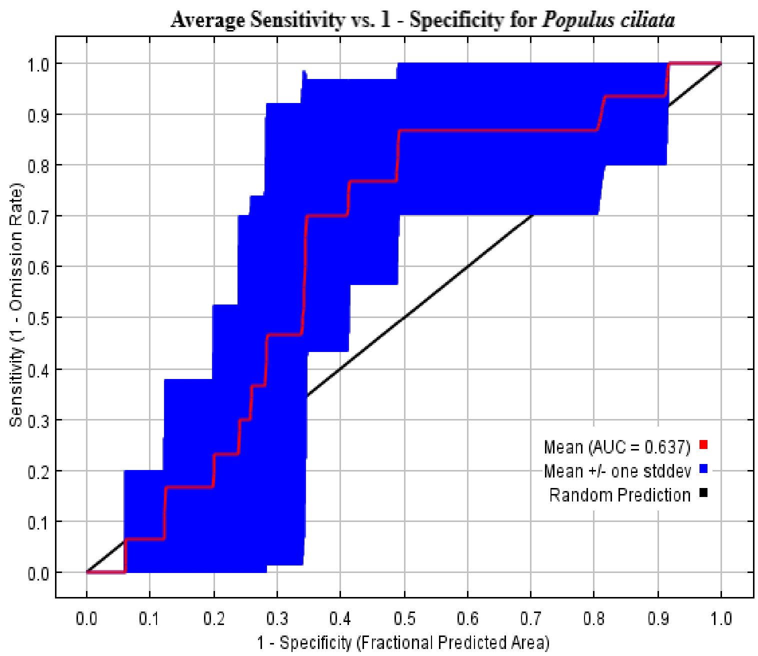

Figure 4.27. Receiver Operating Characteristic (ROC). The black linear line represents a random forecast, whereas the red curve represents the species' model prediction. This ROC plot's AUC is 0.676 ± 0.016.

4.7.2 Jackknife test for *Populus ciliata*

The jackknife test verified that Mean Temperature of Driest Quarter, Perception Seasonality are the most important variables in the current climatic condition for *Populus ciliata* habitat suitability.

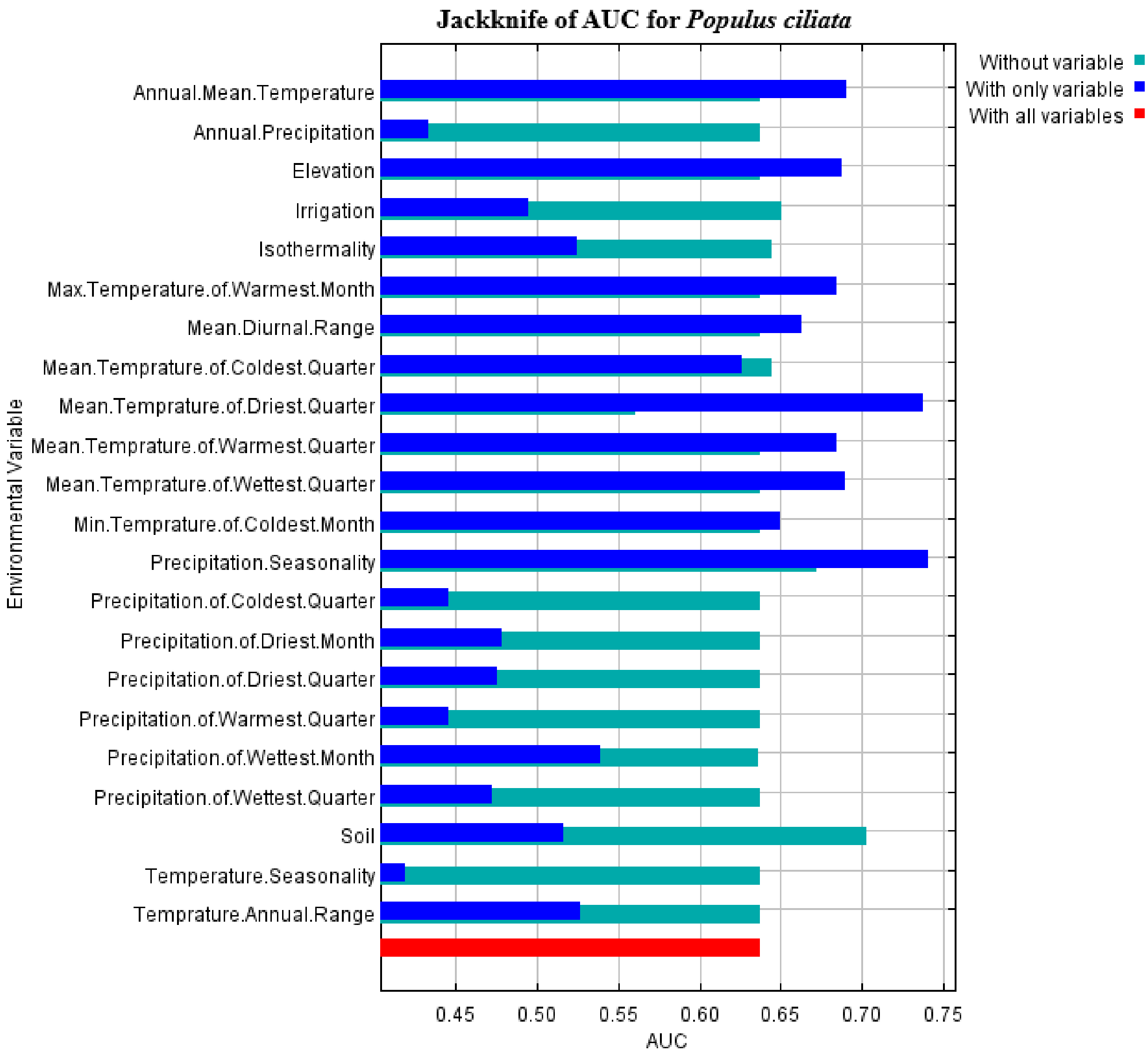

Figure 4.28. Jackknife test for *Populus ciliata*. The value considering just one of the climate indicators is shown by the length of the blue bar; the longer the bar, the more important the climatic variable is. The score of a model generated using the remaining indices is represented by the length of the sea green bar.

4.8 *Vachellia nilotica*

Most of the areas were predicted as potentially suitable for *Vachellia nilotica* under current climatic, northern part of KP (Fig. 4.29a). In binary projection (Fig. 4.30a) projected potential suitable areas contain Mohmand Agency, Kohat, Karak, Nowshera, Haripur, Dara Adam Khel, Hangu, Bannu, Landi Kotal, Peshawar, Lakki Marwat, Tank, Dera Ismail Khan and Waziristan. Afforestation sites of Swabi, Mardan, and Bajuar Agency are not potentially suitable for Vachellia nilotica.

Some southern areas of KP were predicted as potentially suitable for *Vachellia nilotica* in the SSP2-4.5 (2041-2060) scenario (Fig. 4.29b). In binary projection (Fig. 4.30b), Haripur, Nowshera, Kohat, Mohmand Agency, Landi Kotal and Bannu, a slight decline was forecasted as compared to the current climate scenario (Fig. 4.30a). A few forested areas in Bannu were designated as unsuitable.

The potential suitable area for Vachellia nilotica declined in the SSP2-4.5 (2081-2100) scenario in the north and west of KP (Fig. 4.29c). According to Binary projection (Fig. 4.30c) potential suitable regions were further decreased in Haripur, Mohmand Agency, Landi Kotal, Nowshera, Kohat, and Bannu.

A slight decline is predicted near Swabi district in the SSP5-8.5 (2041-2060) future scenario (Fig. 4.29d). According to binary projection (Fig. 4.30d) Haripur, Mohmand Agency, Landi Kotal, Nowshera, Kohat, Bannu, Karak, and Laki marwat were projected to get significant decrease in suitability. Afforested areas in Swabi, Mardan, Bajuar Agency, and one site in Karak are not suited for *Vachellia nilotica* in the future climate.

Some potential suitable areas are expanded in the SSP5-8.5 (2081-2100) scenario (Fig. 4.29e) when compared to the SSP5-8.5 (2041-2060) scenario (Fig. 2d). In binary projection (Fig. 4.30e), however, Haripur, Mohmand Agency Karak, Kohat, Landi Kotal, and Dara Adam are expected to have an increase in suitability. For this prediction, the estimatedpotential suitable area for *Vachellia nilotica* is 20,323.6 Km^2, or 19.9%%of the entire area of KP. Swabi, Mardan, and Bajuar Agency's forested areas are potentially unsuitable for *Vachellia Nilotica*.

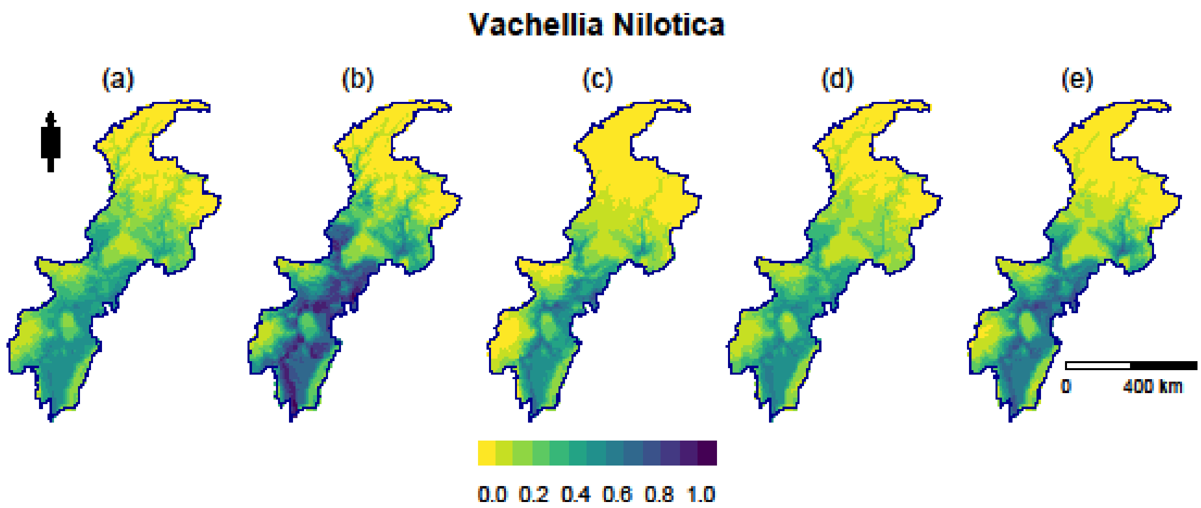

Figure 4.29. Raw-value maps derived from Maxent Exponential output. (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5(2081-2100).

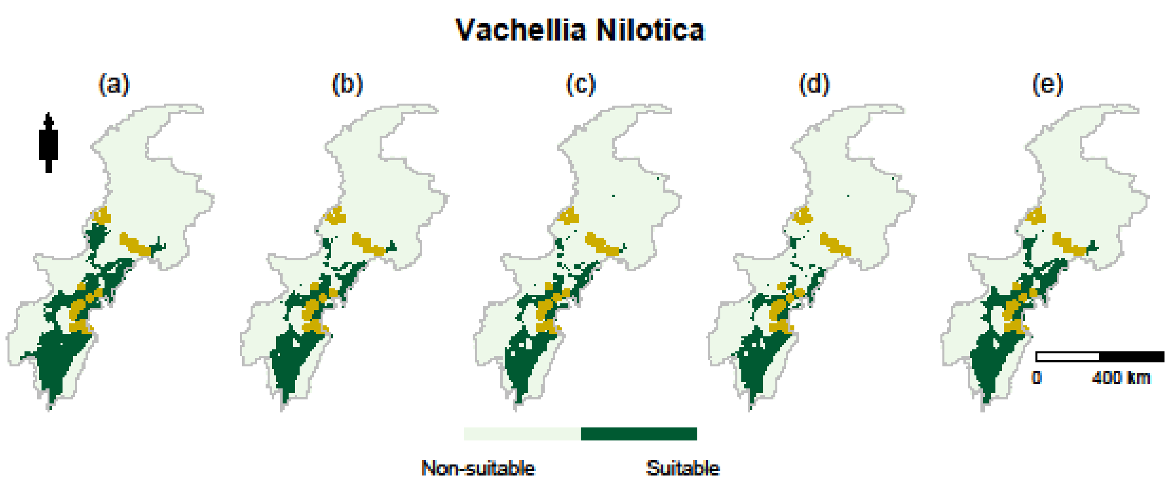

Figure 4.30. Binary maps (threshold value 0.8). (a) Current (b) SSP2-4.5 (2041-2060) (c) SSP2-4.5 (2081-2100) (d) SSP5-8.5 (2041-2060) (e) SSP5-8.5 (2081-2100). Yellow dots are recent afforestation sites for *Vachellia Nilotica*.

4.8.1 Evaluation of Model Accuracy

The accuracy of the model prediction is validated by ROC Curve (Fig 4.32). The model's AUC mean score, obtained using 5-fold cross-validation, is 0.804, showing excellent performance (AUC score > 0.80). The analyses also indicated that the model is quite good at predicting *Vachellia nilotica* habitat suitability.

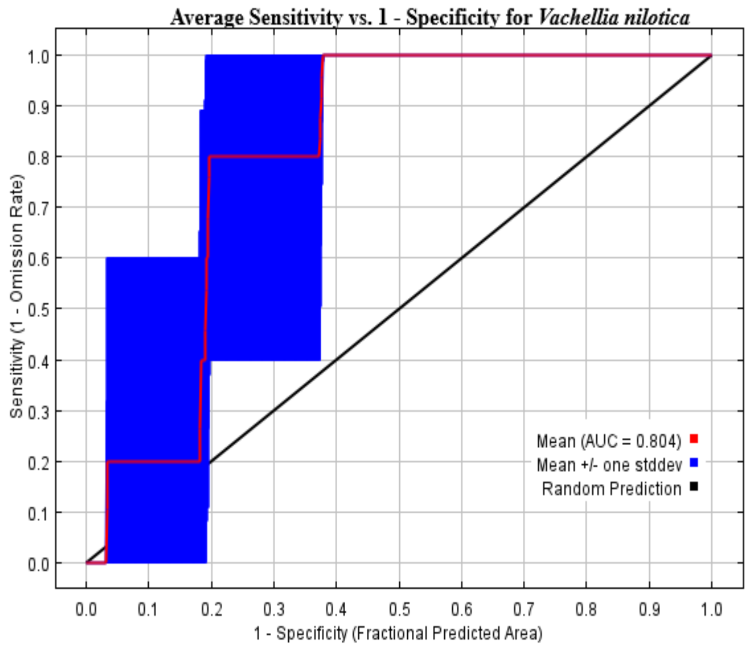

Figure 4.31. Receiver Operating Characteristic (ROC). The black linear line represents a random forecast, whereas the red curve represents the species' model prediction. This ROC plot's AUC is 0.804 ± 0.016.

4.8.2 Jackknife test for *Vachellia nilotica*

The jackknife test verified that Minimum Temperature of Coldest Month, Mean Temperature of Coldest Quarter are the most important variables in the current climatic condition for *Vachellia nilotica* habitat suitability.

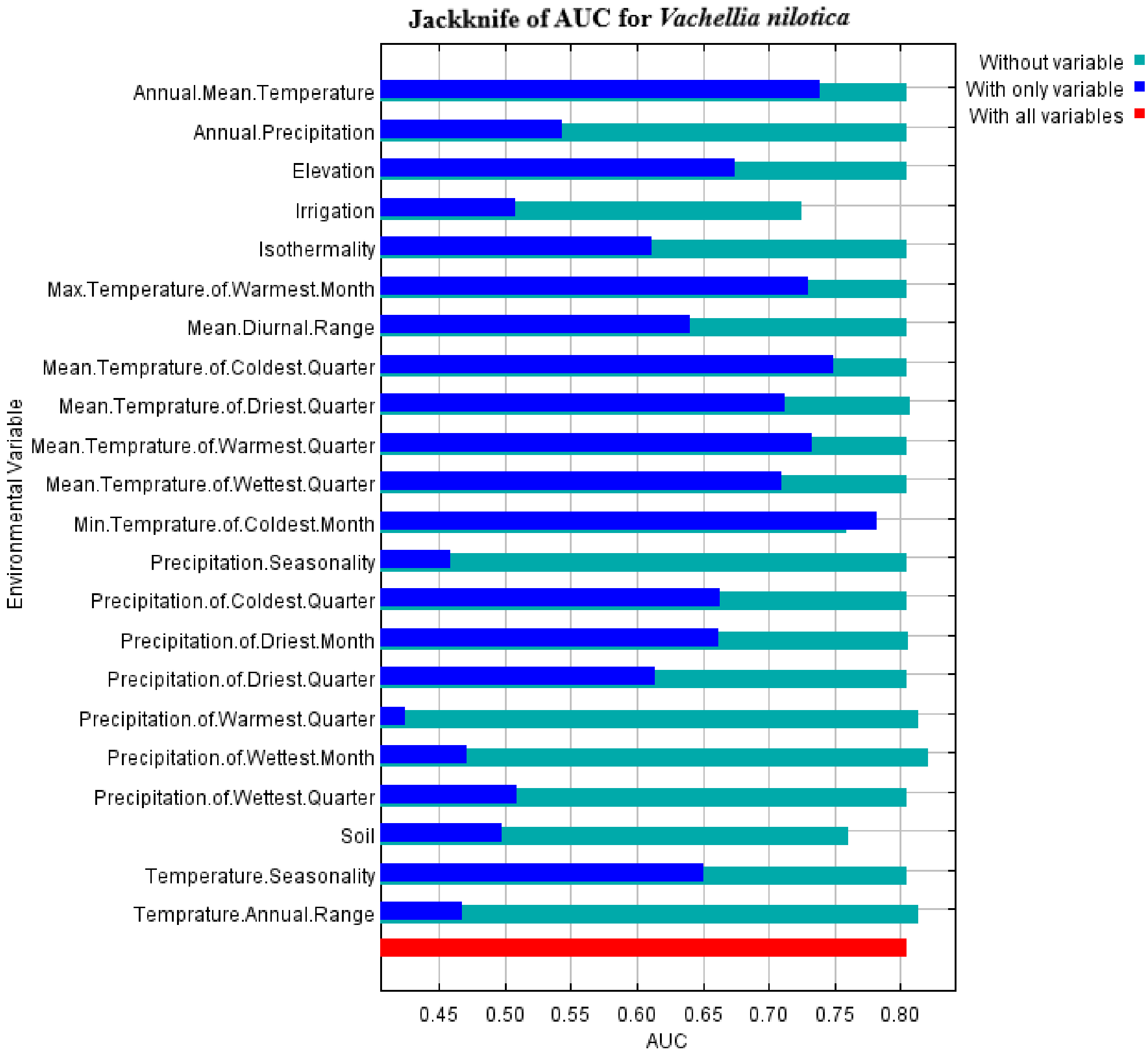

Figure 4.32. Jackknife test for *Vachellia nilotica* the value considering just one of the climate indicators is shown by the length of the blue bar; the longer the bar, the more important the climatic variable is. The score of a model generated using the remaining indices is represented by the length of the sea green bar.

4.9 Identifying Species at Risk of Losing Habitat

In current climatic projections, 7098 Km² area is potentially suitable for *Cedrus deodara* in KP, or 7% of its entire area. However, under the moderate scenario by the mid of current century, the overall predicted potentialy suitable area is 8951 Km², accounting for 8.8% of the entire area of KP. 26.07%% increase from current scenario. Similarly, under moderate scenario by the end of century, overall gain in potential suitable area of *Cedrus deodara* was noticed. The total potential suitable area predicted as 11,024.7 Km², or 10.8% of KP. Hence 55.30 and 23.18% potential suitable area is increased from current and SSP2-4.5(2041-2060) respectively. For extreme scenario by the mid of century, 7,380 Km² predicted as potential suitable area which is 7.25% of KP's total land area, there is a slight rise of 3.8% as compared to current projection. By the end of century under extreme scenario, with the 15.86% increase from SSP5-8.5(2041-2060) and 20.34% increase from current scenario, overall potential suitable area predicted as 8,549.9 Km², or 8.4% of the total land area in KP. Overall, in all scenarios *Cedrus Deodar's* habitat increased and hence it has low risk of extinction (Fig. 4.34).

In current climatic projections, about 2,161.1 Km^2 area is predicted as a potentially suitable area for *Dalbergia sissoo*, which is only 2.1% of KP total area. For SSP2-4.5 (2041-2060) Total potential suitable area predicted as 3414 Km² which is 3.36% of total land area of KP, hence 59.99% increase from current scenario. For SSP2-4.5 (2081-2100) The overall potential suitable area in KP is predicted as 1,473.5 Km², or 1.5% of the total land area. which decreased 56.9 and 31.04% from previous timescale of SSP2-4.5 and current scenario respectively. For SSP5-8.5(2041-2060) increase of 17% in potential suitable area as compare to current climate, predicted potential suitable area for *Dalbergia sissoo* is 2,505 Km², which is 2.5% of KP. For SSP5-8.5(2081-2100) predicted potential suitable area is 1,833.3 Km², or 1.8% of the entire area of KP. it is 26.82 and 14.2% less from SSP5-8.5(2041,2060), current scenario respectively. Overall, in all scenarios *Dalbergia sissoo's* habitat decrease and hence it has high risk of extinction.

In current climatic projections, about 16951.1 Km^2 area is predicted as a potential suitable area for *Juglans regia*, which is only 16.7% of the entire area of KP. For SSP2-4.4 (2041-2060) total potential suitable area for *Juglans regia* predicted as 6,554 Km² which is 6.4% of total land area of KP, hence a decrease of 61.4% as compare to current scenario. For SSP2-4.5 (2081-2100) total potential suitable area predicted as 4,730.9 Km², or 4.6% of the total land area. which decreased 27.9% from previous timescale of SSP2-4.5. For SSP5-8.5(2041-2060) decrease of almost 60% in potential suitable area as compare to current climate, predicted potential suitable area for *Juglans regia* is 6,644.5 Km², which is 6.5% of KP. For SSP5-8.5(2081-2100) predicted potential suitable area for *Juglans regia* is 4,634.2 Km², or 4.5% of the entire area of KP and it is worst amongst all scenarios. Overall, in all scenarios *Juglans regia's* habitat decreased and hence it has high risk of extinction.

In current climatic projections, about 14,699.3 Km^2 area is predicted as a potential suitable area for *Pinus wallichiana*, which is 14.4% of KP total area. For SSP2-4.5 (2041-2060) Total potential suitable area predicted as 1,434.8 Km^2 which is 1.4% of total land area of KP, hence 90.2% decline from current scenario. For SSP2-4.5 (2081-2100) The overall potential suitable area in KP is predicted as 12,577.7Km^2, or 12.3% of the total land area. A significant decrease of 14.4 % from current scenario. For SSP5-8.5(2041-2060) decrease of 75% in potential suitable area as compare to current scenario, predicted potential suitable area for *Pinus wallichiana* is 3,553 Km^2, which is 3.5% of KP. For SSP5-8.5(2081-2100) predicted potential suitable area for *Pinus wallichiana* is 4,229.1 Km^2, or 4.1% of KP, significant decrease of 71% from current scenario. Overall, in all scenarios *Pinus wallichiana's* habitat decreased and hence it has high risk of extinction.

In current climatic projections, about 6,119.3Km^2 area is predicted as a potential suitable area for Eucalyptus, which is 6% of KP total area. For SSP2-4.5 (2041-2060) Total potential suitable area predicted as 9,460.5 Km^2 which is 9.3% of total land area of KP, hence 54% increase from current scenario. For SSP2-4.5 (2081-2100) The overall potential suitable area in KP is predicted as 10,389 Km^2, or 10 % of the total land area. A significant increase of 69% from current scenario. In comparison to the current circumstance, the overall potential suitable area has expanded by around 16.9%. Under SSP5-8.5 (2041-2060), the total potential suitable area is 7,350.1 Km^2 which is 7.22% of KP's total area. For SSP5-8.5(2081-2100) predicted potential suitable area for Eucalyptus is 7,219.5 Km^2, or 7.1% of KP, significant increase of 17.9% from current scenario. Overall, in all scenarios Eucalyptus's habitat increased and hence it has low risk of extinction (Fig. 4.35).

In current climatic projections, about 16,207.7Km^2 area is predicted as a potential suitable area for *Senegalia modesta*, which is 15.9% of KP total area. Estimated potential suitable area for *Senegalia modesta* under SSP2-4.5 (2041-2060) is 24137.3 Km^2 which is 23.7% of total land of KP and which is 49% higher than current scenario. For SSP2-4.5 (2081-2100) The overall potential suitable area in KP is predicted as 7191.6 Km^2, almost 7% of KP and decrease of 70.46 ,55.9% from SSP2-4.5 (2041-2060) and current scenario respectively. Under SSP5-8.5 (2041-2060), the total potential suitable area is 17659.8 Km^2 which is 17.23% of KP's total area, hence 9.11% potential suitable area is increased from current scenario. For SSP5-8.5(2081-2100) predicted potential suitable area for *Senegalia modesta* is 10686Km^2, or 10.7% of KP, significant decrease of 34% from current scenario. Overall, in all scenarios *Senegalia modesta's* habitat decreased and hence it has high risk of extinction.

Under the current scenario, the total potential suitable area for *Populus ciliata* is estimated to be 28,208.7 Km^2, which accounts for over 27.7% of KP's land area. For SSP2-4.5 (2041-2060) Total potential suitable area predicted as 29,990.1Km^2 which is 29.4% of total land area of KP, hence 6.1% increase from current scenario. For SSP2-4.5 (2081-2100) The overall potential suitable area in KP is predicted as 23,137.6Km^2, or 22.7% of the total land area. A significant increase of 17.9% from current scenario. In comparison to the current scenario, the overall potential suitable area has expanded by around 64% under SSP5-8.5 (2041-2060), the total potential suitable area is 46,270 Km^2 which is 45.4% of KP's total area. For SSP5-8.5 (2081-2100) predicted potential suitable area for Eucalyptus is 31,527.2 Km^2, or 31% of KP, significant increase of 11.7% from current scenario. Overall, in all scenarios *Populus ciliata's* habitat increased and hence it has low risk of extinction.

Under the current scenario, the total potential suitable area for *Vachellia nilotica* is estimated to be 24,780.1Km^2, which accounts for over 24.3% of KP's land area. For SSP2-4.5 (2041-2060) Total potential suitable area predicted as 18,776.7Km^2 which is 18.5% of total land area of KP, hence 24.4% decrease from current scenario. For SSP2-4.5 (2081-2100) The overall potential suitable area in KP is predicted as 16,910.4Km^2, or 16.6% of the total land area which is a significant increase of 31.7% from current scenario. In comparison to the current scenario, the overall potential suitable area decreased by around 37.49% under SSP5-8.5 (2041-2060), the total potential suitable area is 15,489.6Km^2 which is 15.2% of KP's total area. For SSP5-8.5 (2081-2100) predicted potential suitable area for *Vachellia nilotica* is 20323.6 Km^2, significant decrease of 19.9% from current scenario. Overall, in all scenarios *Vachellia nilotica* habitat decreased and hence it has high risk of extinction.

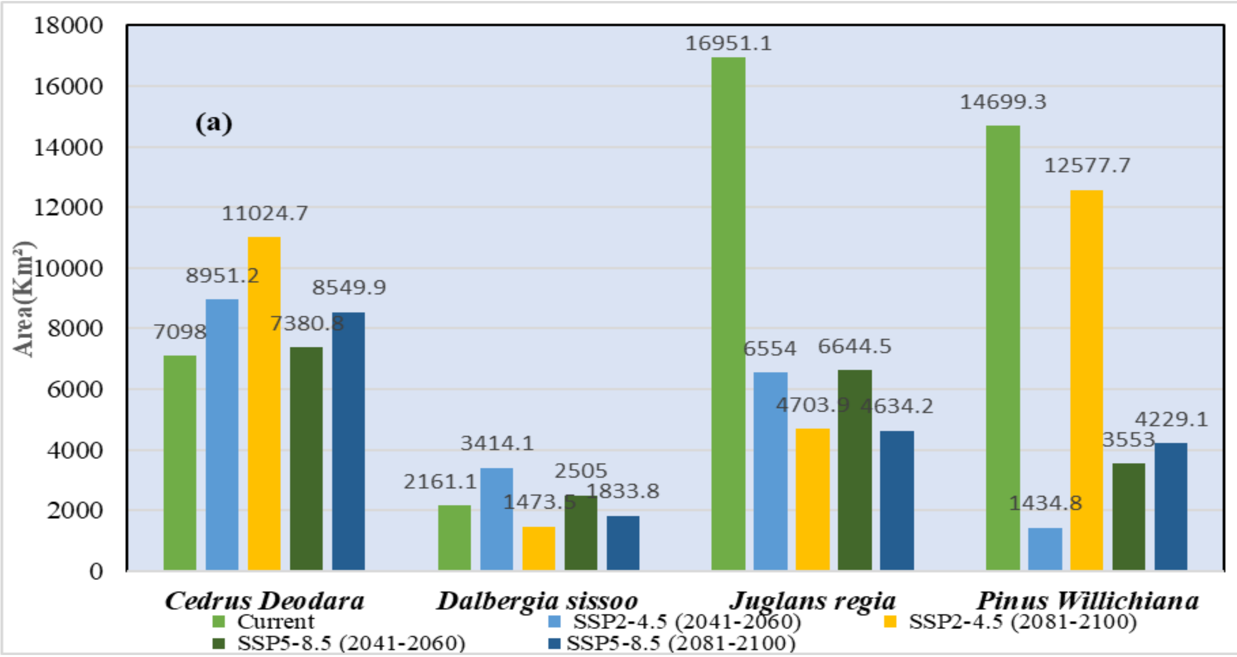

Figure 4.33. Bar plots showing calculated potential suitable area of different species under different climatic Scenario.

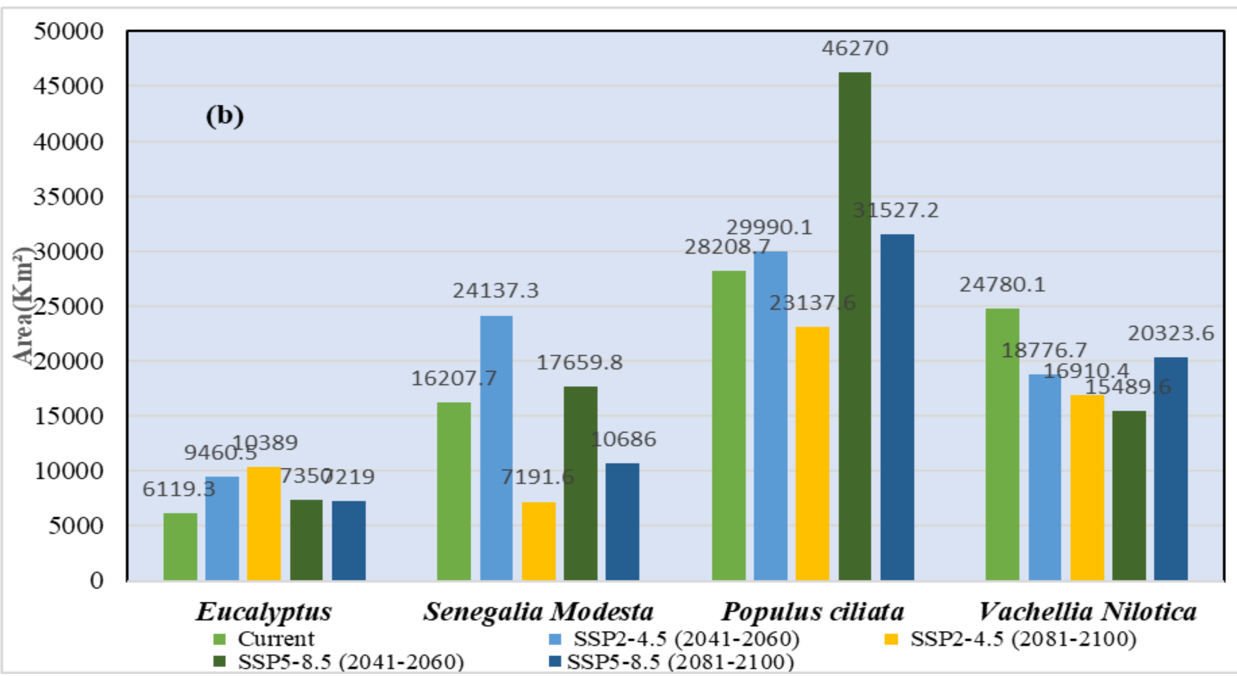

Figure 4.34. Bar plots showing calculated potential suitable area of different species under different climatic Scenario.

Chapter 5

DISCUSSION

5.2 Discussion

Pakistan has been the most active participant in the Bonn Challenge in South Asia. While Pakistan's activities have earned widespread worldwide commendation, minimal attention has been paid to post-plantation care and selection. In 2016, a prolonged dry weather reduced the rate of block planting sustenance in many parts of KP (WWF, 2017). This study aims to determine the suitability of various species utilized in block plantations under current and future climate situations, as well as estimate the stability of afforested areas for these species. The adaption reactions of species to climate change alter their distributions. Each tree species has adapted differently to future climate circumstances for each period, according to our findings. In comparison to the current scenario, *Cedrus deodara*, Pakistan's national tree, exhibited an increase in appropriate area under scenario SSP2-4.5 (2041-2060), and it gained even more under SSP2-4.5 (2041-2060). (2081-2100). Similarly, the potential suitable habitat for *Cedrus deodara* in SSP5-8.5 (2041-2060) improved from its current scenario to SSP5-8.5 (2081-2100). However, all predictions showed an increase in potential suitable area, still the majority of the recent afforested sites were all in non-suitable areas due to a minor shift in potential suitable habitat to the north. Sheikh et al. (2015) projected a slight shift of *Cedrus deodara* onto higher altitudes due to increased temperatures. The *Dalbergia sissoo* tree, often known as the "Shisham" tree, is planted for its high-quality wood. The elimination of Shisham from the subcontinent, on the other hand, is mostly due to poor management tactics, ineffective planning, and illnesses (Mukhtar et al., 2015). The potential suitable area for *Dalbergia sissoo* improved in scenario SSP2-4.5 (2041-2060) compared to the current scenario, but reduced in scenario SSP2-4.5(2081-2100). Likewise, the potential suitable area for *Dalbergia sissoo* improved in SSP5-8.5 (2041-2060) compared to the current condition and reduced in SSP5-8.5 (2041-2060). (2081-2100). In all scenarios, the stability of afforested *Dalbergia sissoo* sites remained critical. *Juglans regia*, often known as Persian walnut, is a rich woody oil plant that is grown all over the globe for its wood and nuts. Our findings demonstrate that eligible regions declined over both potential SSP timelines when compared to the current scenario. Paź-Dyderska et al. (2021) anticipated a decline in appropriate area of *Juglans regia* in Europe for three distinct GCMs, over three different climate projections for (2061-2080), and identified a migration towards northern portions of Europe. As per the data given by the afforestation project in KP, BTAP, *Juglans regia* was afforested on a single site and it was not placed in a highly potential suitable location, as predicted. Under scenario SSP2-4.5 (2041-2060), the potential suitable area for *Pinus wallichiana* is substantially reduced compared to the current situation, although it returns under SSP2-45. (2081-2100). The potential suitable area for *Pinus wallichiana* falls in SSP5-8.5 (2041-2060) scenario but returns in SSP5-8.5 (2041-2060). Another maxent-based research in the Himalaya and Hindu-Kush based on the A2a scenario and GCM, HADCM3, anticipated a high suitability in the current scenario and a significant drop in the future scenario, as well as a migration towards the east (Ali & Begum, 2015). Eucalyptus has been widely planted in BTAP in salty and water-logged areas in KP, primarily in southern areas (WWF, 2017), while our findings imply that potential suitable locations in central KP exist. The potential suitable area for Eucalyptus increased in both SSP2s 4.5 and 8.5, indicating that the species will expand in the future with a little shift eastward. *Senegalia modesta* suitability decreased drastically in (2081-2100) in both SSPs, however it has shown increase in (2041-2060) timescale for both SSPs as compared to current scenario. According to Ali & Begum (2015) research *Senegalia modesta*, also known as *Acacia modesta*, would have a huge potential suitable area in 2080, notably in Swat Valley. Their results are close to our estimates for the (2041-2060) period but disagree with those for the (2081-2100) timescale. Our findings revealed that the most of *Populus ciliata* afforested sites will fall into non-suitable zones. As per our findings, *Vachellia nilotica* has the most suited area under the current scenario and it will decline in the future climate in KP. As per our findings, many afforested *Vachellia nilotica* sites were expected to be in unfavorable environments (Taylor et al., 2018) projected using maxent that elevation, soil, and annual mean temperature are critical variables for *Vachellia nilotica* and that future temperature increases may have detrimental repercussions on the range of *Vachellia nilotica*, especially when winters min-temperatures elevate. These models can be useful in displaying how species respond to restoration efforts (Beatty et al., 2018). Identifying the landscape's potential for plantation has traditionally been one of the most difficult difficulties for non-forest restoration sites. Locating regions within the environment where many functions depending on various parameters can be increased by determining the terrain's suitability for plantation (Schulz &Schroder, 2017). To examine the niche and possible distribution of the species, the SDM is mostly dependent on the species' known distribution and environmental variables. Maxent is a machine-learning technique that provides an iteratively approach to estimate species distributions using maximum entropy methods, in which habitat suitability is forecasted throughout the landscape using the quantities of environmental parameters at established occurrence sites (Raxworthy et al., 2003). The results of the majority of the research that used habitat suitability modelling tools or SDM were used in biodiversity assessments, predicting the effects of climate change on ecology, identifying prospective places for conserving, habitat restoration, and species migration (Araujo et al., 2019). The distribution of tree species is influenced by a variety of biotic and abiotic, such as the environment and competitiveness, and climate change has a significant impact on their regional range. The findings of Lin et al. (2020) study revealed that bioclimatic factors had the biggest impact on tree species distribution as compare to other factors. The most significant element that controls the variety and distribution of plants on the planet is climate on a local scale.

Chapter 6

Conclusion and Recommendations

6.1 Conclusion

A MaxEnt model was used with IPSL-CM6A-LR from CMIP6 GCM IPCC model, to forecast the future appropriate growth area of eight tree species. For this research, SSP2-4.5 (ambitious) and SSP5-85 (realistic) scenarios were utilized to estimate the climate change impact by the middle and end of the twenty-first century (2041- 2060; 2081-2100). Following are the main conclusions:

- Different tree species responded differently to climatic variability, along with migration and expansion
- The current potential suitable growth areas for *Cedrus deodara, Juglans regia, Pinus wallichiana, Populus ciliata* were mainly located in North of KP Pakistan.
- The current potential suitable growth areas for *Senegalia modesta, Vachellia nilotica* were mainly located in South of KP Pakistan and current potential suitable growth areas for Eucalyptus were mainly located in central part of KP, Pakistan.
- Annual Mean Temperature, Mean Temperature of Coldest Quarter, Mean Temperature of Driest Quarter and Elevation are the most important variables in the current climatic condition for *Cedrus deodara* habitat suitability.
- Minimum Temperature of Coldest Month, Mean Temperature of Warmest Quarter and Maximum Temperature of Warmest Month are the most important variables in the current climatic condition for *Dalbergia sissoo* habitat suitability.
- Irrigation, Isothermality, and Precipitation of Warmest Quarter are the most important variables in the current climatic condition for *Julgans regia.*
- Temperature Annual Range, Precipitation of Driest Quarter, and Precipitation of Driest Month are the most important variables in the current climatic condition for *Pinus wallichiana* habitat suitability.
- Irrigation, Precipitation of Warmest Quarter, and Precipitation of Wettest Month are the most important variables in the current climatic condition for Eucalyptus habitat suitability.
- Temperature Seasonality, Elevation, and Irrigation are the most important variables in the current climatic condition for *Senegalia modesta* habitat suitability

- Mean Temperature of Driest Quarter, Perception Seasonality are the most important variables in the current climatic condition for *Populus ciliata* habitat suitability.
- Minimum Temperature of Coldest Month, Mean Temperature of Coldest Quarter are the most important variables in the current climatic condition for *Vachellia nilotica* habitat suitability.

6.2 Recommendations

The key difficulty in the next years will be the selection of tree species for afforestation initiatives, as coexistence between tree species and compliance of tree species with climate changes is not a simple problem to understand using non-spatial methodologies. To minimize budgetary losses and governmental resources, it is critical that scientifical valid research and development institutions, as well as educational institutions are engaged throughout the restoration projects. The findings, in coming years, can help reforestation programs by indicating where these important species might grow in the future, and which afforested sites needs post plantation care for sustenance. Plantations serve an increasingly vital part mostly in restoration of ecological systems, provide ecological commodities, and the improvement of the ecological environment as an integral aspect of terrestrial ecosystems.

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