BAŞKENT UNIVERSITY
INSTITUTE OF SCIENCE
DEPARTMENT OF MOLECULAR BIOLOGY AND GENETICS
MASTER OF SCIENCE IN
MOLECULAR BIOLOGY AND GENETICS

MODELING THE EFFECTS OF GLOBAL CLIMATE CHANGE ON THE DISTRIBUTION OF THE CILICIAN WATER FROG LINEAGE (GENUS: *PELOPHYLAX*) IN THE ÇUKUROVA PLAIN OF TÜRKİYE

BY

İREM GAZEZOĞLU

MASTER OF SCIENCE THESIS

ANKARA- 2025

BAŞKENT UNIVERSITY
INSTITUTE OF SCIENCE
DEPARTMENT OF MOLECULAR BIOLOGY AND GENETICS
MASTER OF SCIENCE IN
MOLECULAR BIOLOGY AND GENETICS

MODELING THE EFFECTS OF GLOBAL CLIMATE CHANGE ON THE DISTRIBUTION OF THE CILICIAN WATER FROG LINEAGE (GENUS: *PELOPHYLAX*) IN THE ÇUKUROVA PLAIN OF TÜRKİYE

BY

İREM GAZEZOĞLU

ADVISOR

ASSIST. PROF. DR. ÇİĞDEM AKIN PEKŞEN

CO-ADVISOR

DR. BANU KAYA ÖZDEMİREL

MASTER OF SCIENCE THESIS

ANKARA- 2025

BAŞKENT UNIVERSITY
INSTITUTE OF SCIENCE

This study, which was prepared by İrem Gazezoğlu, for the program of Master of Science with Thesis (English), has been approved in partial fulfillment of the requirements for the degree of Master of Science in Molecular Biology and Genetics Department by the following committee.

Date of Thesis Defense: 18/08/2025

Thesis Title: Modeling the Effects of Global Climate Change on the Distribution of the Cilician Water Frog Lineage (Genus: *Pelophylax*) in the Çukurova Plain of Türkiye

Examining Committee Members		**Signature**
Prof. Dr. Utku PERKTAŞ	Hacettepe University	**………………...**
Asst. Prof. Dr. Çiğdem AKIN PEKŞEN	Baskent University	**………………...**
Dr. Alper ERTÜRK	Kastamonu University	**………………...**

APPROVAL

Prof. Dr. Dilek ÇÖKELİLER SERDAROĞLU
Director, Institute of Science
Date: … / … / ……….

BAŞKENT ÜNİVERSİTESİ
INSTITUTE OF SCIENCE
YÜKSEK LİSANS / DOKTORA TEZ ÇALIŞMASI ORİJİNALLİK RAPORU

Tarih: 23/08/2025

Öğrencinin Adı, Soyadı: İrem GAZEZOĞLU

Öğrencinin Numarası: 22210301

Anabilim Dalı: Moleküler Biyoloji ve Genetik Anabilim Dalı

Programı: Moleküler Biyoloji ve Genetik Tezli Yüksek Lisans (İngilizce)

Danışmanın Unvanı/Adı, Soyadı: Assist. Prof. Dr. Çiğdem AKIN PEKŞEN

Tez Başlığı: Modeling the Effects of Global Climate Change on the Distribution of the Cilician Water Frog Lineage (Genus: *Pelophylax*) in the Çukurova Plain of Türkiye

Yukarıda başlığı belirtilen Yüksek Lisans/Doktora tez çalışmamın; Giriş, Ana Bölümler ve Sonuç Bölümünden oluşan, toplam 67 sayfalık kısmına ilişkin, 23/08/2025 tarihinde şahsım/tez danışmanım tarafından Turnitin adlı intihal tespit programından aşağıda belirtilen filtrelemeler uygulanarak alınmış olan orijinallik raporuna göre, tezimin benzerlik oranı %5'dir. Uygulanan filtrelemeler:

1. Kaynakça hariç

2. Alıntılar hariç

3. Beş (5) kelimeden daha az örtüşme içeren metin kısımları hariç

"Başkent Üniversitesi Enstitüleri Tez Çalışması Orijinallik Raporu Alınması ve Kullanılması Usul ve Esaslarını" inceledim ve bu uygulama esaslarında belirtilen azami benzerlik oranlarına tez çalışmamın herhangi bir intihal içermediğini; aksinin tespit edileceği muhtemel durumda doğabilecek her türlü hukuki sorumluluğu kabul ettiğimi ve yukarıda vermiş olduğum bilgilerin doğru olduğunu beyan ederim.

Öğrenci İmzası:………………….

ONAY
Tarih: … / … / 20…..

Öğrenci Danışmanı:

Assist. Prof. Dr. Çiğdem AKIN PEKŞEN

………………………………………

ACKNOWLEDGMENT

The completion of this thesis would not have been possible without the support, guidance, and encouragement of many individuals. My profound appreciation goes to my advisor, Assist. Prof. Çiğdem Akın Pekşen, for her exceptional mentorship. Her guidance and expertise were the foundational of this research. Her patient tutelage was a constant source of motivation.

I am equally indebted to my co-advisor, Dr. Banu Kaya Özdemirel. Her role in my thesis journey was indispensable, particularly for her dedicated instruction in the use of the necessary programs and technical skills.

To my dear friends, Nazlıcan Yılmaz, Büşra Nur Karakaya, Yasin Okyay, Zeynep Emiroğlu, Ozan Egemen Kayacı, Yeşim Aycan Erten, Yağmur Nisa İmamoğlu, Simay Bade Gürses, Zeynep Ebrar Gezici and Furkan İmamoğlu, thank you for your unwavering support and friendship. You provided me with the much needed moments of laughter, distraction, fun, and perspectives that helped me a lot with this thesis.

Lastly, this work is dedicated to my family; my mother Ülker Gazezoğlu, my father İsmail Koray Gazezoğlu, and the cherished memory of our late cat of over twenty years, Kömür. His gentle presence and unconditional love filled my life with a warmth that made every day more beautiful. He was a lovely companion throughout this entire process, and his memory will continue to be a source of a lifetime inspiration.

ABSTRACT

İrem GAZEZOĞLU

MODELING THE EFFECTS OF GLOBAL CLIMATE CHANGE ON THE DISTRIBUTION OF THE CILICIAN WATER FROG LINEAGE (GENUS: *PELOPHYLAX*) IN THE ÇUKUROVA PLAIN OF TURKIYE

Başkent University Institute of Science
Department of Molecular Biology and Genetics

2025

This study investigates the impact of global climate change on the distribution of the Cilician water frog lineage (genus: *Pelophylax*) in the Çukurova Plain of Türkiye. Using advanced species distribution modeling (SDM) techniques, particularly MaxEnt, the research identifies key environmental factors influencing the current habitat suitability of the lineage and predicts future habitat shifts under different climate change scenarios (low and high carbon emissions) for the years 2030, 2050, 2080, and 2100. Results indicate that temperature seasonality, minimum temperature of the cold quarter, ruggedness, and proximity to water bodies are critical determinants of the lineage's distribution. Projections reveal a significant northward shift in suitable habitats, accompanied by fragmentation and potential loss of core southern habitats. While the total climatically suitable area may expand, habitat connectivity and anthropogenic pressures pose challenges to the lineage's survival. This study underscores the urgent need for conservation strategies to mitigate climate change impacts, protect critical habitats, and ensure the long-term survival of this vulnerable amphibian lineage.

KEYWORDS: Climate change, modeling, water frog, Cilician lineage, *Pelophylax*.

ÖZET

İrem GAZEZOĞLU
KÜRESEL İKLİM DEĞİŞİKLİĞİNİN KİLİKYA SU KURBAĞASI SOYUNUN (CİNS: *PELOPHYLAX*) TÜRKİYE'NİN ÇUKUROVA BÖLGESİNDEKİ DAĞILIMI ÜZERİNE ETKİLERİNİN MODELLENMESİ
Başkent Üniversitesi Fen Bilimleri Enstitüsü
Moleküler Biyoloji ve Genetik Anabilim Dalı
2025

Bu çalışma, küresel iklim değişikliğinin Türkiye'nin Çukurova Ovası'ndaki Kilikya su kurbağası soyu (cins: *Pelophylax*) üzerindeki etkilerini araştırmaktadır. İleri düzey tür dağılım modelleme (SDM) teknikleri, özellikle MaxEnt kullanılarak, soyun mevcut habitat uygunluğunu etkileyen temel çevresel faktörler belirlenmiş ve 2030, 2050, 2080 ve 2100 yılları için farklı iklim değişikliği senaryoları (düşük ve yüksek karbon salınımı) altında gelecekteki habitat değişimleri tahmin edilmiştir. Sonuçlar, sıcaklık mevsimselliği, soğuk çeyrek minimum sıcaklığı, arazi engebeliliği ve su kaynaklarına yakınlığın soyun dağılımını belirleyen kritik faktörler olduğunu göstermektedir. Projeksiyonlar, uygun habitatların kuzeye doğru önemli bir kayma yaşadığını, bununla birlikte güneydeki çekirdek habitatların parçalanması ve kaybı riskini ortaya koymaktadır. İklim açısından uygun toplam alan genişleyebilirken, habitat bağlantısı ve insan kaynaklı baskılar soyun hayatta kalması için zorluklar oluşturmaktadır. Bu çalışma, iklim değişikliği etkilerini hafifletmek, kritik habitatları korumak ve bu hassas amfibi soyunun uzun vadeli hayatta kalmasını sağlamak için acil koruma stratejilerinin gerekliliğini vurgulamaktadır.

ANAHTAR KELİMELER: İklim değişikliği, modelleme, su kurbağası, Kilikya soyu, *Pelophylax*.

TABLE OF CONTENTS

ACKNOWLEDGMENT i

ABSTRACT ii

ÖZET iii

TABLE OF CONTENTS iv

1. INTRODUCTION 1

2. LITERATURE 3

- **2.1. The Escalating Threat of Climate Change and Its Devastating Consequences 3**
- **2.2. A Call to Action: Sustainable Solutions for A Brighter Future 6**
- **2.3. Modeling As a Tool for the Prediction and Evaluation of species 9**
  - **2.3.1. Historical Context and Evolution Of SDM 10**
  - **2.3.2. Advancements In Ecological Theory and Quantitative Methods 12**
- **2.4. The Significance of the Çukurova Plain as a Center for Biodiversity in Türkiye 16**
- **2.5. The Anatolian Water Frog Complex (Genus *Pelophylax*): A Model Group Under Threat 17**
- **2.6. Purpose 19**

3. MATERIAL AND METHODS 20

- **3.1. Study Area 20**
  - **3.1.1. Buffered Study Area 20**
- **3.2. Data Acquisition and Preparation 21**
  - **3.2.1. Species Occurrence 22**
  - **3.2.2. Environmental Predictor Data 23**
  - **3.2.3. Data Pre-processing using GIS 26**
- **3.3. Data Processing, Integration and Model Development 27**
  - **3.3.1. Model Optimization and Validation 27**
  - **3.3.2. Evaluation Of the Model and Performance Metrics 33**
- **3.3.3. Mapping Potential Species Distribution 35**

4. RESULTS 37

- **4.1. Optimized Model Outputs and Performance Metrics 37**
- **4.2 Key Environmental Variables and Their Influence on Target Lineage 39**
- **4.3. Predicted Habitat Suitability and Current Distribution 44**
- **4.4. Projected Future Habitat Suitability and Distribution under Climate Change Scenarios 47**
  - **4.4.1 Projections for 2030 .... 47**

4.4.2 Projections for 2050 49
4.4.3 Projections for 2080 50
4.4.4 Projections for 2100 52
4.5 Projected Distribution Area Changes 54
5. DISCUSSIONS 57
5.1. Model Performance and Optimization Success 57
5.2. Key Environmental Drivers of Habitat Suitability 58
5.3. Current Distribution and Habitat Suitability of the Cilician Water Frog Lineage 60
5.4. Projected Habitat Shifts and Ecological Implications of Climate Change 61
6. CONCLUSIONS 65
REFERENCES 68

LIST OF TABLES

Page

Tablo 3.2.2.1. List of environmental predictors and sources..25

Table 4.2.1. Optimized model variable importance permutation......................................41

LIST OF FIGURES

Page
Figure 3.1.1. Study area. Created with ArcGIS..20

Figure 3.2.1. Cilician lineage occurrence records. Created with ArcGIS........................23

Figure 3.3.1.1. Model optimization flowchart. Created with ArcGIS...............................32

Figure 4.1.1. Spearman's coefficient results. Created with Rstudio................................37

Figure 4.1.2. Initial ROC curve. Created with Rstudio...38

Figure 4.1.3. Optimized ROC curve. Created with Rstudio..39

Figure 4.2.1. The variable importance values. Created with Rstudio...............................40

Figure 4.2.2. The Jackknife test results. Created with Rstudio..42

Figure 4.2.3. Response curves. Created with Rstudio..44

Figure 4.3.1. Current binary habitat suitability maps. Created with ArcGIS....................46

Figure 4.4.1.1. 2030 Cilician lineage distribution and potential habitat suitability models. Created with ArcGIS...48

Figure 4.4.2.1. 2050 Cilician lineage distribution and potential habitat suitability models. Created with ArcGIS...50

Figure 4.4.3.1. 2080 Cilician lineage distribution and potential habitat suitability models. Created with ArcGIS...52

Figure 4.4.4.1. 2100 Cilician lineage distribution and potential habitat suitability models. Created with ArcGIS...54

Figure 4.5.1. Cilician lineage occurrence records. Created with ArcGIS.........................56

LIST OF SYMBOLS AND ABBREVIATIONS

(cr[pe])	Critically endangered or possibly extinct
AI	Artificial intelligence
AUC	Area under curve
BAM	Biotic-Abiotic-Movement
CNNs	Convolutional neural networks
DEM	Digital elevation models
GAMs	Generalized additive models
GARP	Genetic algorithm for rule-set production
GCMs	Global climate models
GIS	Geographic information systems
GLMs	Generalized linear models
HSM	Habitat suitability modeling
JK	Jackknife
MaxEnt	Maximum entropy
MESS	Multivariate environmental similarity surfaces
MSS/MTP	Maximum training sensitivity plus specificity
PO	Presence only
SDM	Species distribution modeling
SRTM	Shuttle radar topography mission
SWD	Sample with data
UAVs	Unmanned aerial vehicles
WGS	World geodeltic system

1. INTRODUCTION

Anatolia recognized for its rich biodiversity, represents a significant portion of Türkiye's natural heritage [1], [2]. Nonetheless, the escalating climate crisis poses a major threat to it. The United Nations has underscored the gravity of this situation, citing rising atmospheric greenhouse gas concentrations, unprecedented sea levels, and increasing ocean heat content [3]. These changes have resulted in marine heatwaves impacting approximately 33% of the world's oceans on average weekdays in 2023 with over 90% experiencing heatwave conditions at various points throughout the year. That same year marked the highest level of ice loss recorded since 1950, particularly in western North America and Europe, while the Antarctic Sea ice extent reached a historic minimum [3].

In Türkiye, the repercussions of climate change are apparent in the drying of 186 out of 240 lakes over the past sixty years. Such numbers constitute over half of the country's total lake system [4]. The trend is intensified by pollution and long droughts. As a result, there is significant oxygen depletion in the water, which leads to the death of aquatic life [5]. The Mediterranean region, including Türkiye, is undergoing substantial transitions in its unique climate, characterized by alterations in seasonal patterns and complex interactions among temperature, precipitation, and humidity [2], [6]. These changes notably affect Türkiye's natural ecosystems, exacerbating the challenges faced by species that are already struggling to adapt to the rapidly changing environment [6].

Amphibian species, in particular, are highly susceptible to these environmental changes. Multiple comprehensive reports highlight the critical amphibian extinction crisis, with near half of the amphibian species currently facing extinction threats worldwide [7]. Habitat loss, intensified by the effects of climate change, serves as the primary driver behind the decline of amphibian populations particularly in Anatolia [1], [8]. Previous research has demonstrated considerable genetic diversity and significant evolutionary divergence among the populations of Anatolian water frogs (genus: *Pelophylax*), shaped by geological events and climatic variations [9]. As it will all be discussed in detail at following sections, factors such as industrial activities by urbanization, unregulated agricultural irrigation, and overharvesting of Anatolian water frogs have further exacerbated these challenges, pushing populations toward the brink of collapse [1], [8].

The Çukurova Plain at Southeastern and Mediterranean, a vital coastal plain in Türkiye that spans across multiple cities and supports many of these amphibian species, is characterized by diverse habitats that sustain its rich biodiversity, including critical hotspots within the Seyhan and Ceyhan River basins [10], [11], [12]. The lowest temperature in the region is observed in January, while the highest temperatures are observed in August. In addition, the average rainfall is between 562 mm and 1216 mm [13], [14].

However, these habitats are under continuous threat from human activities and are at risk of significant degradation [15]. Tanrıverdi et al. [11] underlines the importance of Ceyhan River, having once faced threats of water pollution caused by human activities, due to its importance to local population, should be monitored. The richness of the Eastern Mediterranean region in terms of available resources also makes the region popular. With the increase in population as a result of human activities, the risk of drier and hotter summers is expected, and key temperature increases are expected in 2030, 2050 and the end of the century, respectively [10], [16]. And as evident in Fujihara's publication regarding Seyhan and climate change in particular [10], these negative changes in the region have been happening for a long time by now, climate change affecting Seyhan's water and implying it would be greatly reduced over time, which is recently supported by other water areas, such as lake bed's, drying up in great numbers throughout years within Anatolia [4]. The Anatolian water frogs, distinguished by their unique traits, represent valuable model organisms for investigating the impacts of these climate changes both on amphibian distributions and wetlands, are also present within that region and hotspots [17].

Consequently, the objective of this thesis is to delineate the current distribution of the Cilician lineage of the Anatolian water frog, which has been inadequately studied yet is prevalent in southeastern and Mediterranean Anatolia. The research identifies the key environmental factors influencing this lineage's distribution. By using modeling techniques that incorporate maximum entropy with tailored, optimized parameters, the study aims to predict the potential impacts of climate change on these species' habitats by the years 2030, 2050, 2080, and 2100. Ultimately, this research hopes to guide conservation strategies that protect these important amphibians and their ecosystems. This is essential not only for them but also for other taxa, inhabit Anatolia and Türkiye, highlighting the need for more conservation efforts.

2. LITERATURE

2.1. The Escalating Threat of Climate Change and Its Devastating Consequences

The growing climate crisis is a significant threat to global biodiversity, and Türkiye is facing its impacts. The United Nations has shared strong evidence highlighting the seriousness of this ongoing crisis. A report released at the UN's climate change conference in Geneva in March 2024 noted a marked increase in greenhouse gas levels in the atmosphere, alongside unprecedented rises in sea levels and ocean heat content. The report also indicated that on an average weekday in 2023, marine heatwaves impacted about 33% of the world's oceans, which are known to be very harmful to ecosystems and food security. By the end of that year, it was evident that more than 90% of the world's oceans had experienced heatwave conditions at some point, showing the widespread and ongoing nature of these events. Moreover, primary data collected from glaciers worldwide showed that 2023 experienced the most substantial ice loss since 1950, driven by intense melting patterns in regions such as western North America and Europe. Adding to the concerning situation, the Antarctic Sea ice extent reached an unprecedented historic low, with its winter maximum in 2023 measuring 1 million square kilometres less than the previous record. It is important to note that this combined area is approximately equivalent to the sizes of France and Germany combined, as outlined in WMO Report No. 1347 [3].

The crisis intensified further in 2024, as record breaking temperatures and prolonged heatwaves dominated global weather patterns. The planet has seen a significant temperature increase as a result of these alarming trends. This rise has already pushed global temperatures past the critical 1.5°C threshold of the Paris Agreement, a limit set to prevent the most severe effects of climate change [18], [19]. The rising global temperature has several connected effects, including higher temperatures, less rain, and more frequent and severe natural disasters. We are witnessing floods, wildfires, and extreme heat events become more common, which increases the vulnerability of critical ecosystems like wetlands. These wetlands, which serve as important habitats for amphibians and other species, are especially at risk from the impacts of climate change. As rainfall decreases and temperatures rise, these ecosystems are shrinking significantly. This shrinkage results in the loss of breeding grounds, reduced food sources, and increased risks of predation for amphibians [20].

A stark and concerning example of wetland loss in Türkiye is the drying of 186 out of 240 lakes over the last sixty years. This accounts for an astonishing 77.5% of the country's total lake system. The ongoing crisis of global warming is a major factor in worsening this environmental problem. The situation could get worse unless effective actions are taken soon. According to Dr. Erol Kesici, a Scientific Advisor at the Association for the Protection of Turkish Nature (TTKD), as of September 2024, there is not a single lake in Anatolia that can be considered ecologically healthy. Many of the remaining lakes face severe threats, including pollution and the imminent risk of drying up due to prolonged drought conditions. Dr. Kesici points to key issues impacting these water bodies, namely, critically low water levels, reduced surface areas, and significant pollution levels [4]. These factors result in oxygen depletion, which can reach sometimes levels insufficient to sustain aquatic life. Even if these dried lakebeds were to be refilled with water, the damage to their ecosystems would often be irreversible, as the loss of plant and animal species disrupts the balance of ecological cycles, prompting species to migrate or go extinct [5].

Türkiye is well-known among researchers and conservationists for its remarkable biodiversity and various habitats. However, it is now facing serious challenges that threaten its natural heritage. Climate change plays a major role in this situation, affecting Türkiye’s ecosystems and species. As global warming continues to worsen, it is expected that Türkiye will see major changes in species locations, leading to significant shifts in ecological dynamics. The biodiversity loss that already exists and continues in the country will likely be exacerbated over time due to these changes. Moreover, if combined with the serious losses that are already ongoing, this will lead to serious decline in biodiversity and environmental damage. The widespread impact of these changes threatens not only species, but also the fragile balance of ecosystems that support biodiversity [2], [3], [4], [5], [6], [20], [21]. The climate in the Mediterranean region is undergoing serious changes. Among these changes, a shift in seasons has been observed. In addition, there are also complicated interactions between temperature, precipitation, and humidity. All of this has a serious impact on Türkiye's natural systems. On top of that, it puts even more difficulty in species that are already struggling to adapt to their rapidly changing environment. As global temperatures rise, precipitation levels also fall. Naturally, extreme weather is also becoming more frequent and serious. As a result, the pressure on Türkiye’s economic systems continues to increase. Consequently, conservationists are highlighting the urgent need for coordinated action to address these problems and protect the rich biodiversity that Türkiye is renowned for [2], [6], [22].

Many climate-related changes, as well as rising temperatures and changing rainfall cycles, put ecosystems at risk of total destruction. The rate of drying of wetlands in Türkiye due to increasing evaporation and decreasing rainfall is also a great alarm. As water levels decrease, lake systems struggle to cope with the pollution that occurs. This, together with the decline in fish populations, the spread of invasive species and fast-growing aquatic plants, causes more ecological problems and accelerates the drying process. All this situation draws great attention to the importance of sustainable management strategies [21], [23], [24].

Amphibians have long been considered the most at-risk vertebrates. In the context of climate change, it is indisputable that they are even more sensitive and fragile. Re; A comprehensive report by wild, Synchronicity Earth, and the IUCN SSC Amphibian Specialist Groups also emphasizes the risk of extinction of amphibians. Currently, 40% of amphibian species are at risk of extinction. Moreover, there has also been an acceleration in the rate of mass extinction trajectory of amphibians in recent decades. To elaborate on this, 23 amphibian species were documented as extinct by 1980. Then, by 2004, 10 more species had disappeared, and by 2022, 4 more species were lost. All in all, there are 37 known species extinctions. Alarmingly, the number of Critically Endangered or Possibly Extinct (CR[PE]) species has risen sharply from 24 in 1980 to 162 in 2004. By 2022, 23 more species were further identified. If all CR(PE) species turn out to be extinct, the total number of known amphibian extinctions could reach 222 over the past 150 years [7]. Habitat loss is the reason that puts amphibian populations at risk the most in Anatolia and causes them to decrease. And climate change is exacerbating this habitat loss. As if that weren't enough, industrial activities, uncontrolled agricultural irrigation, and uncontrolled overharvesting of Anatolian water frogs make the battle for survival terrifying for this species. So much so that their populations came close to the brink of collapse A study by the Cambridge University Press draws attention to the decline of species in the Ceyhan and Seyhan deltas. It is estimated that in the period from 2013 to 2015, the Anatolian water frog population experienced a 20% decline every year [1], [7].

The Mediterranean region, especially Adana, is a key focal point as climate change affects the local climate conditions to the extent of reshaping them there. The region's unique Mediterranean climate is being disrupted by growing water scarcity, decreasing rainfall levels and rising temperatures. The Mediterranean climate, which is normally defined by seasonal changes in temperature, precipitation and humidity, is becoming more and more unpredictable. Recent studies regarding Adana region have documented some of the impacts of global climate change there. These are significant temperature increases between the summer zone and mid-autumn, as well as decreases in average temperatures in winter. Although earlier reports observed no significant alterations in precipitation patterns, subsequent data has indicated a marked decline in rainfall, particularly in Yumurtalık during October and in the Karataş and Kozan districts. Conversely, Tufanbeyli experienced a substantial increase in rainfall levels during August. Furthermore, fluctuations in humidity levels have been observed, with a decline recorded in Yumurtalık, Ceyhan, and Karataş. However, it has been demonstrated that urbanization and lifestyle changes have contributed to overall increases in relative humidity during all seasons except summer [25]. For the period between 2020 and 2050, projections indicate a temperature increase of 0.5°C to 4.0°C. The change will be accompanied by significant reductions in precipitation, especially in western and southern Türkiye, where the Mediterranean climate is most common [26].

2.2. A Call to Action: Sustainable Solutions for A Brighter Future

Given the adverse effects of climate change on amphibians, particularly those endemic to limited geographic regions, concerted action is imperative to ensure their survival. It is essential to preserve Türkiye's natural heritage in a long-lasting way. To do this, it is necessary to have a thorough understanding of the relationship between geography, climate and amphibian diversity. The employment of evidence-based, sustainable management and conservation strategies is also very important to protect this noteworthy tapestry of life for future generations. One climate action that The WMO Report No. 1347 [3] focuses on is renewable energy. Especially solar energy, wind turbines and the water cycle. This method is also seen as useful because it supports the achievement of decarbonization goals. The report cites significant increases in renewable energy capacity by as much as 50% in 2023 compared to 2022. That's 510 gigawatts, the highest rate seen in past twenty years [3].

The biggest impact of climate change on these frogs is the hydrological changes in the Lakes District. Since the 1980s, changes in temperature and precipitation have led to drastic declines in lake water levels. This decrease in water has naturally disrupted the frogs' important breeding grounds and foraging habitats [27]. Such environmental transformations have a severe impact on species such as *P. caralitanus*, as well as other Anatolian water frog lineages [2], [27]. What's more, local communities are economically dependent on frog harvesting, an activity that has been going on for more than 40 years. Türkiye exports almost 700 tons of frogs annually, mainly to the European Union, and makes significant contributions to Türkiye’s economy. Unfortunately, this trade resulted in an overharvest of frogs. Only 19% of the frogs caught meet the minimum weight requirements. If these practices continue, the model estimates that there is a 90% risk of some populations going extinct in the next 50 years. In fact, for some groups, extinction is at risk as early as 2032. This, of course, requires urgent conservation measures. For example, harvesting during the mating season could be banned, stricter export rules could be introduced, and sustainable harvesting methods could be adopted. These are very important because they not only guarantee the survival of frog populations but also ensure that the people who earn their income from this trade are not harmed [1]. In addition to overharvesting, the survival of native *Pelophylax* species in Türkiye is threatened by another significant challenge, which is the presence of amphibian pathogens, including the chytrid fungus *Batrachochytrium dendrobatidis* (Bd) and *Ranavirus* [28], [29]. These pathogens have been widely recognised as critical drivers of global amphibian population declines [28]. A major threat from Bd to biodiversity comes from chytridiomycosis, the deadly disease it causes. The disease has been linked to severe declines and extinctions of amphibian populations around the world. Because of this, it is considered one of the most significant infectious diseases in the animal kingdom. Bd infects the keratinized layers of amphibian skin, according to what has been observed. For amphibians, their skin is a critical organ because it performs key functions such as respiration, hydration, and osmoregulation. The physiological problems caused by this fungal infection usually result in lethargy and loss of reflexes and ultimately lead to death. Tadpoles are also not safe, having a risk of contracting this fungus. The disease primarily targets their keratinized mouthparts, causing them to lose color and suffer from developmental problems that seriously hurt their ability to eat and grow. The combination of overharvesting and habitat degradation has been demonstrated to have a detrimental effect on the subject in question [1], [8], [27], [30], [31].

While mortality rates depend on the level of exposure, infected amphibians often die within weeks, with adult life stages being the most affected. Conversely, whereas larvae can act as carriers. Bd. exhibits optimal growth condition thrives in moist and cool environments, thus rendering aquatic and semi-aquatic amphibians particularly vulnerable. The organism easily spreads through aquatic environments and among amphibian movements. Furthermore, there is a possibility that it may be transmitted via various carriers, including birds, humans, and insects. The rapid propagation of the disease, coupled with its high mortality rates, has led to the attribution of the term "biodiversity killer" to Bd. This term is a consequence of the observation that certain species have undergone precipitous declines over brief periods [28], [30]. In Türkiye, the presence of the Bd pathogen, has been conclusively identified in numerous amphibian populations, including the one of two endemic anuran species: Beyşehir frog (*Pelophylax caralitanus*) [28], [29]. Studies conducted on the populations of *Pelophylax ridibundus*, *Pelophylax bedriagae*, and *Pelophylax caralitanus* populations reveals a high prevalence of infection. For instance, of the 198 *Pelophylax caralitanus* individuals sampled, 72 tested positive for Bd, which highlights the fragile state of these populations. This data underscores the urgent need for comprehensive conservation strategies. These strategies must address pathogenic threats as well as the unsustainable harvesting practices that make the species more vulnerable. The combined pressure of disease and overexploitation creates a complex conservation challenge, which endangers the long-term viability of these species and the ecosystems they inhabit [32].

Prevalence rates for this pathogen are alarmingly high, reaching up to 32% at critical amphibian breeding sites, especially within the Lakes District. This concerning data highlights the urgent need to preserve amphibian populations. Amphibian species that live in specialized and highly sensitive ecological niches are clearly very vulnerable to the damaging effects of this disease. A prime example is the marsh frog (*Pelophylax ridibundus*). The far reaching consequences of chytridiomycosis extend well beyond individual amphibian species, as their decline causes significant disruptions to ecosystem functions, food web structures, predator - prey relationships, and overall ecological balance [33]. Furthermore, amphibians serve as crucial bioindicators of environmental health, and their population declines often signal broader ecological crises. Effective conservation plans need to focus on three key areas: protecting habitats, putting strict biosecurity measures in place to stop the spread of Bd, and creating antifungal treatments to help the most vulnerable populations recover. Without coordinated and immediate interventions to address issues such as habitat destruction, climate change, pollution, and other exacerbating factors, the future of amphibian populations is precarious and uncertain [7], [29]. Preserving these species is extremely important for both their survival and the maintenance of ecological equilibrium [1], [17], [28].

Anatolian water frogs are confronted with a multitude of threats that jeopardise their survival, extending beyond the risk of fungal infections. The causes of the destruction and fragmentation of essential wetlands, lakes, and other aquatic habitats include habitat loss, urbanization, the expansion of farming, and infrastructure growth [34]. Pollution caused by industrial waste, agricultural runoff and pesticides further contaminates water resources, and as a result, these habitats are becoming increasingly unsuitable for breeding and foraging [35], [36]

Taken collectively, these interconnected challenges show one thing. That being the urgent need for the urgent implementation of comprehensive and well-coordinated conservation strategies to address the various threats that endanger Anatolian water frogs. Addressing these issues is essential to ensure that these unique amphibians continue to survive. Their presence is also highly essential to maintain ecological balance in the wider ecosystems that rely on them. For conservation to be managed effectively, a deep understanding of taxonomic groups is essential. All this must be combined with an appreciation of the geographical and environmental factors that affect their habitat. Despite the significant presence of vertebrate conservation projects in Türkiye, the threats facing anuran species are still particularly serious. This poses a significant risk to their population [29].

2.3. Modeling As a Tool for the Prediction and Evaluation of species

Habitat Suitability Modeling (HSM) is a method used to predict in which specific geographic area a species is most likely to be found. HSM makes it possible to understand ecological relationships in an easy, convenient and cost-effective way, and also helps to predict how environmental factors will affect natural habitats in current and future conditions [37], [38]. Species Distribution Modeling (SDM), which will be mentioned many times in this thesis, is a powerful tool that falls under HSM. With SDM, it can visualize species distributions and their relationships with both living and non-living environments. In this way, important insights about conservation planning and management can be gained. It is especially useful when it comes to climate change and the challenges it brings [37], [39], [40], [41].

One of the most important advantages of SDMs is that fine-tuning can achieve the optimal balance between generality and accuracy. These Regularization settings are also possible thanks to the settings provided by Maximum Entropy (Maxent) modeling. By assigning these settings to a value that is two to four higher than the default, the robustness of the model is greatly strengthened, and overfitting is significantly reduced. This is especially important when applying a model to new environments or independent datasets [42]. Maxent modeling is particularly valuable because it uses presence-only data. This is important in areas where detailed absence data is not easy to find. And with this flexibility, researchers can capture the ecological complexities of species distributions, while at the same time achieving a high level of prediction accuracy [43], [44].

The integration of new techniques, such as masked geo-partitions, has led to an increase in the reliability of SDMs. While these validation methods are spatially explicit, they also consider natural geographical, and environmental differences in species distribution. In this approach, it reduces bias and increases the accuracy of the predictions on the species' range. At the same time, it can facilitate the inclusion of local and regional situations. As a result, predictions become more realistic. This allows them to be applied to multiple, different and various situations. For species with fragmented habitats or limited space to disperse, these validation methods are extra important for the impact of environmental changes being assessed [43], [44].

For example, its role in diverse areas such as conservation biology, wildlife management and environmental policymaking is very important. It is also possible to identify the places where species survive, and to determine which habitats are in need of protection. The tool also highlights in which regions species are most at risk of habitat loss, as well as other pressures, such as climate change [37], [38]. SDMs have become an essential tool for addressing the multifaceted challenges posed by global environmental change. The primary function of these models is to predict where species currently live. However, it is also important to recognize that they help predict possible changes in species ranges in future climate scenarios. The capacity to predict is of crucial importance in the identification of areas of biodiversity loss, the location of climate refugia, and the provision of information for the development of adaptive management strategies that respond to changing environmental conditions [37], [42], [44], [45].

2.3.1. Historical context and evolution of SDM

The groundwork for modern SDM was established in the mid-19th century by the zoologist Andrew Murray. His 1866 publication *The Geographical Dispersal of Mammals* laid the groundwork for future ecological research by exploring the influence of environmental factors on mammalian distribution [46]. At the same time, botanist A.F.W. Schimper was investigating the complex relationship between geography and environmental factors and how they shape the places where plants grow. His key publication, *Pflanzengeographie auf physiologischer Grundlage* (Plant Geography on a Physiological Basis), came out in 1898 and was later translated to English in 1908. In it, he argued that environmental variables play a crucial role in determining where species are found. This work was a powerful confirmation of just how important ecological factors are to the field of biogeography [47]. During the early to mid-20th century, important advances in ecology and biostatistics helped the fast growth of the field. Descriptive methods for mapping species' occurrences changed into more quantitative techniques with the introduction of Generalized Linear Models (GLMs) and Generalized Additive Models (GAMs) in the 1970s and 1980s [48], [49]. The mid-20th century later marked a critical turning point in the evolution of SDM, as ecological research began to emphasize meticulous field-based observations and systematic data collection. The rise of structured methodologies during that period was highlighted by the development of modern SDM techniques. This advancement led to a notable increase in SDM related studies. It was accompanied by a transition from Genetic Algorithm for Rule-set Production (GARP) [50] to more sophisticated tools such as BIOCLIM and MaxEnt, with an annual growth rate of 11.99%. Therefore, it also eliminates what GARP is lacking in [49], [51]. The advent of computational technologies in the late 20th century, including the development of Geographic Information Systems (GIS), revolutionized the field by enabling the integration of species occurrence data with environmental predictors on a spatial scale [52]. Early statistical methods, like logistic regression and generalized linear models (GLMs), were the fundamental building blocks for all the more advanced techniques that came later. Among these methods, MaxEnt modeling has become a key tool because it can adapt well and handle presence-only data with high accuracy. These improvements have increased the usefulness of SDMs by providing effective methods to tackle urgent environmental issues, such as habitat loss and climate change [51], [53], [54].

At this time of substantial transformation, ecologists gained the standardized tools. Those being, spatially explicit datasets, new techniques for systematic survey protocols, and new ways of classifying habitat to study species-area interactions. The use of these tools exemplified an appreciation for the role of local and regional environmental context in ecological phenomena. In contrast, species distribution modeling (SDM) has become a very data rich discipline due to new technologies including deep learning, machine learning, and remote sensing, most notably Convolutional Neural Networks (CNNs) [51]. These attributes not only increase accuracy, and efficiency. It is also a step forward in fire detections, climate change scenario development and habitat mapping. When viewed collectively these advances show a twofold progression in the progression of SDM research, one based on ecological principles and the other based on technological expansion. As the two converge there is momentum to adopt more accurate, and multifaceted approaches to SDM research. It enables some understanding of the multifaceted ways that interactions among species, habitat, and environment change occur [51], [55]. By incorporating these methodologies, SDM has become a keystone in the discipline of ecology and conservation science. In this way, it has led to a more nuanced understanding of biodiversity.

In recent years, SDMs have increasingly begun to use new computational methods. In other words, it has started to use not only machine learning algorithms, but also artificial intelligence (AI). For example, these advances have improved the ecological relevance and forecast accuracy of SDMs. Thus, researchers can focus on global problems such as biodiversity loss, habitat degradation, and the impacts of climate change [51], [56]. By obtaining and integrating real time data from satellite imagery and Unmanned Aerial Vehicles (UAVs), the area and accuracy of SDMs were also increased. Thanks to all these new features, it is possible to model species distribution in response to changing environmental conditions [51].

2.3.2. Advancements in ecological theory and quantitative methods

Field of ecological theory experienced significant advancements during the 20th century. At the start, these advancements were driven by introductory works in the field. For instance, Robert Whittaker's research on plant communities and Robert MacArthur's investigations into bird ecology emphasized the pivotal influence of environmental variables on species' spatial distributions [57], [58]. Building on these theoretical foundations, Elgene O. Box brought more revolutionary innovations to the field. He did this by developing the earliest quantitative methods for predicting species distributions. In the 1980s, Box's pioneering work [39] involved the first computer generated models of tree species distribution prediction using environmental data. These innovative models, grounded in the ecological principles of the early naturalists, represented a major shift in ecological research. The contributions of these researchers have also paved the way by playing an important role in the development of modern SDMs and machine learning today. The development of SDM, from the observations of those naturalists to today's computational modeling, shows its important role in bridging ecological theory with real world applications. By predicting where species will be found under various environmental conditions, it helps ecologists tackle urgent issues like climate change, habitat loss, and invasive species management [46], [47].

Recent advancements in data availability and computational tools have further refined SDMs. Prior to the integration of more straightforward algorithms provided by MaxEnt and BIOCLIM data, GARP was more commonly used in SDM projects as prementioned. However, subsequent analysis by Stockman et al. [49] revealed noteworthy deficiencies in GARP's capacity to accurately replicate species distributions. Challenges stemmed from number of factors, including resolution of spatial data, the opaque nature of the algorithm, and the omission of critical environmental variables in model construction. For highly non-vagile species with restricted dispersal capabilities, GARP often failed to address microhabitat heterogeneity and overpredicted suitable habitats, resulting in a high commission error. These limitations highlighted the importance of selecting appropriate spatial scales and environmental parameters when modeling species with isolated distributions. In contrast, simpler and less computationally intensive algorithms such as MaxEnt and BIOCLIM have been shown to provide more consistent predictions and greater adaptability for ecological niche modeling, particularly under diverse environmental conditions [49]. However, it should not be dismissed that GARP models still have the capacity to predict wider areas than MaxEnt models [59], [60]. This suggests that GARP models are more relevant for wider areas, whereas MaxEnt algorithms are better at making precise predictions and minimising errors. The combination of these models would enhance the model's accuracy [61]. Building on these advancements, MaxEnt emerged as a transformative tool due to its unique capability to model presence-only data—a significant advantage in regions lacking comprehensive surveys. By incorporating regularization techniques has enabled MaxEnt to achieve widespread utilisation across a range of ecological applications. These applications include conservation planning to the assessment of risks posed by invasive species [52]. The method relies on presence-only (PO) data, consisting of species presence locations, and integrates this with a set of environmental predictors (e.g., maximum temperature, mean diurnal range) across a user-defined landscape subdivided into grid cells. Within this framework, MaxEnt compares background locations, where a species' presence is unmeasured, with known presence locations. This approach helps identify patterns in the relationship between a species and its environmental conditions. Since these background locations provide a comparative baseline and not true absences, they offer stronger ecological insights [56].

The continuous development of Maxent has increased its usefulness in species distribution modeling. Recent developments have aimed to improve the quality of the transfer of models between different spatial and temporal scales by targeting biases in presence-only data. For example, Multivariate Environmental Similarity Surfaces (MESS) and clamping diagnostics have helped researchers understand species-environment relationships by visualizing them. Thus, the predictions of new environmental conditions are guaranteed to be strong [54]. These innovations not only improved MaxEnt's modeling framework but also expanded its practical uses. Biodiversity mapping and habitat suitability assessment are some of them. MaxEnt's transition to an open-source platform under the MIT license has also made it both more transparent and, most importantly, accessible. This decision to become open source is a big step, encouraging collaboration, and lays the groundwork for important developments in the future of species distribution modeling [62].

The Coupled Model Intercomparison Project (CMIP) is an international group of climate models and WorldClim datasets are important for informed and detailed species distribution models (SDMs). CMIP was a collaborative effort led by many scientists from across the globe. The project produced multiple Global Climate Models (GCMs) and accounts for different climate projection pathways based on scenarios with different levels of greenhouse gas emissions [63]. WorldClim complements CMIP by offering several high-resolution climate datasets, which include monthly and annual means of temperatures and precipitation [52]. When combined, these resources help researchers integrate baseline climate data with future projections. This raises intricate questions about species' sensitivity to climate change. Investigating species distribution has the advantage of allowing for a more complete consideration of dispersal mode and then making a more useful reference to possible future refugia or new and suitable habitats. However, the limitations of some datasets particularly those don't seem particularly representative of waterbodies or streams has highlighted the importance of always cautiously treat dataset and limitations researchers often employ MaxEnt for climate change and climate vulnerability assessments, and to address these limitations and facilitate the accuracy of species designation and location through verse location. By applying the maximum entropy principles, the covariation distribution that matches the observed data can be estimated. At the same time, assumptions about unknown factors are minimized. Regularization and feature selection are also two key features to prevent overfitting, while ensuring that predictions remain ecologically relevant [64], [65]. The MaxEnt model has proven particularly effective in scenarios with complex environmental factors or limited occurrence records, making it an indispensable tool for ecological research and conservation planning [54].

The methodological evolution of SDM introduced advanced validation strategies to address issues such as sampling biases and limited data availability. In this way, geographically structured evaluation data sets and independent validation processes have significantly increased the reliability and accuracy of model prediction [66], [67]. By adjusting the fine-tuning regularization parameters to values that exceed the default settings, a balance between the complexity and generalization of the model could be achieved, thus enabling ecological realism and transferability of predictions across different regions and scenarios [54]. In addition to numerical techniques, visual model output analyses also provided important insight into ecological patterns. For example, patterns that would normally be obscured, thus enriching the ecological interpretation of results [54]. Furthermore, tools such as MESS maps and docking diagnostics play an effective role in ensuring model robustness, especially when extending predictions to suit new environments or future climate scenarios [67]. These developments further underline the central role of MaxEnt and related tools in producing reliable, ecologically informed predictions [65].

Importantly, the SDM is also conceptually supported by the Biotic-Abiotic-Movement (BAM) framework developed by Soberón and Peterson in 2005 [68]. The BAM framework combines the effects of non-living conditions, living interactions, and locomotion abilities, giving a clear view of species distributions. Non-living factors, such as climate and soil type, determine the limits of species survival. Living factors include interactions such as reciprocity, competition, and predation that affect population dynamics. Finally, the third part, movement, involves geographic barriers that limit a species' ability to disperse and access to otherwise suitable habitats. The interaction of these three factors with each other determines the actual niche and actual geographical distribution of a species. Soberón and Peterson [68] further distinguish between mechanistic and correlative approaches to niche modeling, both of which are relevant within the BAM framework. The mechanistic approach uses physiological measurements to outline a species' fundamental niche. However, it often leaves out biotic interactions. In contrast, the correlative approach depends on species occurrence data and environmental factors. This approach naturally considers biotic elements but requires careful interpretation. Importantly, the BAM framework shows how the combination of beneficial abiotic conditions, helpful biotic interactions, and available movement pathways shapes the true geographic distribution of a species [69], [70] Regions that meet only one or two of these conditions might stay unoccupied, even if they are suitable from an environmental or biological standpoint, because of limits in dispersal. The combination of SDM with tools like MaxEnt and the support from the BAM framework shows a significant change in ecological research [68]. The combination of theoretical foundations with practical methods, especially the use of MaxEnt, allows researchers to address critical ecological issues. This includes understanding how species respond to climate change and shaping conservation strategies and habitat management. As ecological theory and computational tools continue to improve, SDM will stay essential in biodiversity research. It provides insights that are crucial for environmental sustainability [54], [64], [65], [68].

2.4. The Significance of the Çukurova Plain as a Center for Biodiversity in Türkiye

Southeastern Anatolia is a large and productive plain located at an altitude of 300–1000 meters above sea level. It is dissected by the Tigris and Euphrates rivers and is bordered by the volcanic Karacadağ Mountain and the Mardin Mountains. The region is characterised by a continental climate, influenced by the Mediterranean macroclimate [71]. The Çukurova Delta, a substantial coastal plain located within Türkiye’s Mediterranean Region, encompasses the provinces of Adana and Mersin. Plain is characterized by a relatively simple topographical features; the average elevation of the delta is approximately 142.7 meters above sea level. The most prominent geographical feature disrupting the plain's uniformity is the Karataş Hills, which are composed of limestone, clay-shale, and calcareous pebble formations [12]. The eastern portions of the delta are characterized by the Yumurtalık lagoons, while the western regions exhibit a mosaic of freshwater and saltwater marshes, reed beds, sand dunes, wet meadows, mudflats, and diverse vegetation, including the Ağyatan, Akyatan, Tuzla, and Dipsiz lagoons. This variety of habitats supports a rich biodiversity. Coastal lagoons, central to this study, are under constant pressure from human activities and are at risk of disappearance. Physical geographical factors such as climate, geomorphology, hydrography, and vegetation significantly influence these spatial changes [15]. Another important aspect of biodiversity is the presence of the whitefly *Bemisia tabaci* [72]. While they are regarded as pests and parasites, they are of considerable significance [73]. The water potential of the region is a key factor in the growth and diversity of the local flora [74], with the Adana region having been identified as a significant biodiversity hotspot, Sarıkaya et al. [75] mentions that a total of 48 distinct amphibian and reptile species have been identified in the region by multiple previous studies [76], [77], [78], [79]. The count includes four species of frog (three families), two species of salamander (one family), six species of turtle (five families), 16 species of lizard (6 families), one species of blind lizard, and 19 species of snake (four families). However, species previously documented in the literature for Adana, specifically *Neurergus strauchii*, *Pelobates syriacus*, *Anatololacerta pelasgiana*, *Darevskia valentini*, *Eirenis decemlineatus*, *E. eiselti*, *E. lineomaculatus*, and *Rhynchocalamus melanocephalus*, were not encountered during the field studies. Combining the results of the field surveys with existing literature records, it was determined that 56 amphibian and reptile species, representing 21 families, are distributed throughout the Adana province. Furthermore, detailed information regarding the chorological characteristics of these species and the specific localities within Adana where they are found is provided [75].

In the meanwhile, the importance of the amphibians is highlighted by the frogs from Cilicia to Çukurova, which serve to reduce the number of mosquitoes and, by correlation, the number of malaria cases. It is therefore essential to create an ecological balance in the Eastern Mediterranean region [80]. In fact, it is indicated that the amphibians and reptiles are more prevalent in the southeastern Mediterranean basin hotspots than in the rest of Anatolia, a result of the drier climates characteristic of the region [81], [82]. However, the shifting climates and risk factors caused by the climate disasters have the potential to put this biodiversity under alarm. This includes globally threatened animals. It is estimated that approximately 1103 of these species are threatened in the region, and amphibians are naturally not excluded from the danger [71].

2.5. The Anatolian Water Frog Complex (Genus *Pelophylax*): A Model Group Under Threat

Located at the intersection of the Caucasus, Irano-Anatolian, and Mediterranean biodiversity hotspots, Türkiye is home to an extraordinary variety of amphibian species, including a rich diversity of anurans [29]. Among these, Anatolian water frogs (genus *Pelophylax*) stand out due to their unique genetic and ecological traits. These frogs inhabit a wide range of freshwater habitats and are highly sensitive to environmental changes, a vulnerability reflected in their delicate, biologically structured skin [83], [84], [85]. Anatolian water frogs play a vital role in maintaining healthy ecosystems and contribute significantly to Türkiye's economy, especially through ecotourism associated with thriving natural habitats [1]. However, their future is increasingly threatened by climate change, as their reliance on aquatic habitats and sensitive physiology makes them exceptionally vulnerable to climatic and geological changes [84], [85].

Studies have demonstrated the significant extensive genetic diversity and significant evolutionary divergence among the populations of Anatolian water frogs [84], [85], [86], [87]. Comprehensive mitochondrial DNA (mtDNA) analyses have categorized eastern Mediterranean water frogs into six distinct primary haplogroups (MHGs), representing their unique genetic lineage shaped by historical geological events and climatic fluctuations. Of these MHGs, three (MHG4, 5 and 6) are distributed across the Anatolian mainland. The most widespread haplogroup (MHG6), exhibits the highest levels of genetic diversity, consists of four subgroups (MHG6a, b, c and d). MHG6a (cf. *caralitanus)* has been observed to be distributed in the Lake District and the Konya Plain in southwestern of Türkiye. MHG6b (cf. *cerigensis*) has been identified in the southwestern region of Türkiye, extending from Muğla to Antalya, and on the islands of Rhodes and Karpathos. MHG6c (cf. bedriagae) extends from western Anatolia to the north of the Caspian Sea (including type locality of *Pelophylax ridibundus*) and to Central Russia. MHG6d (*Euphrates*) has been identified throughout the Euphrates and Tigris rivers [84], [85], [86], [87]. Both evolutionary distinctness and genetic subdivision and also different degree of gene flow among subgroups of this group were verified by nuclear markers serum albumin intron-1+RanaCR1 (SAI-1+RanaCR1) and uqcrfs1 allele groups [86], [87].

In contrast to the other group, the remaining two Anatolian haplogroups (MHG4 and 5) are only found in the Cilician/Çukurova plain in southeastern Türkiye, where MHG4 (Cilician West) is confined to regions west of the Amanos Mountains and MHG5 (Cilician East) most frequently occupies areas to the east of Amanos Mountains. These two groups are both genetically older and more distinct group from other populations in Anatolia. Moreover, there is a strong phylogenetic link between the Cilician haplogroups and the genetic diversity of *Pelophylax bedriagae* populations in the Levant [84], [85], [86], [87]. The nuclear markers (SAI-1+RanaCR1 and uqcrfs1) verify the hypothesis of evolutionary independence this group as a single Cilician group rather than two groups. Moreover, many heterozygous individuals have been found between Cilician group and the other Anatolian groups, as well as the Bedriagae group in the Levant [86], [87]. These findings provide further evidence in support of the importance of the Çukurova plain as a critical biodiversity centre in Anatolia. However, water frog populations to Cilician lineage in the Çukurova plain (alternatively termed Cilician) particularly the Seyhan and Ceyhan Deltas in Adana province have been subject to substantial harvesting for more than 40 years [1], [84], [88]. These products are not used for domestic consumption; with the exception of tourist restaurants, they are traded for international demand. The modeling estimate of these harvested populations, based on mark and recapture analysis, revealed a population reduction of approximately 20% per year. If this dramatic rate continues, the harvested populations will face a 90% risk of extinction within 50 years [1]. Anatolian water frogs, especially the ones from the Cilician lineage, are the main focus of this study. These frogs live on the Çukurova side of Türkiye. Unfortunately, there is a risk of hotter and drier summers in this region in 2030, 2050 and the end of the century [10], [16]. These frogs are unique model organisms for studying the effects of climate changes on amphibian distributions. They can provide key insights into how *Pelophylax* distribution changes with climate and geography [84], [89], [90].

2.6. Purpose

The aim of this thesis is to analyze the effects of climate change on the Cilician water frog species found in the Çukurova Plain on a large scale. To achieve this, the research focuses on using advanced species distribution modeling to find key environmental factors, how they affect the current distribution of the species, and to predict future habitat suitability for different climate change scenarios by 2100. In this way, this research will provide actionable insights into ecological risks such as habitat fragmentation, range shifts, and potential population changes, and will ultimately inform conservation strategies to safeguard the frog’s critical habitats.

3. MATERIAL AND METHODS

3.1. Study Area

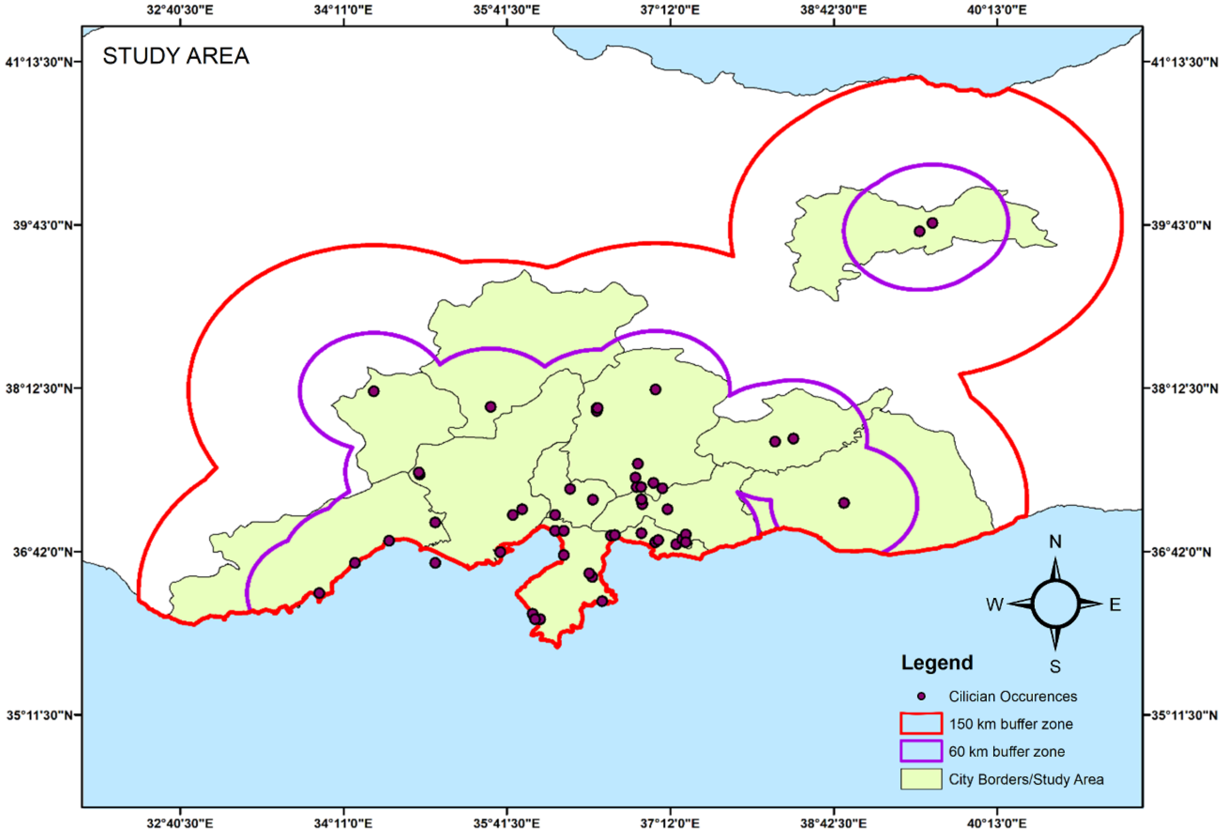

Figure 3.1.1. Geographic extent of Cilician occurrence records and associated buffered study areas across the provinces of Mersin, Adana, Hatay, Niğde, Kayseri, Kahramanmaraş, Kilis, Gaziantep, Şanlıurfa, Erzincan, Osmaniye, and Adıyaman. Dots represent individual occurrence points, while purple and red polygons outline 60 km and 150 km buffer zones around the cities.

The Adana Plain, which encompasses Çukurova in its southern part and Yukarıova, also known as Anavarza, in the north, is an area where the Cilician lineage is predominantly found [86]. The region is located between latitudes 35° and 38° North and longitudes 34° and 36° East [91]. Its elevation is about 24 meters above sea level. The climate of the Çukurova region is classified as Mediterranean, with hot, dry summers and mild, rainy winters [92], with an average annual rainfall of approximately 750 mm [93]. Orographic effects have significant influence on rainfall patterns, with the tall Taurus Mountains acting as a trap for moisture-rich winds, resulting in higher rainfall in the upland and northern regions of the plain. In contrast, lowland areas are characterised by hot, humid summers with sparse or absent rainfall. Such natural climatic shifts lead to a cycle of dry and wet periods, resulting in a wide variety of microclimates. These microclimates are vital because they shape agricultural landscapes. They also greatly enhance biodiversity by supporting a wide range of plant and animal species [91], [93]. The region is characterised by the presence of two main river systems: the Seyhan and Ceyhan rivers. The Seyhan River, with a basin size of 21,700 km², is situated between 34. 25 ° E - 37. 0 ° E longitudes and 36. 5 ° N - 39. 25 ° N latitudes. It originates in the Taurus Mountains and eventually flows into the Mediterranean Sea [10], [93The Ceyhan River starts in Kahramanmaraş Province, near the Seyhan River. It lies between 36°30' N and 35°20' E longitudes and drains into the Mediterranean. The upper and middle basins cover an area of 14,346 km², while the lower basin adds another 6,324 km². This brings the total basin area to 20,670 km² [11]. These large river systems, alongside their wetlands which are recognized as biodiversity hotspots and the Taurus Mountains, provide vital ecosystem services. They both play a crucial role in maintaining the region's ecological health. They facilitate diverse habitats, enable species movement, and support essential interactions with the environment that promote regional biodiversity [84], [85], [93].

3.1.1. Buffered study area

Buffer zones serve a crucial role in species distribution modeling by establishing the calibration area. They are commonly known as the "M-area" or accessible area. The M-area is defined as the geographical extent that a species is capable of accessing and colonising. The buffer zone is also considered in terms of the dispersal capacities and tolerance of a species to environmental conditions [94]. The selection of background points for model training is thoughtfully sampled within this specified buffer zone, ensuring the representation of the available environmental conditions [95], [96]. The primary objective of implementing buffer zones is to more accurately define the relevant geographic area for modeling. Thereby enhancing the prediction accuracy and better reflecting the species' ecological range [96], [97], [98]. The size and extent of these zones are flexible and depend on the specific modeling goals and the ecological traits of the species involved [99]. In this study, two buffer zones, 60 km and 150 km, were used to surround the study area. The buffer distances selected were determined by considering the species' potential dispersal abilities and the influence of broader regional environmental gradients within the region. This procedure created a projected study area that extends significantly north from southern Anatolia, mainly along major river systems. This broader scope is essential because it enables a thorough examination of possible shifts in the species' distribution, including areas beyond its current known range (Figure 3.1.1).

3.2. Data Acquisition and Preparation

This section explains how species occurrence and environmental data were acquired and pre-processed. It also provides the basis for the subsequent habitat suitability modeling using a machine learning algorithm in R. ArcGIS Desktop (version 10.0.7) was the primary Geographic Information System (GIS) platform used for managing, preparing, and initially visualizing all spatial data. Its features were important in converting various raw datasets into ecologically relevant inputs for species distribution models (SDMs). Specifically, ArcGIS is used to organize and combine complex spatial datasets, including high-resolution climate variables, detailed topographic features, and accurate species occurrence records [51], [100]. Preparing environmental predictors was crucial for obtaining precise models in R. ArcGIS ensured high quality inputs and maintained spatial consistency by carefully preparing the environmental predictors and occurrence data. This data preparation is vital because it directly influences the accuracy and ecological relevance of the species distribution models. Additionally, ArcGIS provides a robust environment for initial spatial visualization, enabling an early examination of species occurrence patterns in environmental factor gradients.

3.2.1. Species occurrence

This habitat suitability modeling study aims to investigate the Cilician water frog lineage (*Pelophylax. cf. bedriagae* 1), which is the important evolutionary group of the Anatolian water frog complex and is known for its reliance on freshwater ecosystems. For this lineage, presence-only occurrence data were compiled from existing genetic research. The analysis incorporated a comprehensive dataset comprising 167 georeferenced presence record, encompassing entire Cilician region and neighbouring areas. The initial recording of these precise latitude and longitude coordinates was conducted using GPS technology. The data points represent individuals identified as belonging to the Cilician water frog lineage through mitochondrial DNA (mtDNA) analysis, focusing on the highly variable and informative ND2 and ND3 genes taken from previous studies [84], [85], [86], [101], [102], [103], [104]. The genetic identification of the lineage was critical to guarantee that the occurrence data precisely represented the target lineage's distribution. The strong phylogenetic signal and substantial sequence length of these genes provided sufficient resolution to define the evolutionary boundaries of the lineage [105], [106]. The spatial distribution of these occurrence records across the designated study area is shown in Figure 3.2.1.

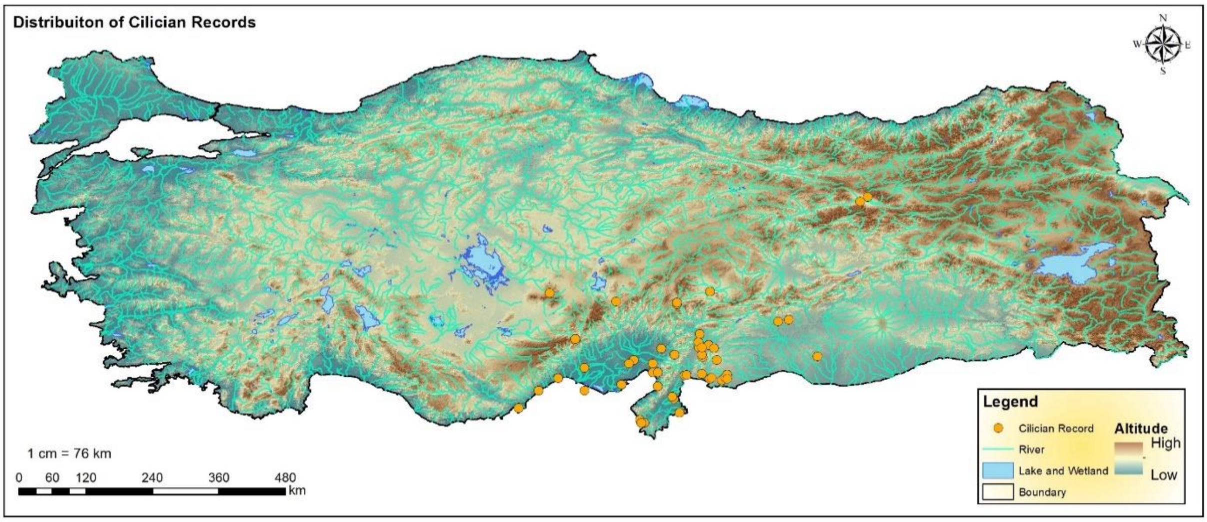

Figure 3.2.1. Distribution of the Cilician water frog lineage occurrence records

3.2.2. Environmental predictor data

To model the habitat suitability of the Cilician water frog lineage, a comprehensive set of 17 environmental predictors was gathered. These variables were chosen to represent a broad range of factors crucial to amphibian ecology, specifically climatic, topographic, and hydrological influences, as detailed in Table 3.2.2.1

Climatic variables were prioritized due to their direct impact on the physiological processes of amphibians, their breeding cycles, and their overall survival [107], [108]. The importance of climate on amphibians is highlighted by evidence that changes in temperature and precipitation can significantly impact breeding success and survival rates [108]. Studies have shown that amphibians are especially vulnerable to climatic shifts, as these factors directly affect their reproductive behaviours and ecological interactions [107], [109]. For the purposes of this study, nine bioclimatic variables derived from monthly temperature and precipitation data were collected from the WorldClim database (https://www.worldclim.org/). These data originate from the Coupled Model Intercomparison Project, Phase 6 (CMIP6) ACCESS-CM2 model outputs [63]. Climate data with a resolution of 30 arc seconds were downloaded for current conditions (representing the 2000s). Moreover, to understand the impact of climate change on the distribution of the target lineage, future climate projections were also incorporated for the periods of 2021-2040 (representing 2030), 2041-2060 (representing 2050), 2061-2080 (representing 2080), and 2081-2100 (representing 2100).

Topographic variables have been demonstrated to play a significant role in the formation of local microclimates, the regulation of water availability, and the patterns species dispersal patterns. As demonstrated in the study by Nikolakopoulos [110], the Shuttle Radar Topography Mission (SRTM) Digital Elevation Models (SRTMDEM) provided altitude data along with derived topographic variables. These variables included ruggedness (calculated as the standard deviation of altitude within a neighbourhood), slope (gradient of the terrain), north aspect, and east aspect (direction of slopes). The incorporation of these topographic parameters is crucial for understanding the ecological dynamics within diverse habitats, as they directly influence the habitat suitability of species distribution.

Hydrological variables are directly related to the obligate aquatic nature of water frogs. The proximity of these species to permanent water bodies has been identified as a key factor influencing their distribution. Therefore, distances to lakes, rivers, and wetlands were calculated as Euclidean distances from their respective features. The geographical data for these water bodies was obtained from the relevant ministry of Türkiye.

This comprehensive and multi-faceted set of environmental parameters was meticulously assembled to capture the key ecological requirements and potential limiting factors influencing the distribution and habitat suitability of the Cilician water frog lineage across both current conditions and various future climate change scenarios.

Table 3.2.2.1. List of environmental predictors and sources

Variable name	Abbreviation	Source
Annual precipitation	an_prep	WorldClim Database
Mean Diurnal Range	diur_rng	
Isothermality	isother	
Mean Temperature of Coldest Quarter	m_tmp_cq	
Mean Temperature of Driest Quarter	m_tmp_dq	
Mean Temperature of Wettest Quarter	m_tmp_weq	
Precipitation of Coldest Quarter	prep_coq	
Precipitation Seasonality	prep_sea	
Temperature Seasonality	temp_sea	
Distance to Lakes	d_gol	Derived from Related Ministry
Distance to Rivers	d_nehir	
Distance to Wetlands	d_golsula	
Altitude	srtmdem	SRTM
Ruggedness	ruggedness	Derived from SRTM
Slope	slope	
North aspect	northness	
East aspect	eastness	

3.2.3. Data pre-processing using GIS

All raw spatial data acquired, comprising both species occurrence points and environmental raster layers, underwent rigorous and systematic pre-processing within ArcGIS Desktop (v10.0.7) [111]. Maintaining and guaranteeing consistency, adaptability, and ecological relevance is the critical prerequisite for robust species distribution modeling. In this regard, the following vital steps have been followed:

- Projection and Resampling: To establish a unified spatial framework for all analyses, it was necessary to standardise every environmental raster layer, and the species occurrence points to the World Geodetic System 1984 (WGS84) geographic coordinate system. This step is important for global interoperability and to prevent spatial misalignment between different datasets. Subsequent to this, all raster layers were resampled to a spatial resolution of 30 arc seconds (approximately 1 km). The chosen resolution was subjected to careful consideration to ensure it alignment with an ecologically appropriate scale for species distribution, its facilitation of maximum integration with environmental parameters, and its maintenance of computational efficiency.
- Masking and Clipping: To concentrate the environmental data with a high degree of precision on the relevant geographical extent, a mask representing Türkiye's national borders was initially created using ArcGIS's extraction tools. The application of the comprehensive mask was then applied to all environmental variable raster layers, including both current and future projections. Subsequent to this national-scale clipping, the layers were further restricted and clipped to our specific study area, which encompasses the Çukurova region and its associated cities, as well as the defined 60 km and 150 km buffer zones (as described in Section 3.1.1, Buffered Study Area). The restriction of the spatial area is instrumental in ensuring a perfect match between all environmental data and the modeling extent. This approach effectively lessens computational costs and prevents the inclusion of any irrelevant background information from outside the species' potential accessible zone [52], [68], [112].
- Derived Variable Generation: To enrich the environmental dataset and capture more nuanced ecological influences, several new, derived environmental variables were created using ArcGIS's Spatial Analyst tools. Topographic variables, such as ruggedness (calculated as the standard deviation of altitude within a defined neighbourhood), slope (the steepness of the terrain), and aspect (north aspect and east

aspect, representing the direction a slope faces), were derived from the resampled SRTM Digital Elevation Model. These derivatives exert an influence on microclimates, solar radiation levels, and water flow regimes. Furthermore, critical hydrological variables, including proximity to lakes, rivers, and wetlands, were determined by calculating the Euclidean Distance. These proximity metrics are directly relevant for a water dependent species such as the Cilician water frog lineage and provide essential information about access to aquatic habitats.

- Data Stacking and Extraction: Following the completion of all individual variable processing, the prepared and aligned environmental variables were aggregated into a unified, multiband raster stack. This stack, comprising all 17 selected predictors, exhibited consistency in terms of resolution, extent, and projection. It served as the primary environmental input for the subsequent species distribution models. Finally, the ecological values corresponding to each species occurrence point were extracted directly from this integrated raster stack. This step constituted the creation of a tabular dataset, where each row represented a species occurrence, with the columns denoting the associated environmental conditions. This data was then used as the core input for the modeling analysis in R.

These mentioned data preparation steps were of crucial importance in ensuring the high quality, spatial consistency, and ecological appropriateness of all inputs. This careful approach provides a robust foundation for increasing the predictive power, accuracy, and reliability of the habitat suitability models.

3.3. Data Processing, Integration and Model Development

The workflow for species distribution modeling is outlined in this section. We used a single software to manage the entire process, including the construction of initial spatial data, model development, and validation of habitat suitability models. A systematic approach was employed to connect species occurrence data with environmental predictors using the robust analytical capabilities of the R programming environment (RStudio 4.3.3) [113]. This methodological framework is a cornerstone for improving ecological research workflows [114] and guarantees the reliable creation and validation of predictive models.

The core of the advanced computational workflow was executed within the R programming environment (RStudio 4.3.3), leveraging a suite of specialized packages. The SDMtune package (version 2.0.1) [115], [116] served as the central framework for training, assessing, and optimizing species distribution models. SDMtune offers advanced methods for the selection the most relevant environmental predictors from complex datasets, thereby, supporting a wide array of SDM algorithms such as MaxEnt, boosting methods, and regression models, thus improving overall accuracy and ecological relevance [117]. In addition to the foregoing, the Terra package (version 1.7-71) [118] was indispensable for modern and versatile spatial data analysis, efficiently handling both raster (grid-based) and vector (points, lines, polygons) data. In its capacity as a successor to older spatial packages, Terra provides enhanced functionality and improved performance, particularly for large datasets. This is achieved by supporting a wide range of raster operations including local, focal, global, and zonal calculations. The latter are essential for ecological and geographical research. Furthermore, the RGDAL package (version 1.5-31), an older but robust R package, was explicitly utilized as a crucial bridge for reading, writing, and manipulating raster and vector spatial data by interfacing with the Geospatial Data Abstraction Library (GDAL) and the OGR Simple Features Library. In this study, RGDAL was notably employed for the purpose of rasterizing specific climate data that exhibited compatibility issues with the more modern terra package. In addition to these core packages, several additional R packages were used for various supporting tasks, including dismo for general ecological modeling functions; RasterVis and ggplot2 for high-quality data visualization; methods, lattice, latticeExtra, sf, sp, predicts, maps, and reshape2 for data manipulation, spatial data handling, and utility functions; rJava for Java-based functionalities often required by specific algorithms; plotROC for Receiver Operating Characteristic (ROC) curve analysis in model evaluation; and kableExtra for generating publication-quality tables.

The subsequent subsections detail the specific methodologies employed in this phase.

3.3.1. Model optimization and validation

The process of successful species distribution modeling needs careful calibration of hyperparameter settings. It is called as hyperparameter tuning or optimization. This adjustment provides a balance between model complexity and generalization. Optimization increases the probability that the predictions are both statistically correct and ecologically relevant. It also means they are applicable across a variety of spatial and temporal scales. To achieve optimized predictions, a detailed and robust SDM workflow was followed. This systematic process integrates predictor selection, model validation, and advanced hyperparameter optimization from start to finish. The SDMtune package in R [117] played a key role in rendering these complex tasks more manageable. The objective of the proposed methodology is to construct a unified, efficient, and repeatable modeling method. The modeling process was started by the creation a Sample with Data (SWD) object. This specialized object efficiently integrates the essential components required for model training. The components include georeferenced records of the species' occurrence, their corresponding environmental variable values, and a carefully generated pseudo-absence dataset. For this study, a total of 5,000 randomly generated background points were included to effectively represent the environmental conditions across the broader study area, serving as a robust contrast to presence data for model calibration [66], [96], [119].

To ensure rigorous internal validation and an unbiased assessment of model performance, the entire dataset (comprising both presence and pseudo-absence points with their associated environmental data) was systematically partitioned. A robust three-subset partitioning strategy was employed: 60% of the occurrence data was allocated to the training set, 20% to a dedicated validation set, and the remaining 20% to an independent testing set. This method is highly recommended for comprehensive model evaluation by Vignali et al. [120] and facilitates a rigorous assessment of model reliability and predictive accuracy by evaluating performance on data not used during training or tuning. An initial baseline model was subsequently generated using MaxEnt's default settings to provide a reference point for further optimization [56], [117]. Subsequent to the establishment of the baseline model, a data-driven variable selection mechanism was executed using the "varSel" function within the SDMtune package (see Figure 3.3.1.1.). The function employs an iterative methodology grounded in a leave-one-out Jackknife (JK) test to identify and remove redundant or less influential environmental predictors. During each iteration, environmental predictors were scrutinized based on two primary criteria: their relative contribution to the model and their pairwise correlation (Spearman's rho ≥ 0.80) with other predictors. In the event that the exclusion of a predictor resulted in a non-significant reduction in model accuracy, or if it exhibited a high correlation with another more influential predictor, it was systematically removed from the predictor set. The iterative nature of this process ensured that all pairwise correlations between the remaining predictors were reduced to below the 0.80 threshold. The development of a systematic variable selection strategy was driven by the necessity to mitigate the consequences of overfitting, which can arise when there is multicollinearity in a dataset. This strategy also aimed to reduce redundancy within the dataset and to optimise the final model's simplicity and its capacity to provide effective predictions.

Following the refinement of the predictor, the model hyperparameters were systematically optimized using the "optimizeModel" function of the SDMtune package (see

Figure 3.3.1.1). This function employs a sophisticated genetic algorithm to efficiently search for hyperparameter configurations that yield optimal or near-optimal model performance. This algorithmic approach has been shown to be particularly time-efficient and computationally effective in comparison to traditional exhaustive search methods. Furthermore, it provides researchers with a high degree of flexibility through a variety of adjustable parameters that can be used to guide the optimization process [117]. The hyperparameter tuning process was initiated by defining a comprehensive search space for the MaxEnt model parameters. The search space included a regularization coefficient ranging from 0.2 to 5.0, with increments of 0.1, to regulate model complexity. The maximum number of iterations was set to range from 500 to 9900, in intervals of 200. Furthermore, all possible combinations of the five primary feature classes were considered: linear ("l"), quadratic ("q"), product ("p"), hinge ("h"), and threshold ("t"). The initial population for the genetic algorithm was then generated by randomly selecting 20 distinct model configurations from this defined search space. These 20 configurations formed the basis for the "first generation" of models. Each model within this initial population was evaluated based on its fitness score, which was quantified using the Area Under the Receiver Operating Characteristic Curve (AUC) metric. The area under the curve (AUC) was calculated using a separate validation dataset, serving as a standard and unbiased method for assessing accuracy in presence-absence (or presence-background) models [121], [122]. The "first generation" was subsequently formed by a selection process designed to balance the exploitation of good solutions with the exploration of new ones. The top 40% of the fittest models (i.e. those with the highest AUC scores) were directly retained, ensuring the propagation of successful configurations. Additionally, a random sample of 20% of the less fit models from the initial population were also included in the study. This adaptive approach, as recommended by Vignali et al. [117], has been shown to effectively mitigate the risks of convergence to local optima and prevent underfitting by maintaining diversity within the population. The overall generation size was consistently maintained at 20 models through the incorporation of new configurations generated via mutation and crossover operations. During the process of mutation and crossover, new models were created by the blending and alteration of attributes from selected "parent" models. Specifically, two parent models were chosen at random, and a new "offspring" model was generated by combining their hyperparameter values. To further enhance variability within the generation and prevent premature convergence, a 40% probability of mutation was applied. In the event of mutation, a randomly selected hyperparameter from one of the parent models was randomly altered and incorporated into the new offspring model. This iterative optimization process, guided by a genetic algorithm, continued over multiple generations until a predefined number of iterations was completed. This ultimately yielded a highly refined set of hyperparameter configurations that optimized model performance.

Finally, to comprehensively evaluate the potential impacts of climate change, this entire optimized modeling framework was applied independently for each future period (2030, 2050, 2080, 2100) and for each distinct carbon emission scenario, represented by ACCESS-CM2 model outputs under Shared Socioeconomic Pathways (SSPs) 2-4.5 (GCM-245) and 5-8.5 (GCM-585). This rigorous approach ensured that the habitat suitability projections for each specific future case were generated from a model that was uniquely and specifically calibrated for the chosen and filtered environmental conditions pertinent to that scenario. The entire process yielded reliable and robust habitat suitability models for every projected scenario, providing detailed insights into the potential future distribution of the Cilician water frog lineage.

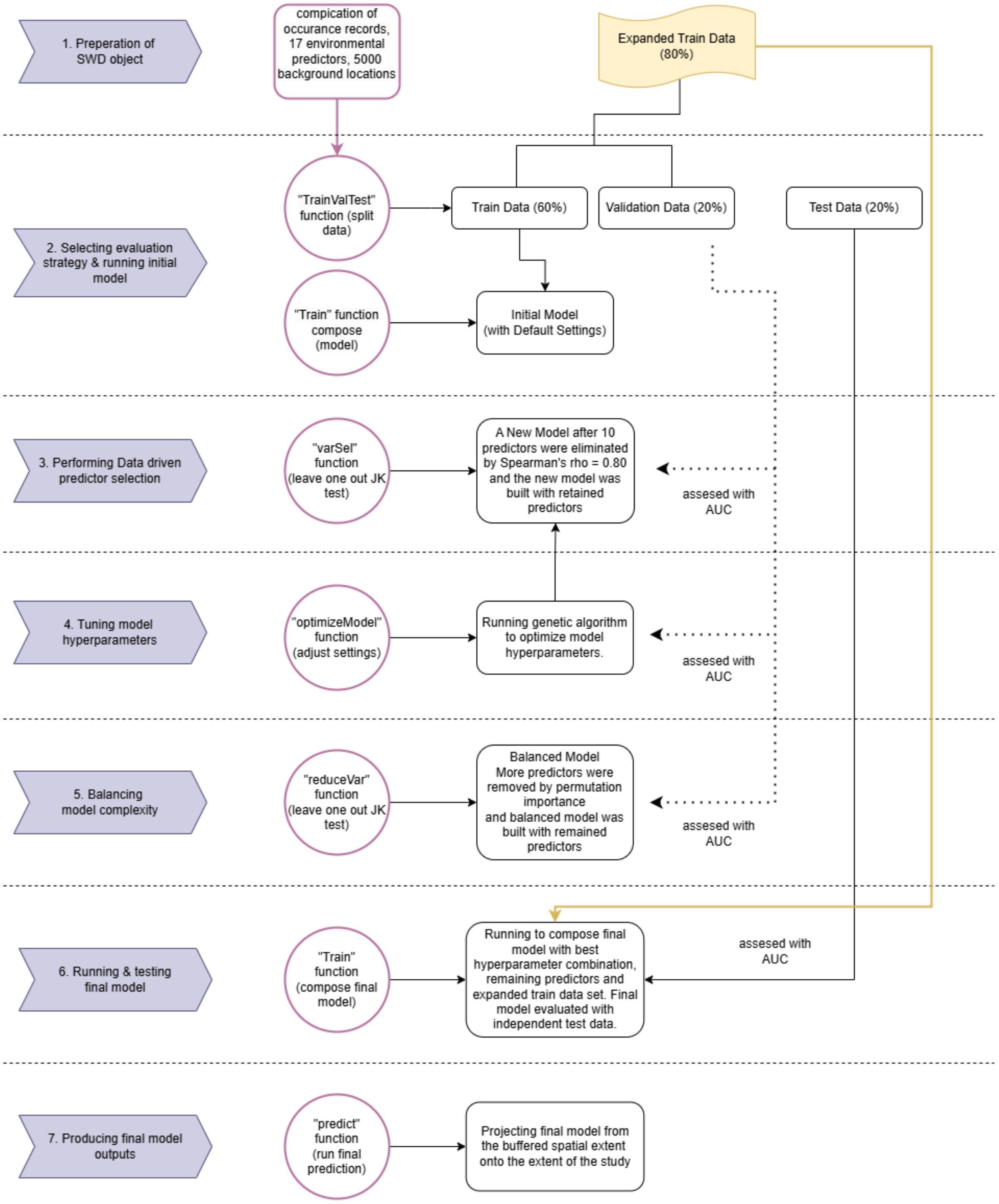

Figure 3.3.1.1. The Flowchart illustrates the steps that were taken during the model tuning process, in addition to the functions that were required to perform the steps that are presented in the figure.

3.3.2. Evaluation of the model and performance metrics

Model validation and careful evaluation are crucial steps in species distribution modeling. The purpose of these models is to ensure that the predictions are reliable, accurate, and meaningful for nature. Following the optimization of the model (as explained in Section 3.3.1), a comprehensive evaluation of its performance was conducted. This was achieved by utilising a distinct test dataset. This dataset was not used during the training or optimization stages, thereby ensuring an accurate and reliable estimate of the model's true predictive capability [117].

Model Accuracy Metrics: ROC Curve and AUC:

The primary quantitative metric of model accuracy was derived from the Receiver Operating Characteristic (ROC) curve. The ROC curve serves as a detailed graphical representation of a classification model's overall performance, particularly effective for models with a modifiable threshold parameter, and is widely utilized in presence-absence modeling [122], [123], [124]. This curve is constructed by plotting the true positive rate (sensitivity) against the false positive rate (1-specificity) across various threshold values, thereby illustrating the model's ability to discriminate between presence (ones) and background/absence (zeros) points [125], [126]. Each coordinate point on the ROC curve represents a specific threshold scenario, where the x-axis denotes the fraction of background/negative cases that are falsely identified as positive, and the y-axis represents the proportion of true positive cases that are correctly identified [124].

The quantitative evaluation of the model's capacity to discern between presence and background points was conducted by measuring the Area Under the Receiver Operating Characteristic Curve (AUC). The Area Under the Curve (AUC) provides a single statistical representation of the classifier's overall effectiveness across all possible thresholds [127], [128]. A perfect classification model attains an AUC value of 1.0, signifying impeccable discrimination between positive and negative instances [129], [130]. However, it is crucial to recognise a methodological consideration when applying ROC curves and AUC to presence-only data. In such datasets, all background grid cells lacking observed occurrences are implicitly treated as negative instances, even if some of these cells might represent suitable, yet unrecorded, habitat for the species [52]. This inherent constraint results in the maximum achievable AUC value for presence-background models frequently falling short of a theoretical 1.0 [131]. Notwithstanding this, the AUC remains a robust and widely accepted metric for assessing the predictive power of presence-only SDMs, indicating the probability that the model will rank a randomly chosen presence location higher than a randomly chosen background location [127], [132].

To gain deeper insights into the ecological drivers of the species' distribution and the predictive power of individual environmental variables, several analytical approaches were employed:

- Jackknife Test for Variable Importance: The Jackknife test is applied at various stages of model development (including post-optimization). The tool is designed to evaluate the relative contribution and significance of each environmental predictor. The objective of this test is to evaluate the statistical reliability of predictors by systematically eliminating variables while re-evaluating the model's performance. It highlights the unique and interactive importance of each variable [133].
- Percentage Contribution and Permutation Importance: In addition to the results of the Jackknife, percentage contribution and permutation importance metrics, as outlined by Liu et al. [119], provided further insights into the influence of variables. The percentage contribution quantifies the isolated impact of each variable on the model's fit. On the other hand, permutation importance quantifies the loss in predictive power when a variable's values are randomly permuted to capture its interactive effects with other predictors.
- Response Curves: To elucidate visually the manner in which individual predictor variables influence species distribution, response curves were generated. The plots illustrate the predicted probability of species occurrence across the range of a specific environmental variable while keeping all other variables constant [116]. The model output comprises these curves, which provide valuable knowledge about the relationship between the Cilician water frog lineage and its optimal environment conditions and limiting factors for its distribution.

The employment of these evaluation and analytical methodologies has been demonstrated to enhance comprehension of the model and its constituent variables to a considerable degree. The enhanced performance and accuracy of the model in prediction are now better recognized. These evaluations also clarified the ecological factors that influence the observed and future distribution of the Cilician water frog lineage.

3.3.3. Mapping potential species distribution

The final stage in our Modeling process involved the conversion of the revised and enhanced species distribution models into geographical representations. These maps were intended to indicate the potential locations of suitable habitats. This approach facilitated the interpretation and comprehension of the model outcomes. This is of crucial importance in order to comprehend the present and future distribution of species. The predicted habitat suitability maps, generated in RStudio using the most successful model (as determined by performance metrics detailed in Section 3.3.2), were initially exported as GeoTIFF files. These raw TIFF outputs were then imported into ArcGIS Desktop v10.0.7 for further spatial processing and visualization. To ensure complete compatibility with ArcGIS's geoprocessing tools and to enable subsequent analyses, it was necessary to convert the imported TIFF files to ESRI Grid raster format. This was achieved by utilising the designated conversion tools within ArcToolbox.

To comprehensively interpret potential changes in habitat dynamics, including areas of expansion, contraction, and shifts in suitable and unsuitable zones, a series of three distinct spatial outputs were generated for each scenario:

1) Continuous Habitat Suitability Map: The initial continuous prediction map was directly generated by the optimized MaxEnt model. The resulting data set provides a gradient of values, typically ranging from 0 (lowest suitability) to 1 (highest suitability), which quantitatively indicates the environmental suitability for the Cilician water frog lineage across the entire study area. Higher values on this scale indicate regions in which ecological conditions are predicted to be more conducive to the survival and propagation of the species in question, while lower values suggest less favourable or unsuitable conditions.
2) Binary Habitat Suitability Map (Potential Habitat Map): To provide a clear, interpretable representation of presence and absence, the continuous habitat suitability map was transformed into a binary (two-class) map. This conversion was achieved by applying a specific threshold to the continuous suitability values, classifying every pixel as either "suitable" (1) or "unsuitable" (0) habitat [37], [122], [134]. The Maximum Training Sensitivity plus Specificity (MTP or MSS) threshold was chosen for this binarization. The MSS threshold is widely recognized for its ability to maximize the model's capacity to correctly identify both true positive (correctly predicted presences) and true negative (correctly predicted absences/background) rates

[121], [122]. This approach enables the accurate estimation of distribution areas and ranges while avoiding overestimation of suitable habitats. Furthermore, it engenders a lucid visual depiction of potential suitable habitats [135]. The binarization was performed using the Spatial Analyst toolset in ArcGIS, with areas that met the threshold categorised as '1' and those that did not as '0'.

3) Geographic Distribution Range Map: This final map represents the estimated spatial extent within which the species is most likely to occur. The map was derived from a previously generated binary potential habitat map through further spatial editing and refinement processes within ArcGIS. The utilisation of mapping tools facilitated the refinement of habitat maps, leading to the enhancement of their boundaries and the smoothing of their edges. Furthermore, the removal of small, isolated, suitable areas that were not truly viable habitats was also undertaken. This facilitated the incorporation of a more realistic estimated range for the species into the maps.

The entire workflow for generating, converting, and refining spatial outputs was systematically applied for each future period and each carbon emission scenario considered in the study. This involved the creation of distinct sets of maps for the current period (2030, 2050, 2080, and 2100) under both the low-carbon (SSP2-4.5) and high-carbon (SSP5-8.5) emission scenarios. This comprehensive approach facilitated the analysis of how species' habitats and locations might be impacted by various plausible future climates. The study provided comprehensive insights into the anticipated shifts in habitat. The resulting maps were produced at a high-quality resolution (350 dpi), facilitating more precise and more detailed insights for each scenario and period.

4. RESULTS

4.1. Optimized Model Outputs and Performance Metrics

To improve the accuracy of predictions concerning the Cilician water frog lineage, this study adjusted the standard hyperparameter settings. It focused on modifying specific factors in the MaxEnt modeling approach. The optimization process, which employed machine learning techniques, involved several steps to develop the final predictive model.

Initially, all 17 environmental predictors were included in the "train" process. The varSel function was then employed to mitigate multicollinearity among predictors. This process resulted in the removal of variables with minimal influence, based on a Spearman's rho of 0.80 (Figure 4.1.1), following the guidelines of Vignali et al. [117], [120]. This approach enabled the attainment for more precise results and enhanced AUC metrics for the final optimized model. The algorithm applied by the function evaluated the existence of correlations and reduced the number of variables to enhance the model's fitness (Figure 3.3.1.1). Before this step, the initial model's AUC train value was 0.701, and the test value was 0.637.

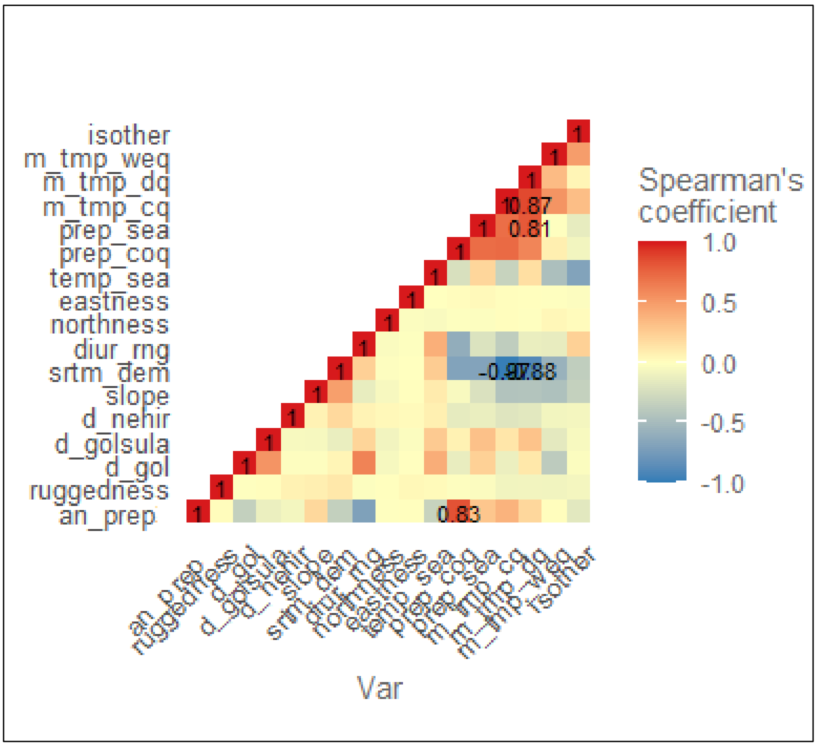

Figure 4.1.1. Spearman's coefficient results of the model.

The final set that was selected comprised seven variables, as depicted in the model results that had been optimised (Table 4.2.1). The elimination of redundant variables significantly enhanced the model's generalization performance. The key evaluation metrics, including AUC and ROC curves, were visualized using RStudio (Figures 4.1.2 and 4.1.3). AUC values, obtained through the "plotROC" function, reflect the classification model's performance, with higher values indicating greater predictive accuracy. The ROC curve, explained in Section 3.4.2, illustrates the model's performance. A value close to 1 indicates that the model classifies almost perfectly. An AUC value above 0.7 is considered acceptable, and a value above 0.8 is regarded as excellent [136].

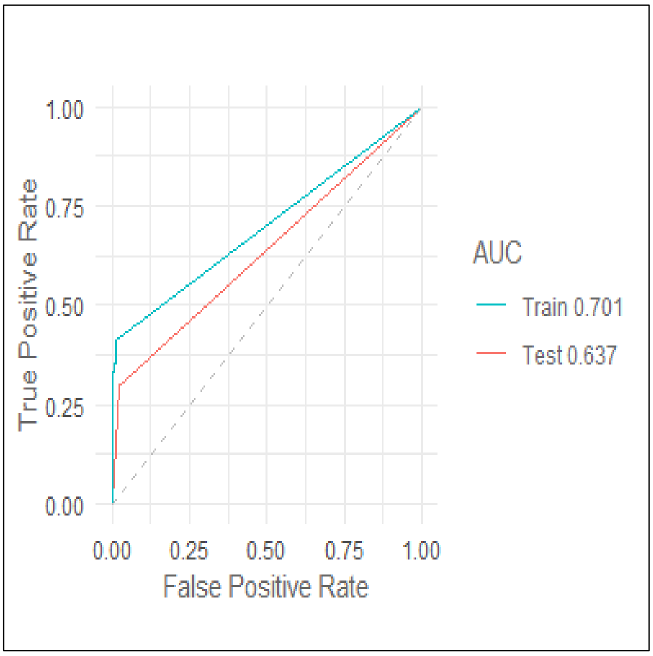

Figure 4.1.2. The initial ROC curve of the model plotted by "plotROC" function and the printed AUC value. When curves are closer to the upper left corner, they are also closer to perfect sensitivity and higher accuracy. The blue line representing the train AUC and the red line representing the test AUC.

During the process of model optimization and evaluation, the initial ROC results (Figure 4.1.2) served as a baseline for comparison. The ROC curve visualization shows the blue line representing the train AUC and the red line representing the test AUC. After removing unnecessary variables, the improved model showed a training value of 0.965. The test value also exhibited a substantial increase, rising from 0.637 to 0.881. This result is very encouraging and highlights the model's reliability. The findings suggest that the optimization process successfully enhances the model's performance and prediction accuracy. The final optimized and balanced model, using this improved set of predictors, attained training and validation AUC scores of 0.965 and 0.881, respectively.

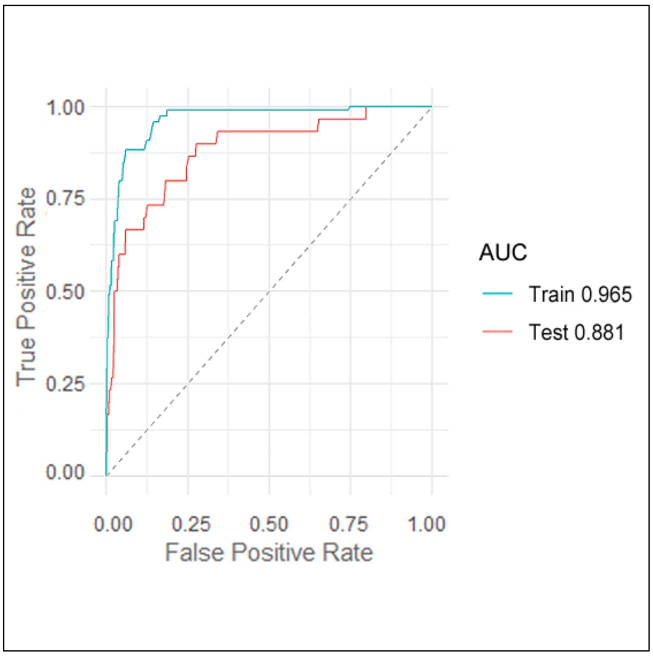

Figure 4.1.3. The optimized ROC curve of the model plotted by "plotROC" function and the printed AUC value. The blue line representing the train AUC and the red line representing the test AUC.

4.2 Key Environmental Variables and Their Influence on Target Lineage

The predictive model for the Cilician water frog lineage was developed through a meticulous optimization procedure. This process included the analysis of the impact of various environmental factors on the model's precision. In this section, the final collection of variables and their significance to the model's predictive capacity were outlined. Additionally, insights are provided from the Jackknife test and response curves to help understanding of how these factors impact the target water frog lineage.

Percentage Contributions of Environmental Predictors (Figure 4.2.1) were analyzed to identify the key factors influencing the distribution of the Cilician water frog lineage. The minimum temperature of the cold quarter was identified as the most significant predictor, contributing to approximately 25% of the model. Following closely, the variable of temperature seasonality contributed around 20.5%. Ruggedness also played a substantial role, accounting for approximately 23.5%. Other contributing factors included slope (around 12.5%), distance to lake (approximately 10%), annual precipitation (around 4%), and isothermality (approximately 2.5%).

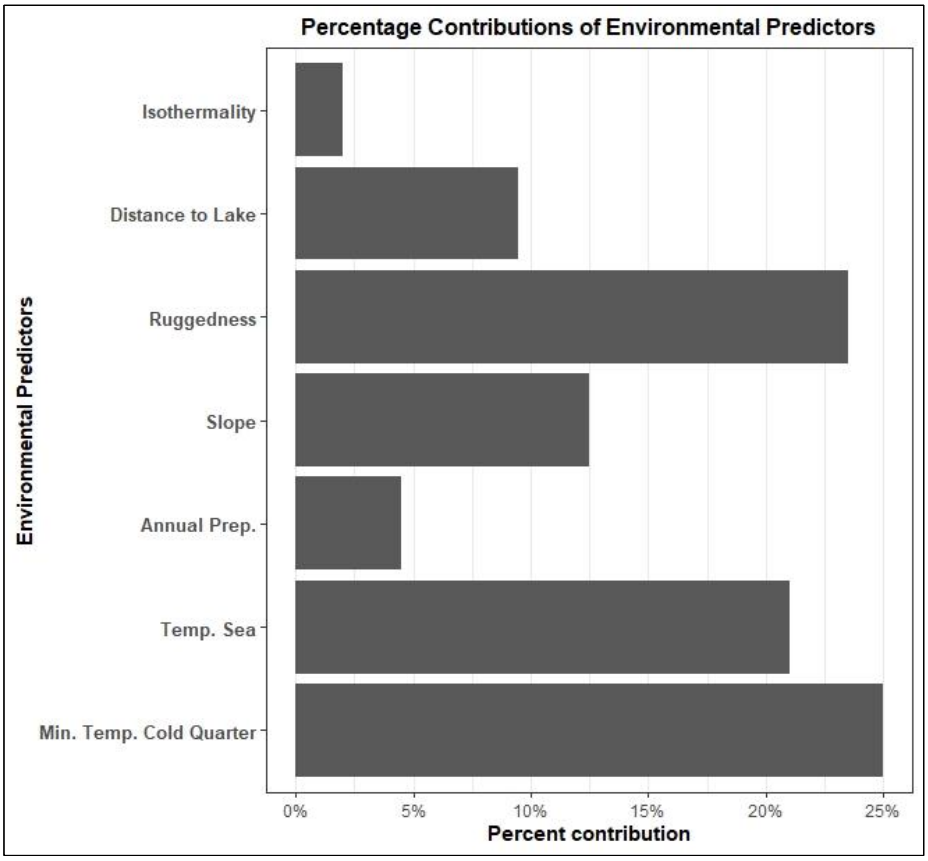

Figure 4.2.1. The variable importance values as a bar plot. Environmental predictors with permutation importance < 5% for the Cilician water frog lineage are annual precipitation and isothermality.

The Optimized Model Variable Importance Permutation analysis (Table 4.2.1) supports the above findings by illustrating how each variable affects the distribution of the target lineage. Temperature seasonality exhibited the highest importance score of 32.9, with a very low standard deviation of 0.008. This indicates that it consistently influences the model across different tests. In addition, the minimum temperature of the cold quarter also showed a significant importance score of 21.7, with a standard deviation of 0.006, confirming its reliable role. The annual precipitation exhibited a permutation importance of 19.4 (standard deviation: 0.014). Other variables, including slope with 10.3 (standard deviation: 0.005), ruggedness with 9.8 (standard deviation: 0.004), and distance to lake with 5.2 (standard deviation: 0.001) also exhibited stable contributions. Isothermality showed the lowest permutation importance of 0.7 (standard deviation: 0.002), consistent with its lower percentage contribution.

Table 4.2.1. Shows the permutation importance and lineage distribution of environmental variable importance.

OPTIMIZED MODEL VARIABLE IMPORTANCE PERMUTATION		
Variable	**Permutation Importance**	**Lineage Distribution**
temp_sea	32.9	0.008
m_tmp_cq	21.7	0.006
an_prep	19.4	0.014
slope	10.3	0.005
ruggedness	9.8	0.004
d_gol	5.2	0.001
isother	0.7	0.002

To further evaluate the unique contribution and influence of each environmental predictor on the model's performance in predicting the presence of the target water frog lineage, a Jackknife Test was performed on both the test and training AUCs (Figure 4.2.2, Panels A and B). This analysis assesses the gain in AUC when a single variable is used in isolation ("With only" - peach bars) versus the decrease in AUC when a single variable is omitted from the model ("Without" - cyan bars). The red dashed line in the figure represents the AUC of the model with all variables included.

For the Test AUC (Figure 4.2.2, Panel A), the minimum temperature cold quarter showed the highest gain when used in isolation, thus indicating its strong individual predictive power for the target lineage. When the minimum temperature cold quarter was excluded from the analysis, the overall performance of the model (as measured by Test AUC) underwent the most significant decline. This illustrates the significant role this factor plays in determining the habitat of the Cilician lineage. Similarly, the temperature seasonality and ruggedness also demonstrated considerable individual predictive power (as indicated by their "With only" bars), resulting in noticeable reductions in model performance when removed. Isothermality consistently showed the lowest individual contribution and the least impact on overall model performance when removed.

The pattern observed in the Train AUC (Figure 4.2.2, Panel B) largely mirrored that of the Test AUC, thereby reinforcing the findings. Predictors such as minimum temperature cold quarter, temperature seasonality, and ruggedness maintained their status as highly influential variables, both when used in isolation and when omitted from the whole model.

The agreement between the training and testing outcomes from the Jackknife test indicates that the model is excessively tailoring itself to the training data. The key variables we identified are successfully applied to new data, thus demonstrating their effect on the target lineage.

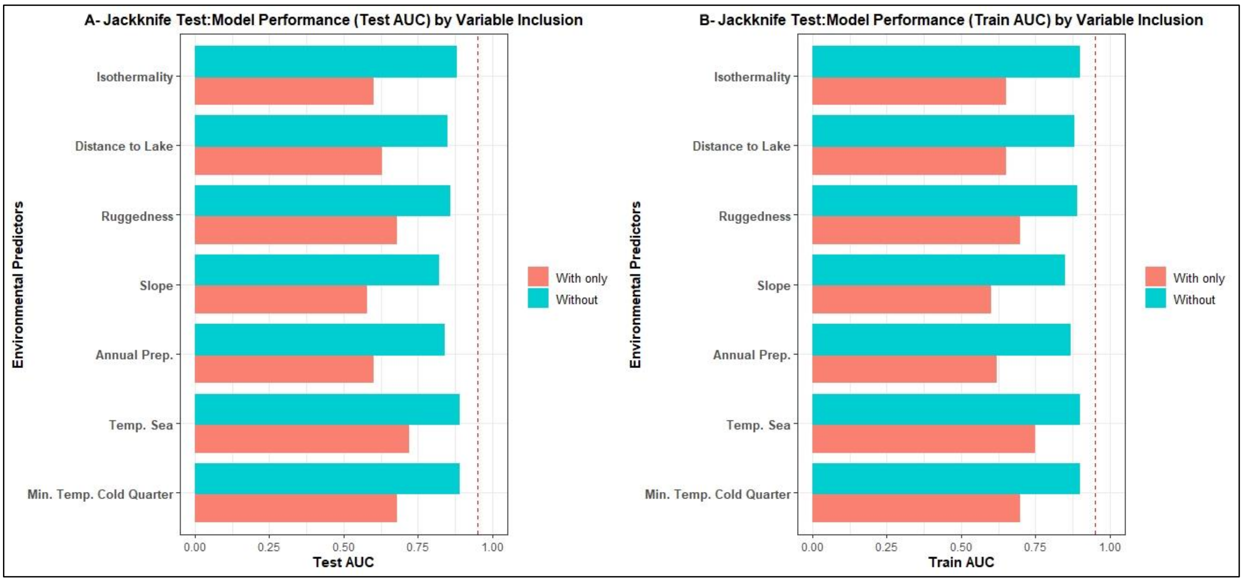

Figure 4.2.2. Jackknife test results for both test AUC (A) and Train AUC (B) models. Test AUC (A): shows the accuracy performance of the model on the test data. Using variables alone (red) and running without them (blue) are compared. Train AUC (B): Shows the model's performance on the training data.

The Response Curves (Figure 4.2.3, Panels A-G) illustrate how the predicted probability of presence for the Cilician water frog lineage changes across the range of each environmental variable, holding all other variables at their average values. These curves provide insights into the lineage' specific ecological niche and the nature of each variable's influence:

- A: Isothermality: The Cilician water frog lineage is unlikely to be found in areas with low isothermality values. Its chances of being present increase significantly when isothermality reaches 30-35. After that point, the probability remains elevated, with even higher values being attained. This indicates that the water frogs belonging to Cilician lineage prefers places with stable daily and annual temperatures.
- B: Distance to Lake: The probability of presence is highest at very short distances to lakes (close to 0 km). A significant decrease in probability is observed at approximately 0.5 km, and this probability remains at a lower, stable level as the distance to a lake increases. This indicates a strong preference for proximity to lacustrine habitats.

- C: Ruggedness: The probability of presence is very high in areas of low ruggedness (close to 0). The lineage exhibits a marked decline in abundance as the ruggedness of the terrain increases, beyond approximately 0.2, suggesting a behavioral adaptation that avoids highly rugged terrain.

- D: Slope: The probability of the lineage being present stays high across a range of slope values. This indicates that, within the range we studied, slopes do not limit the lineage's ability to live, thereby increasing the likelihood of occurrence.

- E: Annual Precipitation: The probability of presence is found to be minimal in conditions of low annual precipitation. The data demonstrates a precipitous increase in probability commencing at approximately 500-750 mm, with a subsequent peak at elevated precipitation levels. This finding suggests that the lineage requires sufficient annual rainfall to thrive.

- F: Temperature Seasonality: The probability of presence is highest at lower temperature seasonality values. It shows a significant drop around a seasonality of 7000-8000, and then a slight increase before stabilizing at a moderate probability for very high seasonality. This implies a preference for less extreme seasonal temperature variations.

- G: Minimum Temperature Cold Quarter: The probability of presence is very low at extremely low minimum temperatures of the cold quarter. It begins to increase noticeably around -50°C to 0°C and sharply rises to its highest probability as the minimum temperature of the cold quarter becomes warmer, particularly above 0°C. This indicates a strong preference for warmer minimum temperatures during the coldest period of the year.

The response curves illustrate the significant impact of temperature, rainfall, proximity to water bodies, and land features on the habitat of the Cilician water frog lineage. This finding is consistent with the analyses of the most significant factors and provides clear insight into how these elements affect the Cilician lineage.

.

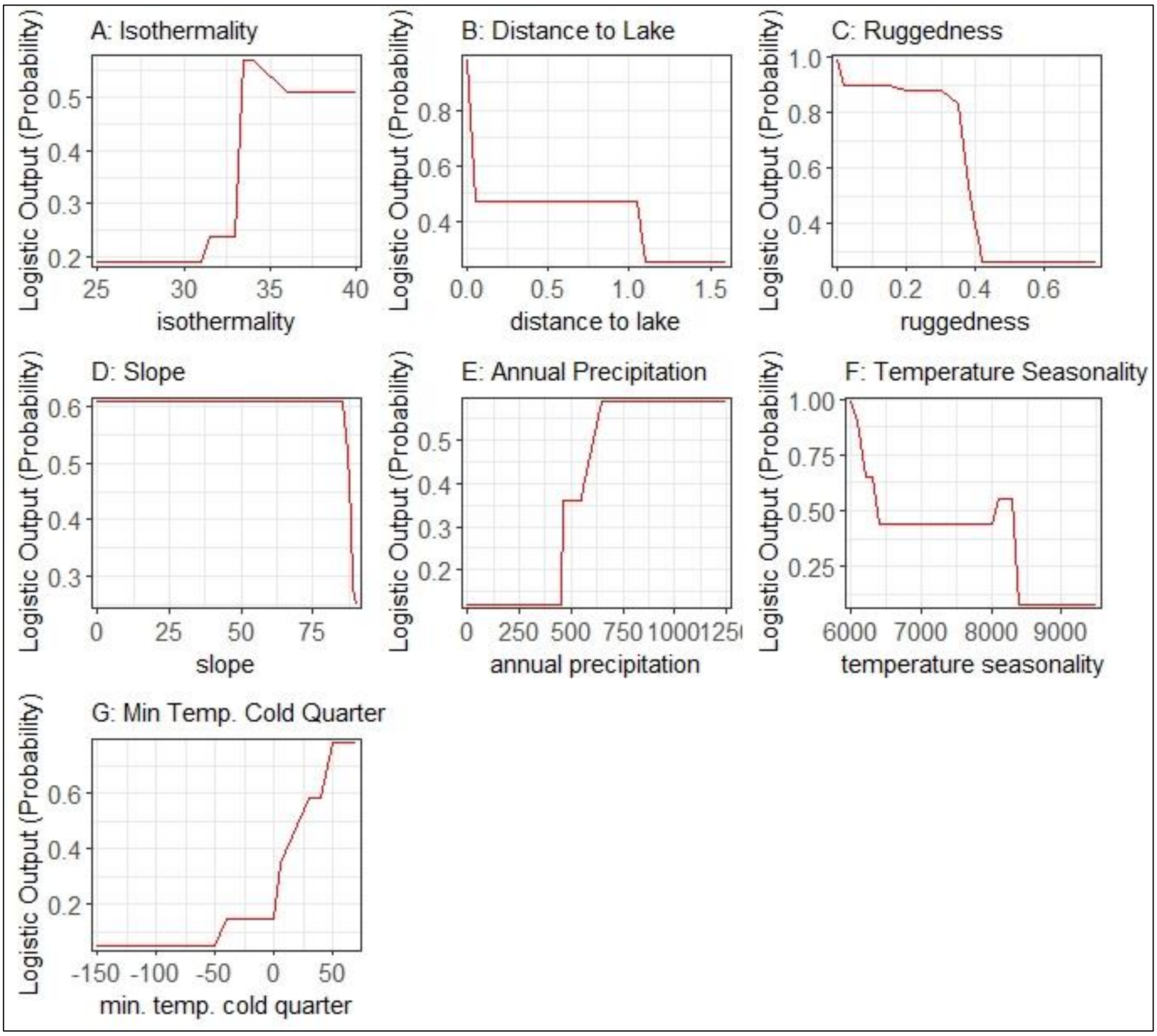

Figure 4.2.3. Response curves showing the key environmental predictors for Cilician lineage water frog lineage (*P. cf. bedriagae 1*). The X-axis represents the species' response to changes in these variables, while the Y-axis displays the logistic probabilities of the Cilician lineage. Isothermality (A), distance to lakes (B), ruggedness (C), slope (D), annual precipitation (E), temperature seasonality (F), minimum temperature cold quarter (G).

4.3. Predicted Habitat Suitability and Current Distribution

The MaxEnt model was used to create habitat maps for the Cilician water frog lineage. The maps presented herein illustrate the potential habitat of the water frogs within the designated study area (see Figure 4.3.1). To make these maps, we applied the MSS threshold to the predicted probabilities. This process turned the suitability scores into simple "suitable" or "unsuitable" categories for the habitat.

Predicted Habitat Suitability (Figure 4.3.1A) displays a continuous gradient of environmental suitability across the landscape, with warmer colors (e.g., orange, yellow, light blue) indicating higher predicted probabilities of the Cilician water frog's presence. This map shows that a substantial expanse within the south-central region of Türkiye exhibits optimal conditions for the proliferation of the lineage. This matches the known geographic range of the Cilician lineage. There are also smaller areas exhibiting moderate suitability in other parts of the country, indicating the potential for less ideal habitats.

The application of the MSS threshold (specifically, the Minimum Training Presence threshold) to these predicted probabilities resulted in the Predicted Potential Habitat (Figure 4.3.1B). The delineation of areas identified as currently suitable habitat (shown in green) is clear in this binary map. The majority of the suitable habitat is concentrated in the southern region, particularly in the Cilician sub-region, extending outwards from the core high suitability areas observed in Figure 4.3.1A. This indicates that a significant portion of the continuous suitable areas falls above the defined threshold, thereby classifying them as ecologically viable for the lineage according to the model's parameters.

Finally, the Estimated Distribution Range (Figure 4.3.1C) illustrates the presumed current geographical extent of the Cilician water frog's presence (shown in brown). The map reveals a more refined and somewhat smaller area compared to the overall predicted potential habitat, focusing on a compact region within south-central Türkiye. This estimated distribution range is likely to represents the most robust and consistently suitable areas, or perhaps the observed and confirmed localities of the lineage within the broader predicted potential habitat. The differences between Figure 4.3.1B and 4.3.1C suggest a refinement from potential habitat to a more conservative estimate of the actual distribution, possibly reflecting additional biological or ecological constraints not fully captured by the environmental predictors, or alternatively representing the known extent of its range.

Collectively, these maps demonstrate that the Cilician water frog's current suitable habitat and estimated distribution are primarily confined to a specific geographical area within Türkiye, driven by the key environmental variables identified in previous sections. The predicted habitat suitability provides a comprehensive overview of potential suitable areas, while the binary maps offer a clearer delineation of the most probable current range.

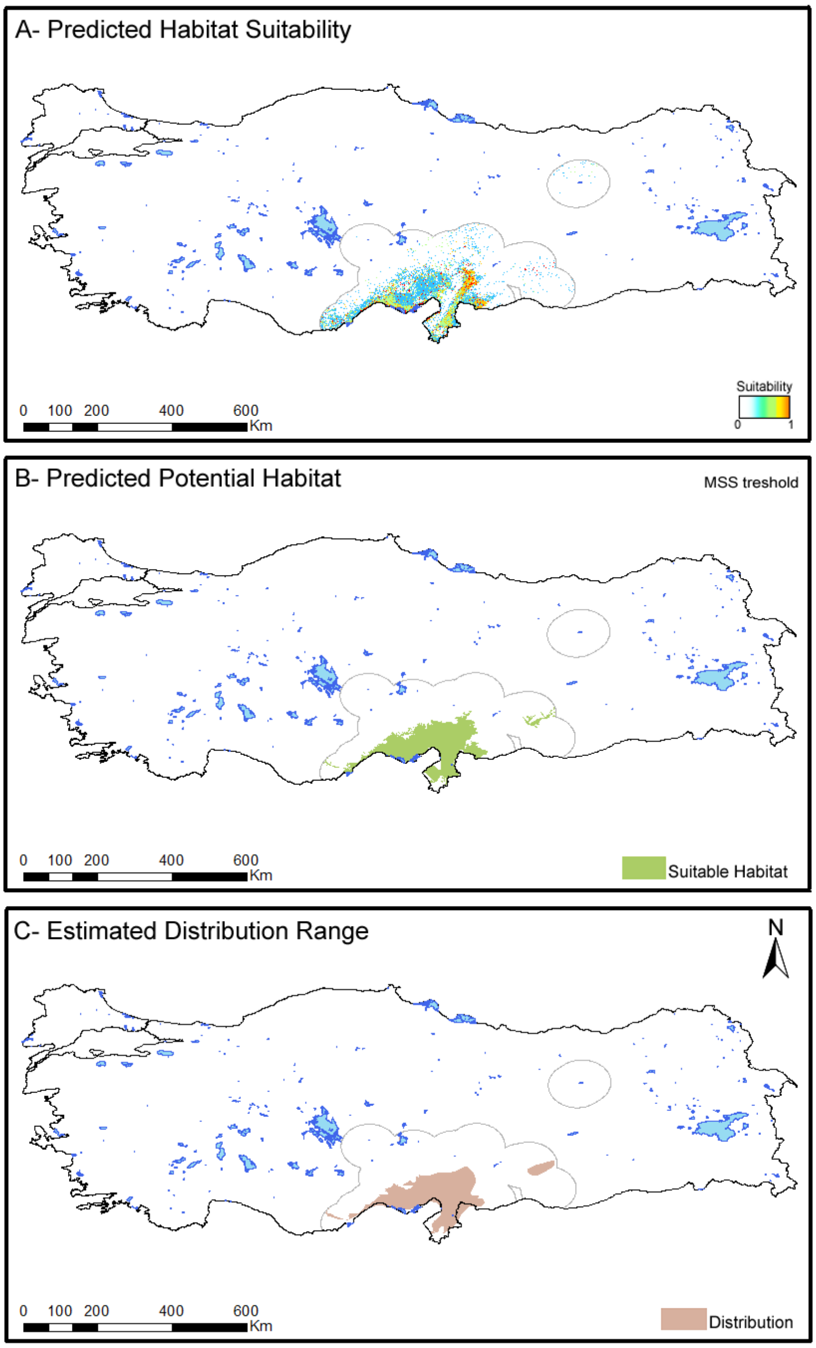

Figure 4.3.1. Binary habitat suitability maps were generated by applying the MSS threshold to the predicted probabilities. (A) Shows current potential suitable habitats for the Cilician lineage. (B) Shows the current predicted potential habitat and (C) shows current estimated distribution range.

4.4. Projected Future Habitat Suitability and Distribution under Climate Change Scenarios

To assess the potential impact of climate change on the Cilician water frog's habitat, the optimized MaxEnt model was projected onto future climate scenarios from CMIP6, specifically GCM-245 (low carbon emission scenario) and GCM-585 (high carbon emission scenario) for the years 2030, 2050, 2080, and 2100. For each time step and scenario, predicted habitat suitability, potential habitat (derived using the MSS threshold), and estimated distribution range were generated.

4.4.1 Projections for 2030

For the year 2030, both emission scenarios (GCM-245 and GCM-585) show a general pattern of habitat shift and potential contraction for the Cilician water frog lineage. Importantly, a noticeable shift towards the northern regions of Türkiye is evident in the predicted suitable areas.

- Predicted Habitat Suitability (Figure 4.4.1.1A and 4.4.1.1B): Under GCM-245 (low emission), the highly suitable areas (red/orange) remain concentrated in the south-central region of Türkiye, largely similar to the current distribution, but with some localized shifts and an emerging trend of increased suitability further north. Under GCM-585 (high emission), there appears to be a slight reduction in the extent and intensity of the highest suitability areas, particularly at the periphery of the core suitable region. This observation suggests an initial negative impact from increased emissions, coupled with an indication of northward expansion of potential suitability.
- Predicted Potential Habitat (Figure 4.4.1.1C and 4.4.1.1D): The binary potential habitat maps (green areas) indicate that under GCM-245, the suitable habitat in 2030 largely maintains its current extent, although some fragmentation or minor shifts might occur, particularly with new patches appearing in northern regions. In contrast, under GCM-585, there is a visually noticeable reduction in the contiguous suitable habitat, with more isolated patches appearing. This suggests increased pressure on the lineage' range even in the near future, alongside a more evident shift of suitable areas to the north.
- Estimated Distribution Range (Figure 4.4.1.1E and 4.4.1.1F): The estimated distribution range (brown areas) for 2030 reflects these trends. Under GCM-245, the core distribution remains relatively stable but hints at new suitable areas to the north.

However, under GCM-585, the estimated distribution range appears to contract slightly, becoming more fragmented and emphasizing the impact of higher emissions even within a decade, with suitable areas indicating a clear northward displacement**.**

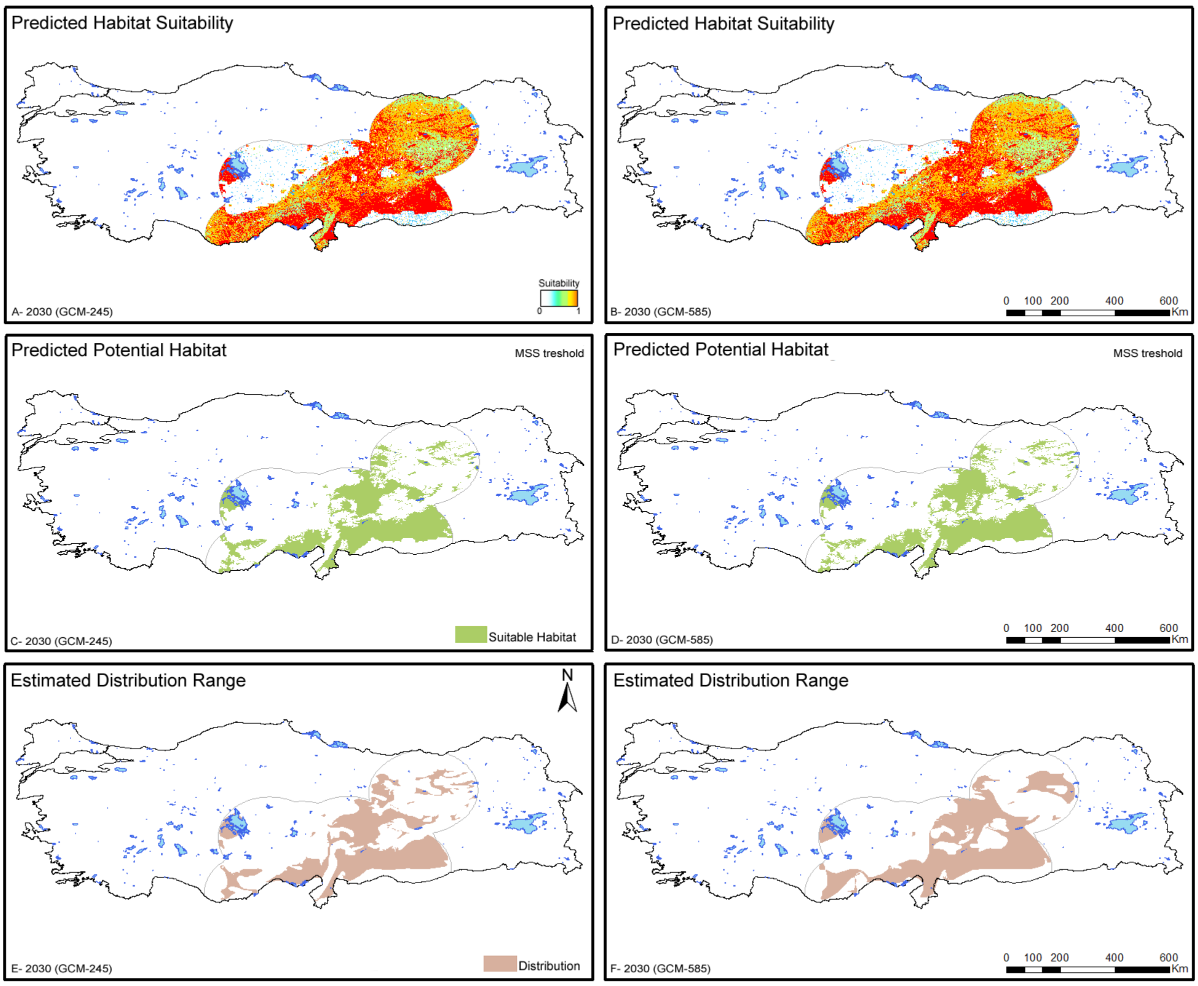

Figure 4.4.1.*1.* 2030 Cilician lineage distribution and potential habitat suitability models. (A) Shows potential habitat suitability for the lineage in 2030 low carbon emission scenario (GCM-245). (B) Shows the high carbon emission scenario's (GCM-585) predicted habitat suitability. (C) Shows where the lineage will be potentially distributed in GCM-245. (D) Shows the high carbon emission scenario for the distribution (E) shows the distribution range in 2030 GCM-245. (F) Shows the estimated distribution range for 2030 GCM-585.

4.4.2 Projections for 2050

By 2050, the divergences between the low and high emission scenarios become more pronounced, indicating a clearer impact of climate change on the lineage's habitat, with the northward shift becoming increasingly prominent.

- Predicted Habitat Suitability (Figure 4.4.2.1A and 4.4.2.1B): In GCM-245, the highly suitable areas generally persist, though there might be some subtle shifts or minor reductions compared to 2030, with a more defined northward expansion of suitability. Conversely, under GCM-585, the areas of highest suitability appear to shrink more noticeably, with a general decline in overall suitability across parts of the historical range, while also showing a distinct northward migration of remaining suitable patches.
- Predicted Potential Habitat (Figure 4.4.2.1C and 4.4.2.1D): The suitable habitat under GCM-245 has been shown to be relatively stable, maintaining much of the current potential range but with a clear expansion into northern areas. However, for GCM-585, the suitable habitat is significantly diminished and becomes more fragmented, indicating a substantial loss of climatically suitable areas for the Cilician water frog lineage, with the surviving suitable areas concentrated further north.
- Estimated Distribution Range (Figure 4.4.2E and 4.4.2F): The estimated distribution range for 2050 under GCM-245 shows a moderate contraction in the south but a clear emergence of new suitable areas in the northern parts of the country. Critically, under GCM-585, the estimated distribution range experiences a more severe reduction and fragmentation, with the remaining distribution heavily biased towards northern locations, suggesting significant range loss and a pronounced northward shift for the lineage.

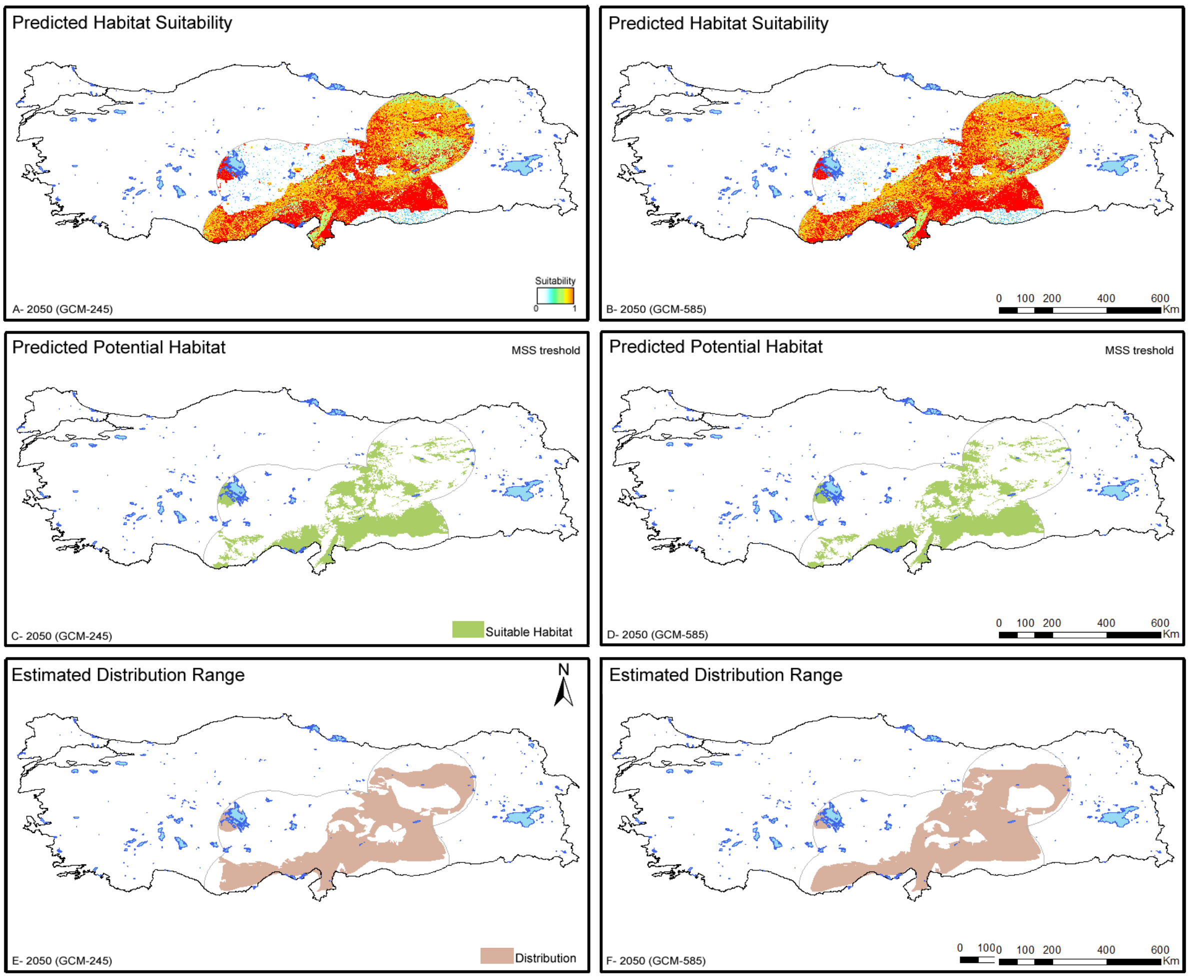

Figure 4.4.2.1. 2050 Cilician lineage distribution and potential habitat suitability models. (A) Shows potential habitat suitability for the lineage in 2050 low carbon emission scenario (GCM-245). (B) Shows the high carbon emission scenario's (GCM-585) predicted habitat suitability. (C) Shows where the lineage will be potentially distributed in GCM-245. (D) Shows the high carbon emission scenario for the distribution (E) shows the distribution range in 2050 GCM-245. (F) Shows the estimated distribution range for 2050 GCM-585.

4.4.3 Projections for 2080

The projections for 2080 reveal a more critical situation for the Cilician water frog, with noticeable declines in suitable habitat, particularly under the high emission scenario, and a continued, more drastic northward shift of the remaining suitable areas.

- Predicted Habitat Suitability (Figure 4.4.3.1A and 4.4.3.1B): Under GCM-245, while some regions of high suitability remain, their extent is clearly reduced in comparison to earlier timeframes. These regions are progressively situated in more northerly latitudes. Under GCM-585, a substantial decline in high suitability areas has been observed. A significant proportion of the previously suitable habitat has become moderately or marginally suitable, with any remaining high suitability restricted to the extreme north.

- Predicted Potential Habitat (Figure 4.4.3.1C and 4.4.3.1D): The suitable habitat under GCM-245 continues to contract, showing further fragmentation, with the bulk of the remaining suitable areas now located in the northern half of Türkiye. For GCM-585, the projected suitable habitat is severely restricted, appearing as highly fragmented and significantly smaller patches, almost exclusively in the northern part of the country, indicating severe habitat loss and a near-complete northward displacement.
- Estimated Distribution Range (Figure 4.4.3.1E and 4.4.3.1F): The estimated distribution range in 2080 under GCM-245 is considerably smaller than current estimates and has clearly shifted towards the north. Under GCM-585, the distribution range is predicted to be severely reduced and become highly fragmented, with a predominance of occurrence in the northernmost regions. This may result in critical population isolation or even extirpation in its traditional southern range.

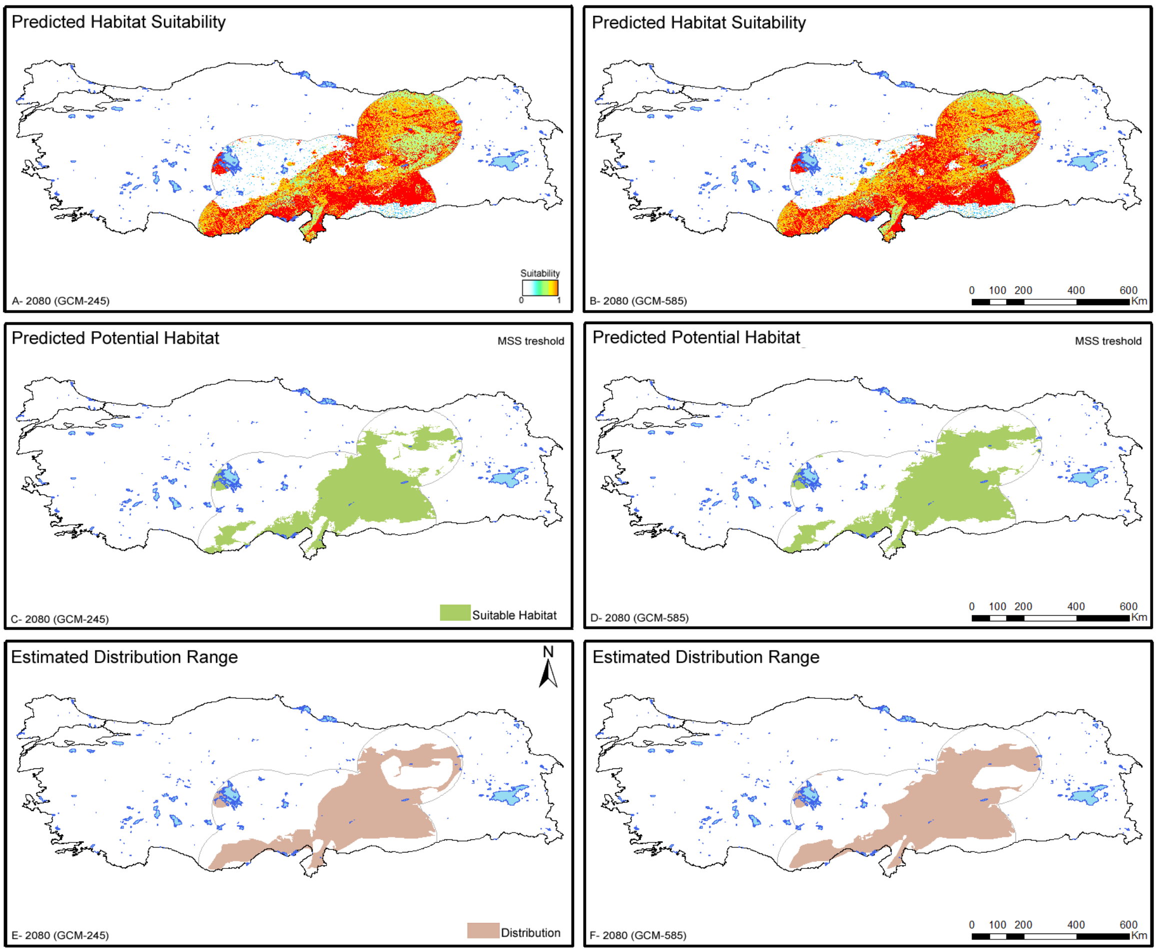

Figure 4.4.3.1. 2080 Cilician lineage distribution and potential habitat suitability models. (A) Shows potential habitat suitability for the lineage in 2080 low carbon emission scenario (GCM-245). (B) Shows the high carbon emission scenario's (GCM-585) predicted habitat suitability. (C) Shows where the lineage will be potentially distributed in GCM-245. (D) Shows the high carbon emission scenario for the distribution (E) shows the distribution range in 2080 GCM-245. (F) Shows the estimated distribution range for 2080 GCM-585.

4.4.4 Projections for 2100

By the end of the century (2100), the model projects the most severe impact on the Cilician water frog's habitat, especially under the high emission scenario, with the lineage' range almost entirely confined to newly suitable northern areas or drastically reduced elsewhere.

- Predicted Habitat Suitability (Figure 4.4.4.1A and 4.4.4.1B): Under GCM-245, the remaining areas of high suitability are minimal and highly fragmented, with a pronounced shift towards the northern parts of Türkiye. For GCM-585, the predicted habitat suitability shows a dramatic decrease, with only a few areas remaining highly suitable, and these are exclusively in the far north, indicating widespread loss of climatically suitable conditions in its traditional range.

- Predicted Potential Habitat (Figure 4.4.4.1C and 4.4.4.1D): The suitable habitat under GCM-245 is predicted to be significantly diminished and highly fragmented, with almost entirely confined to northern regions. Under the GCM-585 scenario, the suitable habitat is projected to be extremely limited, with only isolated, small patches remaining, primarily in the northern mountainous regions. This suggests a substantial loss of suitable habitat across its historical range and a forced retreat northward.
- Estimated Distribution Range (Figure 4.4.4.1E and 4.4.4.1F): The estimated distribution range for 2100 under GCM-245 shows a drastic reduction from the current range, with the remaining distribution heavily concentrated in the northern regions. Under GCM-585, the estimated distribution range is projected to be reduced to very small, scattered remnants, almost exclusively in the northern parts of Türkiye. This is due to highlighting a severe threat of extirpation across much of its current range by the end of the century under a high-emission future, with a clear and substantial northward range contraction.

The projections consistently indicate a downward trend in the suitability of habitats and the distribution range of the Cilician water frog, across all future scenarios and timeframes. Critically, these declines are accompanied by a consistent and increasingly severe northward shift of suitable habitat. This suggests that the lineage may need to migrate to higher latitudes or elevations to track suitable climatic conditions. The negative impacts are markedly more severe under the high carbon emission scenario (GCM-585), emphasizing the critical role of global emission trajectories in shaping the future survival of this lineage and forcing a significant geographical displacement.

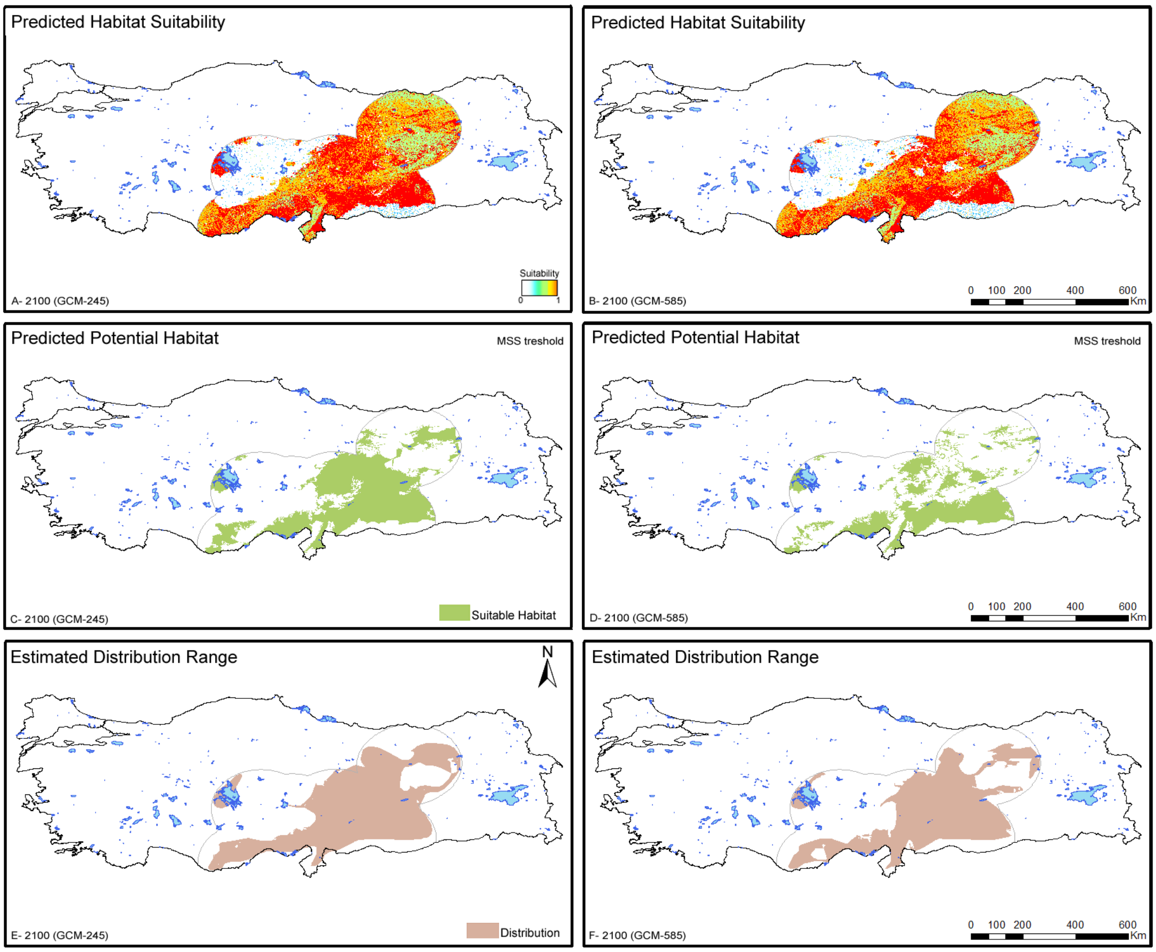

Figure 4.4.4.1. 2100 Cilician lineage distribution and potential habitat suitability models. (A) Shows potential habitat suitability for the lineage in 2050 low carbon emission scenario (GCM-245). (B) Shows the high carbon emission scenario's (GCM-585) predicted habitat suitability. (C) Shows where the lineage will be potentially distributed in GCM-245. (D) Shows the high carbon emission scenario for the distribution (E) shows the distribution range in 2100 GCM-245. (F) Shows the estimated distribution range for 2100 GCM-585.

4.5 Projected Distribution Area Changes

Figure 4.5.1 presents a bar chart illustrating the projected changes in the total distribution area (in square kilometers) for the Cilician water frog lineage, comparing the current estimated range with future projections under different climate change scenarios (GCM-245 and GCM-585) for the years 2030, 2050, 2080, and 2100.

The graph shows a significant increase in the predicted distribution area for the Cilician water frog lineage in the future, in comparison to the current area of approximately 2,000,000 km^2. This suggests that the climatically suitable range for the Cilician lineage may expand under future climate conditions. However, geographical maps (Figures 4.4.1.1-4.4.4.1) also show evidence of changes in its range.

- Initial Expansion (2030): The 2030-245 and 2030-585 scenarios both show a substantial increase in distribution area, reaching approximately 8,200,000 km² and 8,000,000 km², respectively. This represents a significant expansion of over four times in the current distribution area.
- Moderate Fluctuation (2050): By 2050, the distribution areas for both scenarios (2050-245 and 2050-585) show a slight decrease compared to 2030, settling at approximately 7,400,000 km² to 7,500,000 km². Although there is a minor contraction from 2030, this still signifies a considerable increase compared to the current distribution.
- Peak Expansion (2080): The most notable expansion is projected for 2080. The 2080-245 scenario shows the most extensive predicted distribution area, exceeding 11,000,000 km², while the 2080-585 scenario also shows a substantial increase, reaching approximately 12,000,000 km². This suggests that by 2080, climatically suitable conditions might become widespread across new regions.
- Slight Contraction (2100): Towards the end of the century, by 2100, there is a projected decrease in the overall distribution area compared to 2080, though it still remains considerably larger than the current area. The 2100-245 scenario shows an area of approximately 11,000,000 km², while the 2100-585 scenario projects a further reduction to around 7,300,000 km². This late-century decline, particularly under the high-emission scenario, suggests that while an initial expansion is predicted, extreme climate changes may eventually lead to some loss of suitability even in newly colonized areas.

In summary, the bar chart illustrates a dynamic response of the Cilician water frog's potential distribution area to future climate change. Despite the visual evidence of geographical shifts (e.g., northward movement) and potential fragmentation in the detailed habitat maps, the overall climatically suitable area is predicted to expand significantly. The amount of land available for new habitats will change over time and depend on different scenarios for emissions. It will reach its highest point around 2080 and then start to decrease slightly by 2100, especially in high-emission scenarios. This suggests that although new habitats may emerge, the impact of climate change could lead to an overall loss or stabilization of suitable land.

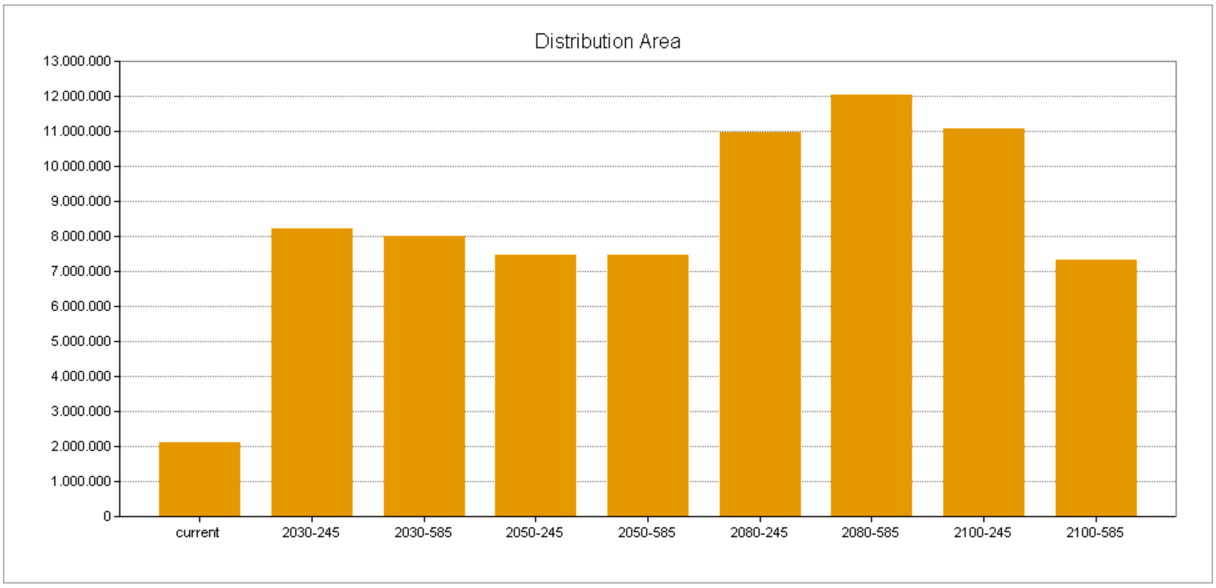

Figure 4.5.1. The bar chart illustrates the total distribution area of the Cilician lineage (in square meters) for the current period and future projection results. A significant increase in distribution area is observed across all future scenarios compared to the current state, suggesting a potential expansion under future climate conditions.

5. DISCUSSIONS

5.1. Model Performance and Optimization Success

The primary goal in improving the model was to develop a robust and reliable predictive model for the Cilician water frog lineage. This was achieved by adjusting the default settings of the MaxEnt framework [37]. The results in the section of the document entitled "Optimized Model Outputs and Performance Metrics" provide clear evidence show that this approach was successful.

The application of the varSel function played a crucial role in enhancing model performance. It is possible to refine the variable set from the initial 17 environmental predictors by systematically reducing multicollinearity. This can be achieved by using a Spearman's rho of 0.80 as a cut-off point. The result of this process is that the variable set is refined to seven key predictors. This approach is in accordance with the established best practices in species distribution modeling, where the reduction of redundant variables has been shown to significantly improve model generalization and reduce overfitting [117], [120], [137]. The improvement in AUC values post-varSel processing—from an initial training AUC of 0.701 and test AUC of 0.637 to the final optimized model's training AUC of 0.965 and test AUC of 0.881—provides strong evidence that the elimination of less influential and correlated variables directly enhanced the model's predictive accuracy and reliability [48].

The substantial increase in both training and test AUC values after optimization is particularly noteworthy. An initial test AUC of 0.637 suggests a model with moderate discriminatory capacity, bordering on acceptable according to Navarro [136], who suggests an AUC above 0.7 as acceptable and above 0.8 as very good [138]. The optimized model with a test AUC score of 0.881, which places it in the "very good" category. This score indicates that the model can effectively distinguish between areas where the Cilician water frog lineage is present and absent [48]. The significant improvement in performance underscores the efficacy of the methodologies employed for fine-tuning and selecting variables. The ROC curves displayed in Figures 4.1.2 and 4.1.3 visually reinforce these findings, indicating that the curve of the optimized model is significantly nearer to the upper-left corner. This shift suggests that the model exhibits increased sensitivity and specificity.

To sum up, the careful optimization process, especially the tactical minimization of environmental predictors using the varSel function, played a crucial role in converting a model initially exhibiting moderate performance into a highly effective and precise predictive instrument. The model, which has been optimised, demonstrates strong AUC performance and provides a solid foundation for evaluating the impact of future climate change scenarios on the distribution of the Cilician water frog lineage [138]. This level of model performance is essential for reliable conservation planning and decision-making in the face of environmental shifts.

5.2. Key Environmental Drivers of Habitat Suitability

The MaxEnt model applied to the Cilician water frog lineage (*P. cf. bedriagae* 1) provides insights into the factors influencing its habitat. The section entitled "Key Environmental Variables and Their Influence on Target Species" emphasizes significant environmental elements that exert a significant influence on the distribution of the lineage in question. The process of choosing and refining these factors was very effective. It allowed us to identify the main predictors and the elucidation of their specific impact on the Cilician water frog lineage.

The findings from the Percentage Contributions of Environmental Predictors (Figure 4.2.2) and the Optimized Model Variable Importance Permutation analysis (Table 4.2.1) consistently highlight temperature-related variables, particularly the minimum temperature of the cold quarter and the temperature seasonality, as paramount drivers of the Cilician water frog's distribution. The significant contributions of 25% and 20.5%, along with the substantial essential scores of 21.7 and 32.9 for these variables, demonstrate their crucial importance. The Cilician water frog lineage is dependent on specific temperature conditions, making it sensitive to temperature changes, especially during periods of cool weather and seasonal shifts. Particularly, the Cilician lineage was found to be exclusively present in the Çukurova plain [84], [85], [86], [87], [101], which provides a rationale for its specific climatic requirements and adaptations in those conditions for survival and growth. This is consistent with ecological principles, as amphibians, being ectotherms, are dependent on surrounding temperatures for optimal growth, reproduction, and survival [139], [140]. Beyond temperature, ruggedness emerged as another topographic factor that exerted a significant influence, contributing approximately 23.5% to the overall variance and exhibiting a permutation importance of 9.8. The response curve for ruggedness (Figure 4.2.3, Panel C) further clarifies this relationship, showing a high probability of presence in areas of low ruggedness and a sharp decline as ruggedness increases. This means that the Cilician water frog lineage may prefer flat or simple areas. This preference may be due to these areas are more conducive to movement, offer suitable habitats for breeding, or reduce exposure to harsh conditions, aligning with extant literature on landscape attributes impacting frog habitat selection [141], [142].

In comparison, findings for another *Pelophylax* lineage, *P. caralitanus*, highlight both similarities and differences in environmental drivers in a study by Kıraç et al. [31]. The bioclimatic variables that limit the distribution of *P. caralitanus* are Temperature Seasonality, Min Temperature of Coldest Month, Temperature Annual Range, Mean Temperature of Wettest Quarter, Precipitation of Driest Month, and Precipitation of Driest Quarter. Notably, both species are influenced by temperature seasonality a key minimum temperature variable (minimum temperature of the cold quarter for the Cilician water frog and minimum temperature of the coldest month for the *P. caralitanus*), suggesting a shared sensitivity to low temperature conditions. It is important to note that the study on *P. caralitanus* by Kıraç et al. [31] did not include topographic or water-related variables, which were found to be essential for the Cilician water frog's distribution. Furthermore, the *P. caralitanus* study used MaxEnt's default parameters without optimization, which raises questions about the full reliability of its results.

The results of Jackknife Test (Figure 4.2.1, Panels A and B) for the Cilician water frog unequivocally support the dominant roles of the minimum temperature of the cold quarter, the temperature seasonality, and the ruggedness. Exclusion of these variables resulted in a significant decline in the model's predictive ability. Each variable showed strong predictive power on its own. This proves that these variables are essential for predicting the lineage' presence. The consistency between the training and test AUC results in the Jackknife analysis further assures that these identified key variables are not merely artifacts of the training data but are truly indicative of environmental preferences that generalize well to new data.

The Response Curves (Figure 4.2.3) collectively provide a comprehensive picture of the Cilician water frog's environmental niche. The strong preference for living close to the lake shows that the lineage is dependent on water or wet areas for survival and reproduction [143]. The positive correlation with annual rainfall at higher levels highlights their need for sufficient moisture, which is crucial for the skin's respiration and overall hydration. While

Slope (Panel D) appeared to have a consistently high probability of presence across its range, suggesting less direct limitation within the observed values, the combined influence of other topographic features, such as ruggedness, remains significant.

The study of environmental factors reveals that the Cilician water frog lineage inhabits areas characterized by a combination of cold temperatures, rugged terrain, and water sources such as lakes and rainfall. The data indicate the frog's current needs and help us predict how it might respond to climate change and land use in the future. This information is important for creating effective conservation plans for the protection of this endangered lineage.

5.3. Current Distribution and Habitat Suitability of the Cilician Water Frog Lineage

The comprehensive analysis of the Cilician water frog's current habitat suitability and distribution, as presented in Section 4.3, offers fundamental insights into the lineage' ecological requirements and spatial occupancy. The MaxEnt model successfully identified climatically suitable areas, largely corroborating the known geographic range of the lineage and providing a data-driven basis for understanding its spatial patterns.

The Predicted Habitat Suitability map (Figure 4.3.1A) displays a continuous gradient of suitability, thereby providing a visual representation of the core suitable region in south-central Türkiye. This concentration corresponds perfectly with the lineage's type locality and known distribution, thereby validating the model's ability to capture its fundamental niche. The presence of moderately suitable patches in other areas of Türkiye, while not representing optimal habitat, suggests the existence of regions where marginal populations might exist or where the species could potentially colonize under different conditions, assuming dispersal capabilities. This continuous output is valuable for identifying areas for further investigation beyond known occurrences.

The transition from continuous suitability to a binary Predicted Potential Habitat map (Figure 4.3.1B), through the application of the Minimum Training Presence (MTP/MSS) threshold, provides a clear and actionable delineation of suitable areas. This threshold, by definition, includes all locations where the lineage has been observed, thus capturing the full extent of its known environmental tolerance. The concentration of this suitable habitat in the Cilician sub-region further reinforces the environmental parameters identified as crucial for the lineage in previous sections (e.g., specific temperature regimes, proximity to water). This binary map serves as a practical tool for conservation planning, highlighting areas that currently possess the necessary climatic conditions for the lineage' s survival.

The Estimated Distribution Range map (Figure 4.3.1C), representing a more refined and often smaller area than the predicted potential habitat, is particularly informative. The distinction between the broader concept of "potential habitat" and the more limited concept of "estimated distribution range" is of ecological significance [144], [145]. It implies that while certain areas may be climatically suitable according to (as per the model's parameters), other factors not explicitly included as environmental predictors in this model (e.g., biotic interactions, dispersal barriers, historical contingencies, land-use practices beyond broad land cover) might limit the species' actual occupancy. Alternatively, it may be interpreted as a conservative estimate based on confirmed observations, highlighting the distinction between climatically possible habitat and realized niche [146]. This refinement is critical for understanding the complexities of species distribution and for focusing conservation efforts on areas where the species is most likely to persist.

In conclusion, these maps collectively demonstrate that the current distribution of the Cilician water frog's lineage is largely confined to a specific geographical area in south-central Türkiye, strongly driven by the key environmental variables identified in the model. The MaxEnt model successfully provided both a comprehensive overview of potential suitable areas and a clearer delineation of the most probable current range. This fundamental understanding of the lineage' current spatial ecology is indispensable for the evaluation of future climate change impacts and the development of effective conservation strategies.

5.4. Projected Habitat Shifts and Ecological Implications of Climate Change

The modeling results consistently project a northward shift in both the potential habitats and the estimated distribution range of the Cilician water frog lineage in future years, supported by other studies by Kıraç et al. [31] and Elverici et al. [147]. This observed range expansion and geographical displacement are indicative of significant environmental changes and have several profound ecological and conservation implications.

The increase in suitable habitats for amphibians is likely occurring in areas such as eastern and northern Anatolia, due to higher humidity and warmer temperatures. These modifications enhance the appeal of these areas for amphibians. Amphibians need warm and humid environments to thrive. They are susceptible to changes in climate conditions. This finding indicates a potential northward shift in the distribution of the species' natural environment, which is characterised by a Mediterranean climate. This phenomenon is supported by recent research, as indicated by Bağçaci et al. [13], Kıraç et al. [31], Y.

Boussalim et al. [148], and Wang et al. [149], who discuss similar climate shifts with Elverici et al. [147]. Previous research has documented this shift in numerous Mediterranean amphibian species, such as the related species *Pelophylax caralitanus* and *P. bedriagae* [147]. These species are projected to lose many of their current habitats in southern Anatolia and establish new ones in the western and northern parts of the region [31], [147]. Despite the known difficulties in modeling *P. bedriagae* due to an inaccurate distribution [147], the area is inhabited by three separate species. Similarly, the modeling of *P. caralitanus* is hindered by a lack of model optimization [31]. Nevertheless, both studies highlight the significant importance of precipitation for *Pelophylax* species. The physiological needs of these species for precipitation suggest that precipitation and temperature will move northward from southeast Türkiye, with humidity being a crucial factor for the Mediterranean climate [150]. Furthermore, the possibility of anticyclonic circulation influencing the Mediterranean climate could lead to a cooling effect in some areas thereby facilitating this northward shift. While the annual precipitation's percent contribution to the model was lower than expected, its influence remains significant due to these overarching climate changes, and the risk of negative impacts from altered humidity in southern Türkiye is notably high.

Türkiye is experiencing a shift in the distribution of animals and plants due to the effects of climate change. This shift may also impact other Mediterranean countries, such as Morocco, which could face similar environmental changes. Türkiye is currently experiencing significant changes, with Bağçaci et al. [13] reporting an unusual rate of warming in the region compared to earlier CMIP5 projections. The models' consistent prediction of a genre shifts in suitable climate zones, mirroring the climatic characteristics directly tied to habitat and ecosystem parameters, aligns well with existing literature on climate change impacts within the sensitive Mediterranean hotspot. Interestingly, while Boussalim et al. [148] observed the most extensive expansion under SSP5-8.5 (high emission scenario) due to accelerated warming. The results of Species Distribution Areas show that the total projected suitable areas for SSP2-4.5 (low emission) and SSP5-8.5 are remarkably similar in terms of total square kilometers. In fact, the low-emission model of 2100 shows a much larger area increase than the high-emission model. This counter-intuitive finding could be attributed to the rapid warming mentioned by Bağçaci [13], which could lead to a quicker initial spread of the species to newly suitable regions by 2030 and its subsequent persistence there.

However, a closer examination of the predicted future habitat areas reveals a nuanced and potentially complex dynamic. While the geographical maps (Figures 4.3.2-4.3.5) clearly illustrate a significant northward shift in suitable habitat and a visible increase in fragmentation and localized loss within the lineage's current core range, the overall quantification of climatically suitable area (Figure 4.3.6) presents a different picture, projecting a substantial increase in total potential distribution area across all future scenarios compared to the current state. This apparent discrepancy is likely due to the model identifying vast new areas in northern Türkiye that become climatically suitable as temperatures rise, offsetting and, in terms of sheer acreage, exceeding the losses in the south. It is crucial to interpret this expansion caution; an increase in total climatically suitable area does not automatically translate to a proportional increase in viable habitat or population size. The ability of the Cilician water frog lineage to effectively colonize these recently suitable northern regions will depend heavily on a number of factors, including landscape connectivity, dispersal capabilities, the availability of specific microhabitats (e.g., proximity to lakes, low ruggedness, suitable precipitation regimes), and the absence of limiting biotic interactions or anthropogenic barriers [151]. While the lineage may find new places to survive as the climate changes, the separation of their current habitats and the difficulties of moving into new areas are still important issues for conservation [152]. This underscores the distinction between a species' fundamental niche, which refers to the climatic regions in which the species is able to thrive, and its realized niche, which denotes the actual areas of occupancy within these niches, particularly in contexts of rapid environmental change [153].

Beyond direct climatic shifts, human activities, particularly rapid urbanization in eastern and northern Anatolia, significantly influence the regional climate balances and, by extension, species habitats. The issues concerning urban expansion and its environmental consequences have been recognised since the 1992 and 1997 UN conferences. The accelerated urbanisation of Türkiye, driven by economic development and population growth, has demonstrably contributed to environmental degradation and rising CO2 emissions [154]. Urban development, characterized by multi-storey and high-rise buildings, alters wind flow and creates heat islands, impacting local rainfall regimes [155].

Ground temperature measurements in Mediterranean region reveal significant variations based on land use and presence of vegetation [14], [156], [157]. Empirical evidence from Hatay province further underscores the detrimental effects of urbanization on local climate [14]. According to Geçen et al. [14], while temperatures of 36 degrees were recorded in southeastern areas and 32.5 degrees in northwestern regions, these values – hovering around 30 degrees – were predominantly observed in urbanised, concreted zones. Even a small park within these cities demonstrated a cooling effect, lowering ground temperatures by up to 4 degrees [14], [157]. Industrial areas faced very high temperatures, often exceeding 40 degrees and reaching up to 45 degrees. In contrast, a nearby forest stayed much cooler at just 10 degrees [14]. This shows how important plants are in moderating heat, similar points also evident in previous studies that have measured the drought and heat in the region [14], [156], [157]. The analysis of temperature patterns in the Çukurova Basin indicates that agricultural practices have a substantial impact on the regional climate. When the land is not farmed, ground temperatures can reach 40 degrees. However, when crops are grown, these temperatures drop significantly to even 28 degrees [14]. This highlights the importance of land management for local climate conditions.

The direct link between climate crises and natural disasters, such as droughts and wildfires, presents a severe risk. Urban expansion in Türkiye has been shown to disrupt the balance between heat and humidity, which is important for amphibians. As temperatures are expected to rise in colder areas like eastern and northern Anatolia, it is more likely that this lineage will move north along major rivers like the Seyhan and Ceyhan. This prediction matches with the findings of the models. This observed expansion and shift into new geographical ranges also raise a critical question. Could the Cilician lineage, in its pursuit of suitable habitat, potentially become an invasive species in these new northern ecosystems? The ability of the species to adapt and expand into previously unsuitable habitats, as suggested by our projections, necessitates careful consideration of its potential ecological impacts on recipient ecosystems, including the risk of hybridization. As mentioned by Dufresnes et al. [158], such genetic intermixing between species may compromise the survival and reproductive success of individuals, while simultaneously undermining the adaptive fitness of local amphibian populations. These projected patterns underscore the critical need for targeted conservation strategies that not only aim to mitigate negative impacts but also adapt to the evolving climate landscape, including proactive assessments of the lineage's potential for invasiveness in newly colonized areas.

6. CONCLUSIONS

This study, employing an optimized MaxEnt model, provides A report that assesses the current and future habitat suitability and distribution of the Cilician water frog lineage *(Pelophylax cf. bedriagae* 1). It shows how different climate will significantly impact the future of the lineage. Currently, the Cilician water frog's distribution is closely tied to specific environmental variables, primarily the minimum temperature of the cold quarter, the temperature seasonality, and the ruggedness, with additional significant influences from the slope, the distance to lake, the annual precipitation, and the isothermality. The model accurately delineates its current core habitat in south-central Türkiye, validating the Cilician lineage' preference for warm, humid conditions near water bodies, as characteristic of Mediterranean climates.

However, projections under climate change scenarios (GCM-245 and GCM-585 for 2030, 2050, 2080, and 2100) paint a challenging picture. The most striking finding is a consistent and increasingly severe northward shift of the lineage' climatically suitable habitat across Türkiye. As temperatures rise and rainfall patterns change, the lineage will need to move from its usual southern habitat to find cooler and wetter areas in northern and eastern Anatolia. While the geographical maps visually emphasize this loss of historical range and growing habitat fragmentation in the south, the analysis of total predicted distribution area suggests a paradoxical net increase in climatically suitable habitat across Türkiye overall, peaking around 2080. This difference highlights an important detail: the total area is increasing because large new regions in the north are becoming suitable for the climate, which exceeds the loss occurring in the south. However, this expansion of the fundamental niche does not guarantee a corresponding expansion of the lineage' realized niche. The Cilician water frog lineage can successfully settle in new northern areas if it can move easily, find suitable habitats (such as specific water bodies and plants), and if there are no obstacles or harmful effects from humans. The observed changes and fragmentation create essential challenges for conservation. The lineage may have difficulty finding suitable conditions, which can lead to isolated groups and possible local extinctions in areas where they were once strong. Furthermore, the study underscores that these climate-induced shifts are compounded by anthropogenic pressures, particularly rapid urbanization. Urban development in important areas of Türkiye changes the local climate, creates hot spots in cities, and disrupts natural water systems. This human-driven landscape transformation directly impacts the heat-humidity balance crucial for amphibians, potentially exacerbating habitat loss and fragmentation even in climatically suitable areas.

In conclusion, the future of the Cilician water frog lineage is very uncertain. Although there may be additional areas that could support the frog due to climate change, the required move north and the expected splitting of its current habitat under both low and high emission scenarios necessitate urgent conservation efforts. Effective strategies must not only consider mitigating global climate change through emission reduction (given the more severe impacts under high emission scenarios) but also focus on habitat connectivity, the protection of critical northern refugia, and managing the local impacts of urbanization to facilitate the lineage' adaptation and long-term survival in a rapidly changing environment. Based on previous genetic research on this species, it can be said that Cilician water frogs will not have any difficulty in adapting to changing climatic conditions and refugia if these correct measures are taken, especially due to their allele richness [86], [87]. The potential for the lineage to become invasive in newly colonized northern ecosystems also warrants proactive ecological assessment and management.

This study, employing an optimized MaxEnt model, provides a detailed assessment of the current and future habitat suitability and distribution of the Cilician water frog lineage (*Pelophylax cf. bedriagae 1*), highlighting the significant impacts of climate change on its survival. Currently, the lineage's distribution is closely tied to specific environmental variables, primarily the minimum temperature of the cold quarter, temperature seasonality, ruggedness, and proximity to water bodies. The model accurately delineates its current core habitat in south-central Türkiye, validating the lineage's preference for warm, humid conditions near water bodies, characteristic of Mediterranean climates.

Projections under climate change scenarios (GCM-245 and GCM-585 for 2030, 2050, 2080, and 2100) reveal a consistent and increasingly severe northward shift of climatically suitable habitats across Türkiye. As temperatures rise and rainfall patterns change, the lineage will need to migrate from its traditional southern habitat to find cooler and wetter areas in northern and eastern Anatolia. While the total climatically suitable area may expand, habitat fragmentation, connectivity challenges, and anthropogenic pressures pose significant risks to the lineage's survival. The observed changes highlight the potential for population isolation and local extinctions in areas where the lineage was historically strong.

Furthermore, the study underscores the compounding effects of human activities, particularly rapid urbanization, which disrupt local climate balances and natural water systems [154]. These anthropogenic pressures exacerbate habitat loss and fragmentation, even in climatically suitable areas. Conservation strategies must address these challenges by focusing on habitat connectivity, protecting critical northern refugia, and managing the impacts of urbanization. Additionally, proactive measures should be taken to assess the lineage's potential for invasiveness in newly colonized northern ecosystems.

In conclusion, the future of the Cilician water frog lineage is highly uncertain. While climate change may create new areas of suitable habitat, the required migration northward and fragmentation of its current range necessitate urgent conservation efforts. Effective strategies must not only mitigate global climate change through emission reductions but also prioritize habitat restoration, connectivity, and protection. This study serves as a call to action for policymakers, conservationists, and researchers to collaborate in safeguarding this vulnerable amphibian lineage and the ecosystems it represents

REFERENCES

[1] K. Çiçek *et al.*, “Unsustainable Harvest of Water Frogs in Southern Turkey for the European Market,” *Oryx*, vol. 55, no. 3, pp. 364–372, May 2020, doi: https://doi.org/10.1017/s0030605319000176.

[2] N. Kaya, C. N. Özgül, T. Yetim, Ö. D. Yürekli, İ. Sarlak, and M. Tosunoğlu, “IMPACTS OF CLIMATE CHANGE ON BIODIVERSITY AND DISTRIBUTION OF ENDEMIC AMPHIBIANS IN TURKIYE,” in *THE BROAD SPECTRUM OF BIOLOGICAL SCIENCES*, S. Maraklı and M. Yılmazer, Eds., Üniversite Bulvarı 27310 Şehitkamil – Gaziantep,Türkiye: Gaziantep Üniversitesi Yayınevi, 2024.

[3] World Meteorological Organization, “State of the Global Climate 2023,” *World Meteorological Organization*, Mar. 15, 2024. https://wmo.int/publication-series/state-of-global-climate-2023

[4] M. Çınar, “Son 60 yılda Turkiye’deki 240 gölden 186’sı kurudu,” *DHA | Demirören Haber Ajansı*, Sep. 15, 2024. https://www.dha.com.tr/foto-galeri/son-60-yilda-turkiyedeki-240-golden-186si-kurudu-2505378/6 (accessed Oct. 02, 2024).

[5] D. Yıldız, “Göllerimiz Neden Kuruyor ?,” *Su Politikaları Derneği*, Sep. 03, 2024. https://supolitikalaridernegi.org/2024/09/03/gollerimiz-neden-kuruyor/ (accessed Oct. 11, 2024).

[6] L. Maiorano *et al.*, “Threats from Climate Change to Terrestrial Vertebrate Hotspots in Europe,” *PLOS ONE*, vol. 8, no. 9, pp. e74989–e74989, Sep. 2013, doi: https://doi.org/10.1371/journal.pone.0074989.

[7] J. A. Luedtke *et al.*, “Ongoing Declines for the World’s Amphibians in the Face of Emerging Threats,” *Nature*, vol. 622, Sno. 622, pp. 308–314, Oct. 2023, doi: https://doi.org/10.1038/s41586-023-06578-4.

[8] H. R. Akcakaya, C. C. Bilgin, and K. Çiçek, "More people eat frog legs than you might think – and humans are harvesting frogs at unsustainable rates," *The Conversation*,

Jun. 12, 2020. [Online]. Available: https://theconversation.com/more-people-eat-frog-legs-than-you-might-think-and-humans-are-harvesting-frogs-at-unsustainable-rates-137474. Accessed: Mar. 5, 2025.

[9] Ç. Akın and C. C. Bilgin, “Preliminary Report on the Collection, Processing and Export of Water Frogs in Turkey,” presented to KKGM, ODTÜ, Ankara, Türkiye, 2010. [in Turkish].

[10] Y. Fujihara, K. Tanaka, T. Watanabe, T. Nagano, and T. Kojiri, “Assessing the Impacts of Climate Change on the Water Resources of the Seyhan River Basin in Turkey: Use of Dynamically Downscaled Data for Hydrologic Simulations,” *Journal of Hydrology*, vol. 353, no. 1, pp. 33–48, May 2008, doi: https://doi.org/10.1016/j.jhydrol.2008.01.024.

[11] Ç. Tanrıverdi, A. Alp, A. R. Demirkıran, and F. Üçkardeş, “Assessment of Surface Water Quality of the Ceyhan River basin, Turkey,” *Environmental Monitoring and Assessment*, vol. 167, no. 1–4, pp. 175–184, Jun. 2009, doi: https://doi.org/10.1007/s10661-009-1040-4.

[12] M. Bayrak, “Çukurova Deltası: Arazi Kullanımı ve İnsan Ortam İlişkisi,” 2020, Available: https://nek.istanbul.edu.tr/ekos/TEZ/ET002735.pdf

[13] S. Ç. Bağçaci, I. Yucel, E. Duzenli, and M. T. Yilmaz, “Intercomparison of the Expected Change in the Temperature and the Precipitation Retrieved from CMIP6 and CMIP5 Climate projections: a Mediterranean Hot Spot case, Turkey,” *Atmospheric Research*, vol. 256, p. 105576, Jul. 2021, doi: https://doi.org/10.1016/j.atmosres.2021.105576.

[14] R. Geçen and D. Aytemus, “Determination of the Surface Temperature of Hatay Province by Using Thermal Remote Sensing Image and Its Relationship with the Land Forms and Land Cover,” *Çukurova Araştırmaları Dergisi*, vol. 8/3, no. 17, pp. 514–534, 2022, doi: https://doi .org/10.29228/cukar.66583.

[15] M. Bayrak, “Çukurova Deltası Kıyı Lagünlerinde Dönemsel Olarak Alansal Değişimler (1985-2022) Ve Ekolojik Risk Faktörleri,” *Uluslararası Anadolu Sosyal Bilimler Dergisi*, vol. 7, no. 2, pp. 532–547, Jun. 2023, doi: https://doi.org/10.47525/ulasbid.1302081.

[16] S. Öney, “Doğu Akdeniz’in Asıl Krizi İKLİM DEĞİŞİMİ,” *DergiPark*, vol. 3, no. 2, pp. 26–30, Jun. 2019, Accessed: Apr. 05, 2025. [Online]. Available: https://dergipark.org.tr/tr/pub/europ/issue/60585/892221/#article-authors-list

[17] Ç. Akın Pekşen and J. Plötner, “Anatolischer Wasserfroschkomplex,” in *Handbuch der Reptilien und Amphibien Europas, Band 5/III, Froschlurche III*, J. Plötner, Ed. Norderstedt, Germany: AULA-Verlag, 2025, pp. 259-292.

[18] R. A. Betts *et al.*, “Approaching 1.5 °C: How Will We Know We’ve Reached This Crucial Warming mark?,” *Nature*, vol. 624, no. 7990, pp. 33–35, Dec. 2023, doi: https://doi.org/10.1038/d41586-023-03775-z.

[19] E. Goniea, “Emotional and Behavioural Implications of Overshooting 1.5o C,” *Cambridge Journal of Climate Research*, vol. 1, no. 1, pp. 20–23, May 2024, Available: https://static.squarespace.com/static/63ed5e6e89bc8f1d5d9183c0/t/66341a0abed5c2414405b126/1714690570528/6632afb97ecc00eb75c7308c_CJCR+Tentative+Final+Draft+%28dragged%29.pdf

[20] S. Salimi, S. A. A. A. N. Almuktar, and M. Scholz, “Impact of Climate Change on Wetland ecosystems: a Critical Review of Experimental Wetlands,” *Journal of Environmental Management*, vol. 286, no. 286, p. 112160, May 2021, doi: https://doi.org/10.1016/j.jenvman.2021.112160.

[21] K. L. Erwin, "Wetlands and global climate change: the role of wetland restoration in a changing world," *Wetlands Ecology and Management*, vol. 17, no. 1, pp. 71–84, Nov. 2008. [Online]. Available: https://doi.org/10.1007/s11273-008-9119-1. Accessed: Mar. 4, 2025.

[22] C. Bellard *et al.*, “Vulnerability of biodiversity hotspots to global change,” *Global Ecology and Biogeography*, vol. 23, no. 12, pp. 1376–1386, Sep. 2014, doi: https://doi.org/10.1111/geb.12228.

[23] A. Çoban, "The effect of climate change on wetlands and the situation of wetlands in Turkey," *The Turkish Journal of Occupational and Environmental Medicine and Safety*, vol. 2, no. 1, pp. 8–20, Jun. 2017. [Online]. Available: https://dergipark.org.tr/tr/pub/turjoem/issue/31076/327729. Accessed: Mar. 5, 2025.

[24] J. Catalan et al., "Reduced precipitation can induce ecosystem regime shifts in lakes by increasing internal nutrient recycling," *Scientific Reports*, vol. 14, no. 1, pp. 1–12, 2024. [Online]. Available: https://www.nature.com/articles/s41598-024-62810-9.pdf. Accessed: Mar. 5, 2025.

[25] G. Kum and M. A. Çelik, “Impacts of Global Climate Change on the Mediterranean Region: Adana as a Case Study,” *Procedia - Social and Behavioral Sciences*, vol. 120, pp. 600–608, Mar. 2014, doi: https://doi.org/10.1016/j.sbspro.2014.02.140.

[26] M. T. Turp, T. Öztürk, M. Türkeş, and M. L. Kurnaz, "RegCM4.3.5 bölgesel iklim modelini kullanarak Turkiye ve çevresi bölgelerin yakın gelecekteki hava sıcaklığı ve yağış klimatolojileri için öngörülen değişikliklerin incelenmesi," *Ege Coğrafya Dergisi*, vol. 23, pp. 1-24, 2014.

[27] M. Kantarcı, “ISINMA – KURAKLAŞMA SÜRECİNİN GÖLLER BÖLGESİNDEKİ DURUMU VE ETKİLERİ ÜZERİNE EKOLOJİK BİR DEĞERLENDİRME”, *Turkish Journal of Forestry*, c. 9, sy. 2, ss. 1–34, 2009, doi: 10.18182/tjf.00314.

[28] U. C. Erismis, M. Konuk, T. Yoldas, P. Agyar, D. Yumuk, and S. E. Korcan, "Survey of Turkey’s endemic amphibians for chytrid fungus *Batrachochytrium dendrobatidis*," *Diseases of Aquatic Organisms*, vol. 111, pp. 153–157, Sep. 2014. [Online]. Available: https://www.int-res.com/articles/dao2014/111/d111p153.pdf. Accessed: Mar. 5, 2025.

[29] U. Sinsch, S. Werding, and U. Kaya, "Diversity of Water Frogs *Pelophylax* spp. in Turkey: Do Mating Vocalizations Mirror Nominal Taxon Delimitation?" *Animals*, vol. 13, no. 11, p. 1725, May 2023. [Online]. Available: https://doi.org/10.3390/ani13111725. Accessed: Mar. 5, 2025.

[30] D. H. Olson et al., "Mapping the Global Emergence of *Batrachochytrium dendrobatidis*, the Amphibian Chytrid Fungus," *PLoS ONE*, vol. 8, no. 2, p. e56802, Feb. 2013. [Online]. Available: https://doi.org/10.1371/journal.pone.0056802. Accessed: Mar. 5, 2025.

[31] A. Kıraç *et al.*, "Climate change and the fate of endemic Beysehir Frog, *Pelophylax* caralitanus," *AMPHIBIAN & REPTILE CONSERVATION*, vol.16, no.1, pp.76-85, 2022

[32] U. C. Erismis, T. Yoldaş, and P. Ağyar, “Anadolu su kurbağaları (Ranidae: *Pelophylax*)' nda iki amfibi patojeni (Batrachochytrium dendrobatidis, Ranavirüs) yaygınlığının saptanması,” in *XII. Ulusal Ekoloji ve Çevre Kongresi*, Muğla, Turkiye, Sep. 2015, pp. 75–75.

[33] A. M. Kilpatrick, C. J. Briggs, and P. Daszak, “The ecology and impact of chytridiomycosis: an emerging disease of amphibians,” *Trends in Ecology & Evolution*, vol. 25, no. 2, pp. 109–118, Feb. 2010, doi: https://doi.org/10.1016/j.tree.2009.07.011.

[34] K. Ng, "Frog populations 'suffering alarming decline' due to over-consumption by people," *The Independent*, May 13, 2020. [Online]. Available: https://www.independent.co.uk/climate-change/news/water-frogs-extinct-decline-turkey-a9510751.html. Accessed: Mar. 4, 2025.

[35] C. A. Brühl, T. Schmidt, S. Pieper, and A. Alscher, “Terrestrial pesticide exposure of amphibians: An underestimated cause of global decline?,” *Scientific Reports*, vol. 3, no. 1, Jan. 2013, doi: https://doi.org/10.1038/srep01135.

[36] A. Garcês and I. Pires, “The Consequences and Challenges Associated with Amphibian Toxicology Regarding Pesticides,” *Research in biotechnology and environmental science*, vol. 2, no. 3, pp. 35–46, Sep. 2023, doi: https://doi.org/10.58803/rbes.v2i3.15.

[37] G. Guillera-Arroita *et al.*, “Is My Species Distribution Model Fit for purpose? Matching Data and Models to Applications,” *Global Ecology and Biogeography*, vol. 24, no. 3, pp. 276–292, Jan. 2015, doi: https://doi.org/10.1111/geb.12268

[38] L. J. Beaumont *et al.*, “Which Species Distribution Models Are More (or less) Likely to Project broad-scale, climate-induced Shifts in Species ranges?,” *Ecological Modeling*, vol. 342, pp. 135–146, Dec. 2016, doi: https://doi.org/10.1016/j.ecolmodel.2016.10.004.

[39] E. O. Box, *"Macroclimate and Plant Forms: An Introduction to Predictive Modeling in Phytogeography"*, Tasks for Vegetation Science, vol. 1, The Hague: Dr. W. Junk BV, Publishers, 1978.

[40] I. Magrans de Abril, J. Yoshimoto, and K. Doya, “Connectivity inference from neural recording data: Challenges, mathematical bases and research directions,” *Neural Networks*, vol. 102, pp. 120–137, Jun. 2018, doi: https://doi.org/10.1016/j.neunet.2018.02.016.

[41] R. Bivand and T. Keitt, “Package ‘rgdal’ Title Bindings for the ‘Geospatial’ Data Abstraction Library,” 2022. Available: http://r.meteo.uni.wroc.pl/web/packages/rgdal/rgdal.pdf

[42] A. Radosavljevic and R. P. Anderson, “Making Better Maxentmodels of Species distributions: complexity, Overfitting and Evaluation,” *Journal of Biogeography*, vol. 41, no. 4, pp. 629–643, Dec. 2013, doi: https://doi.org/10.1111/jbi.12227.

[43] J. Elith and J. R. Leathwick, “Species Distribution Models: Ecological Explanation and Prediction across Space and Time,” *Annual Review of Ecology, Evolution, and*

Systematics, vol. 40, no. 1, pp. 677–697, Dec. 2009, doi: https://doi.org/10.1146/annurev.ecolsys.110308.120159. Accessed: Apr. 6, 2023.

[44] L. J. Beaumont, A. Pitman, S. Perkins, N. E. Zimmermann, N. G. Yoccoz, and W. Thuiller, “Impacts of climate change on the world’s most exceptional ecoregions,” *Proceedings of the National Academy of Sciences*, vol. 108, no. 6, pp. 2306–2311, Jan. 2011, doi: https://doi.org/10.1073/pnas.1007217108.

[45] S. C. Gonzalez, J. A. Soto-Centeno, and D. L. Reed, “Population distribution models: species distributions are better modeled using biologically relevant data partitions,” *BMC Ecology*, vol. 11, no. 1, p. 20, 2011, doi: https://doi.org/10.1186/1472-6785-11-20.

[46] A. Murray, *The geographical distribution of mammals: Murray, Andrew, 1812-1878 : Free Download, Borrow, and Streaming : Internet Archive*. London, Gate Street: Day and Son, 1993. Accessed: Mar. 05, 2025. [Online]. Available: https://archive.org/details/geographicaldist00murr/page/n5/mode/2up

[47] F. W. Schimper, *Plant-geography upon a physiological basis*, 2. unveränderte Aufl. Oxford: Clarendon Press, 1903. Accessed: Dec. 02, 2024. [Online]. Available: https://archive.org/details/plantgeographyup00schi/page/192/mode/2up

[48] D. Stockwell, “The GARP Modeling system: problems and solutions to automated spatial prediction,” *International Journal of Geographical Information Science*, vol. 13, no. 2, pp. 143–158, Mar. 1999, doi: https://doi.org/10.1080/136588199241391.

[49] A. Guisan, T. C. Edwards, and T. Hastie, “Generalized Linear and Generalized Additive Models in Studies of Species distributions: Setting the Scene,” *Ecological Modeling*, vol. 157, no. 2–3, pp. 89–100, Nov. 2002, doi: https://doi.org/10.1016/s0304-3800(02)00204-1.

[50] A. K. Stockman, D. A. Beamer, and J. E. Bond, “An Evaluation of a GARP Model as an Approach to Predicting the Spatial Distribution of non-vagile Invertebrate Species,”

Diversity and Distributions, vol. 12, no. 1, pp. 81–89, Jan. 2006, doi: https://doi.org/10.1111/j.1366-9516.2006.00225.x.

[51] R. N. Vasconcelos *et al.*, “Advances and Challenges in Species Ecological Niche Modeling: A Mixed Review,” *Earth*, vol. 5, no. 4, pp. 963–989, Dec. 2024, doi: https://doi.org/10.3390/earth5040050.

[52] S. J. Phillips, R. P. Anderson, and R. E. Schapire, “Maximum Entropy Modeling of Species Geographic Distributions,” *Ecological Modeling*, vol. 190, no. 3–4, pp. 231–259, Jan. 2006, doi: https://doi.org/10.1016/j.ecolmodel.2005.03.026.

[53] A. Guisan and N. E. Zimmermann, “Predictive Habitat Distribution Models in Ecology,” *Ecological Modeling*, vol. 135, no. 2–3, pp. 147–186, Dec. 2000, doi: https://doi.org/10.1016/s0304-3800(00)00354-9.

[54] J. Elith et al., "A statistical explanation of MaxEnt for ecologists," *Diversity and Distributions*, vol. 17, no. 1, pp. 43–57, 2011. doi:10.1111/j.1472-4642.2010.00725.x.

[55] R. H. Whittaker, “Communities and ecosystems.”, 1970.

[56] C. Merow, M. J. Smith, and J. A. Silander, “A Practical Guide to MaxEnt for Modeling Species’ distributions: What It does, and Why Inputs and Settings Matter,” *Ecography*, vol. 36, no. 10, pp. 1058–1069, Jun. 2013, doi: https://doi.org/10.1111/j.1600-0587.2013.07872.x.

[57] R. H. Whittaker, “Vegetation of the Great Smoky Mountains,” *Ecological Monographs*, vol. 26, no. 1, pp. 1–80, Jan. 1956, doi: https://doi.org/10.2307/1943577.

[58] R. H. MacArthur, “Population Ecology of Some Warblers of Northeastern Coniferous Forests,” *Ecology*, vol. 39, no. 4, pp. 599–619, 1958, doi: https://doi.org/10.2307/1931600.

[59] X. Cui, W. Wang, X. Yang, S. Li, S. Qin, and J. Rong, “Potential distribution of wild Camellia oleifera based on ecological niche modeling,” *Biodiversity Science*, vol. 24, no. 10, pp. 1117–1128, Jan. 2016, doi: https://doi.org/10.17520/biods.2016164.

[60] C. Zhang, L. Chen, and C. M. Tian, “Predicting the distribution of dwarf mistletoe (Arceuthobium sichuanense) with GARP and MaxEnt models,” *Journal of Beijing Forestry University*, vol. 38, no. 5, pp. 23–32, May 2016, doi: https://doi.org/10.13332 /j.1000-1522.20150516.

[61] C. Fu *et al.*, “Comparison of GARP and MaxEnt in Modeling Current and Future Geographic Distribution of *Ceracris nigricornis* Walker (Acrididae, Orthoptera) in China,” *Ecology and Evolution*, vol. 14, no. 10, Oct. 2024, doi: https://doi.org/10.1002/ece3.70439.

[62] S. J. Phillips, R. P. Anderson, M. Dudík, R. E. Schapire, and M. E. Blair, “Opening the Black Box: An Open-Source Release of Maxent,” *Ecography*, vol. 40, no. 7, pp. 887–893, May 2017, doi: 10.1111/ecog.03049.

[63] V. Eyring *et al.*, “Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) Experimental Design and Organization,” *Geoscientific Model Development*, vol. 9, no. 5, pp. 1937–1958, May 2016, doi: https://doi.org/ 10.5194 /gmd-9-1937-2016.

[64] S. J. Phillips and M. Dudík, "Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation," *Ecography*, vol. 31, no. 2, pp. 161–175, 2008. doi: 10.1111/j.0906-7590.2008.5203.x.

[65] Y. Fourcade, J. O. Engler, D. Rödder, and J. Secondi, “Mapping Species Distributions with MAXENT Using a Geographically Biased Sample of Presence Data: a Performance Assessment of Methods for Correcting Sampling Bias,” *PLoS ONE*, vol. 9, no. 5, p. e97122, May 2014, doi: https://doi.org/10.1371/journal.pone.0097122.

[66] S. J. Phillips et al., "Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data," *Ecological Applications*, vol. 19, no. 1, pp. 181–197, 2009. doi: 10.1890/07-2153.1.

[67] J. Elith, M. Kearney, and S. Phillips, “The art of Modeling range-shifting species,” *Methods in Ecology and Evolution*, vol. 1, no. 4, pp. 330–342, May 2010, doi: https://doi.org/10.1111/j.2041-210x.2010.00036.x.

[68] J. Soberon and A. T. Peterson, “Interpretation of Models of Fundamental Ecological Niches and Species’ Distributional Areas,” *Biodiversity Informatics*, vol. 2, pp. 1–10, 2005, Accessed: Mar. 05, 2025. [Online]. Available: https://www.academia.edu/5331193/INTERPRETATION_OF_MODELS_OF_FUNDAMENTAL_ECOLOGICAL_NICHES_AND_SPECIES_DISTRIBUTIONAL_AREAS

[69] J. Soberon and M. Nakamura, “Niches and distributional areas: Concepts, methods, and assumptions,” *Proceedings of the National Academy of Sciences*, vol. 106, no. Supplement_2, pp. 19644–19650, Sep. 2009, doi: https://doi.org/10.1073/pnas.0901637106.

[70] X. Feng, A. T. Peterson, L. J. Aguirre-López, J. R. Burger, X. Chen, and M. Papeş, “Rethinking Ecological Niches and Geographic Distributions in Face of Pervasive Human Influence in the Anthropocene,” *Biological reviews/Biological reviews of the Cambridge Philosophical Society*, vol. 99, no. 4, pp. 1481–1503, Apr. 2024, doi: https://doi.org/10.1111/brv.13077.

[71] D. Ambarlı *et al.*, “An Overview of Biodiversity and Conservation Status of Steppes of the Anatolian Biogeographical Region,” *Biodiversity and Conservation*, vol. 25, no. 12, pp. 2491–2519, Jul. 2016, doi: https://doi.org/10.1007/s10531-016-1172-0.

[72] P. Gennadius, Disease of Tobacco Plantations in the Trikonia. The Aleurodid of Tobacco. Elliniko Georgia, 5, 1-3, 1889.

[73] K. KARUT, M. B. KAYDAN, S. J. CASTLE, C. KAZAK, and M. R. ULUSOY, "Study on Species Composition of Bemisia Tabaci (Gennadius, 1889) (Hemiptera: Aleyrodidae) on Cotton in Çukurova plain, Turkey," *Turkish Journal of Entomology*, vol. 38, no. 1, Feb. 2014, doi: https://doi.org/10.16970/ted.41111.

[74] M. Ando, J. Sano, and S. Tamai, "The Vertical Distribution of the Vegetation on Cukurova Plain in the Eastern Mediterranean Region of Turkey," ICCAP-Cappadocia Workshop, 2005. Accessed: Jul. 05, 2024. [Online]. Available: https://www.chikyu.ac.jp/iccap/ICCAP_Final_Report/4/4-veg_ando.pdf.

[75] B. Sarıkaya, M. Z. YILDIZ, and G. Sezen, "The Herpetofauna of Adana Province (Turkey)," *Commagene Journal of Biology*, vol. 1, no. 1, pp. 1–11, Dec. 2017, doi: https://doi.org__/10.31594/commagene.391784.

[76] U. Fritz and O. Freytag, "The distribution of Mauremys in Asia Minor, and first record of M. caspica caspica (GMELIN, 1774) for the internally drained central basin of Anatolia (Testudines: Cryptodira: Bataguridae)," *Herpetozoa* , vol. 6, no. 3/4, pp. 97–103, Dec. 1993, Accessed: Jul. 06, 2025. [Online]. Available: https://www.zobodat.at/pdf/HER_6_3_4_0097-0103.pdf

[77] U. Fritz, "Zur Systematik westasiatisch-südosteuropäischer Bachschildkröten (Gattung Mauremys)," *Zool Abh St Mus Tierk Dresden*, vol. 49, pp. 223–260, Nov. 1997.

[78] D. Ayaz, Oğuz Türkozan, Murat Tosunoğlu, C. V. Tok, and Durmuş Cihan, "Morphologic and Serologic Comparison of Two Turkish Populations of Mauremys rivulata and Mauremys caspica," *Chelonian Conservation and Biology*, vol. 5, no. 1, pp. 10–10, Jan. 2006, doi: https://doi.org/10.2744/1071-8443(2006)5[10:mascot]2.0.co;2.

[79] J. F. Schmidtler, B Göçmen, M. Z. Yıldız, B. Akman, D Yalçınkaya, and T. Z. Nagy, "Rediscovery of the snake genus Eirenis on Cyprus (Reptilia: Colubridae)," *Entomologica Romanica*, vol. 15, Jan. 2009.

[80] S. Çelik, “The Unsettled Plain: an Environmental History of the Late Ottoman Frontier by Chris Gratien (review),” *Journal of the Ottoman and Turkish Studies Association*, vol. 11, no. 1, pp. 253–256, Mar. 2024, doi: https://doi.org/10.2979/tur.00032.

[81] Ç. Yaşar, K. Çiçek, J. Mulder, and C. V. TOK, “The Distribution and Biogeography of Amphibians and Reptiles in Turkey.,” *North-Western Journal of Zoology*, vol. 17, no. 2, 2021.

[82] D. Arslan *et al.*, “Conservation of More Evolutionary Unique Amphibian Communities in Turkiye: the Role of Protected Areas,” *Journal of Environmental Management*, vol. 368, p. 122001, Aug. 2024, doi: https://doi.org/10.1016/j.jenvman.2024.122001.

[83] P. Beerli, H. Hotz, and T. Uzzell, “GEOLOGICALLY DATED SEA BARRIERS CALIBRATE A PROTEIN CLOCK FOR AEGEAN WATER FROGS,” *Evolution*, vol. 50, no. 4, pp. 1676–1687, Aug. 1996, doi: https://doi.org/10.1111/j.1558-5646.1996.tb03939.x.

[84] Ç. Akın, C. C. Bilgin, and P. Beerli, “Phylogeographic Patterns of Genetic Diversity in Eastern Mediterranean Water Frogs Were Determined by Geological Processes and Climate Change in the Late Cenozoic,” *J. Biogeogr.*, vol. 37, no. 11, pp. 2111–2124, 2010, doi: 10.1111/j.1365-2699.2010.02368.x.

[85] J. Plötner *et al.*, *Genetic Divergence and Evolution of Reproductive Isolation in Eastern Mediterranean Water Frogs*. Berlin, Heidelberg: Springer, 2010, pp. 373–403. doi: https://doi.org/10.1007/978-3-642-12425-9_18.

[86] Ç. Akın Pekşen, “Molecular evolution and phylogeography of the eastern Mediterranean water frog (*Pelophylax*) complex,” Ph.D. dissertation, Middle East Technical University, Ankara, Türkiye, 2015.

[87] Ç. Akın Pekşen, “Structure and Evolution of the *uqcrfs1* Gene in Western Palearctic Water Frogs (Genus *Pelophylax*) and Implications for Systematics of Eastern

Mediterranean Species,” *J. Zool. Syst. Evol. Res.*, vol. 2025, no. 1, 2025, doi: 10.1155/jzs/7457173.

[88] V. Kürüm, “Statistics of frog trade in Turkey.,” *Republic of Turkey Ministry of Agriculture and Forestry General Directorate of Fisheries and Aquaculture, Ankara, Turkey.[in Turkish].,* 2015.

[89] S. N. Litvinchuk, D. V. Skorinov, A. Yu. Ivanov, and O. A. Ermakov, “Detection of Glacial Refugia and Post-Glacial Colonization Routes of Morphologically Cryptic Marsh Frog Species (Anura: Ranidae: *Pelophylax*) Using Environmental Niche Modeling,” *Diversity*, vol. 16, no. 2, p. 94, Feb. 2024, doi: https://doi.org/10.3390/d16020094.

[90] C. Dufresnes *et al.*, “Piecing the barcoding puzzle of Palearctic water frogs (*Pelophylax*) sheds light on amphibian biogeography and global invasions,” *Global Change Biology*, vol. 30, no. 3, Mar. 2024, doi: https://doi.org/10.1111/gcb.17180.

[91] L. Koç and S. Topaloğlu Paksoy, "Daily reference evapotranspiration prediction using empirical and data-driven approaches: A case study of Adana plain," *Journal of Agricultural Sciences (Tarım Bilimleri Dergisi)*, vol. 31, no. 1, pp. 207–229, Jan. 2025. DOI: 10.15832/ankutbd.1481207.

[92] L. Coelho *et al.*, “Assessing the Effectiveness of an Innovative Thermal Energy Storage System Installed in a Building in a Moderate Continental Climatic Zone,” *Energies*, vol. 17, no. 3, pp. 763–763, Feb. 2024, doi:https://doi.org/10.3390/en17030763.

[93] H. Alphan and K. T. Yilmaz, “Monitoring Environmental Changes in the Mediterranean Coastal Landscape: The Case of Cukurova, Turkey,” Environmental Management, vol. 35, no. 5, pp. 607–619, May 2005, doi: https://doi.org/10.1007/s00267-004-0222-7.

[94] Z. Zhang *et al.*, “Incorporating physiological knowledge into correlative species distribution models minimizes bias introduced by the choice of calibration

area," *Marine Life Science & Technology*, vol. 6, no. 2, pp. 349–362, May 2024, doi: https://doi.org/10.1007/s42995-024-00226-0.

[95] P. Acevedo, A. Jiménez-Valverde, J. M. Lobo, and R. Real, "Delimiting the geographical background in species distribution Modeling," *Journal of Biogeography*, vol. 39, no. 8, pp. 1383–1390, Jun. 2012, doi: https//doi.org/10.1111/j.1365-2699.2012.02713.x.

[96] A. M. Whitford, B. R. Shipley, and J. L. McGuire, "The Influence of the Number and Distribution of Background Points in presence-background Species Distribution Models," *Ecological Modeling*, vol. 488, p. 110604, Feb. 2024, doi: https://doi.org/10.1016/j.ecolmodel.2023.110604.

[97] B. A. Wintle, J. Elith, and J. M. Potts, "Fauna habitat Modeling and mapping: A review and case study in the Lower Hunter Central Coast region of NSW," *Austral Ecology*, vol. 30, no. 7, pp. 719–738, Nov. 2005, doi: https://doi.org/10.1111/j.1442-9993.2005.01514.x.

[98] S. J. E. Velazco, M. B. Rose, A. F. A. de Andrade, I. Minoli, and J. Franklin, "flexsdm: an R Package for Supporting a Comprehensive and Flexible Species Distribution Modeling Workflow," *Methods in Ecology and Evolution*, vol. 13, no. 8, pp. 1661–1669, May 2022, doi: https://doi.org/10.1111/2041-210x.13874.

[99] C. L. Yurrita, M. A. Ortega-Huerta, and R. Ayala, "Distributional analysis of Melipona stingless bees (Apidae: Meliponini) in Central America and Mexico: setting baseline information for their conservation," *Apidologie*, vol. 48, no. 2, pp. 247–258, Sep. 2016, doi: https://doi.org/10.1007/s13592-016-0469-z.

[100] G. M. Foody, "GIS: Biodiversity Applications," *Progress in Physical Geography: Earth and Environment*, vol. 32, no. 2, pp. 223–235, Apr. 2008, doi: https://doi.org/10.1177/0309133308094656.

[101] J. Plötner, T. Ohst, W. Böhme, and R. Schreiber, "Divergence in Mitochondrial DNA of near Eastern Water Frogs with Special Reference to the Systematic Status of

Cypriote and Anatolian Populations (Anura, Ranidae)," *Amphibia-Reptilia*, vol. 22, no. 4, pp. 397–412, 2001, doi: https://doi.org/10.1163/15685380152770363.

[102] J. Plötner *et al.*, "Genetic data reveal that water frogs of Cyprus (genus *Pelophylax*) are an endemic species of Messinian origin," *Zoosyst. Evol.*, vol. 88, pp. 261–283, 2012, doi: 10.1002/zoos.201200021.

[103] J. Plötner *et al.*, "Genetic evidence for human-mediated introduction of Anatolian water frogs (*Pelophylax* cf. *bedriagae*) to Cyprus (Amphibia: Ranidae)," *Zool. Middle East*, vol. 61, pp. 125–132, 2015.

[104] Ç. Akın Pekşen and J. Plötner, "Anatolischer Wasserfroschkomplex," in *Handbuch der Reptilien und Amphibien Europas, Band 5/III, Froschlurche III*, J. Plötner, Ed. Norderstedt, Germany: AULA-Verlag, 2025, pp. 259-292.

[105] R. Zardoya and A. Meyer, "Phylogenetic Performance of Mitochondrial protein-coding Genes in Resolving Relationships among Vertebrates," *Molecular Biology and Evolution*, vol. 13, no. 7, pp. 933–942, Sep. 1996, doi: https://doi.org/10.1093/oxfordjournals.molbev.a025661.

[106] J. W. O. Ballard and N. Pichaud, "Mitochondrial DNA: More than an Evolutionary Bystander," *Functional Ecology*, vol. 28, no. 1, pp. 218–231, Dec. 2013, doi: https://doi.org/10.1111/1365-2435.12177.

[107] D. A. W. Miller *et al.*, "Quantifying climate sensitivity and climate-driven change in North American amphibian communities," *Nature Communications*, vol. 9, no. 1, p. 3926, Sep. 2018, doi: https://doi.org/10.1038/s41467-018-06157-6.

[108] A. M. Ray et al., "Influence of climate drivers on colonization and extinction dynamics of wetland-dependent species," Ecosphere, vol. 7, no. 7, Jul. 2016, doi: https://doi.org/10.1002/ecs2.1409.

[109] K. G. Nikolakopoulos, E. K. Kamaratakis, and N. Chrysoulakis, "SRTM vs ASTER Elevation products. Comparison for Two Regions in Crete, Greece," *International*

Journal of Remote Sensing, vol. 27, no. 21, pp. 4819–4838, Nov. 2006, doi: https://doi.org/10.1080/01431160600835853.

[110] A.R. Blaustein and J. M. Kiesecker, “Complexity in conservation: lessons from the global decline of amphibian populations,” *Ecology Letters*, vol. 5, no. 4, pp. 597–608, Jul. 2002, doi: https://doi.org/10.1046/j.1461-0248.2002.00352.x.

[111] N. Barve *et al.*, “The crucial role of the accessible area in ecological niche modeling and species distribution modeling,” *Ecological Modeling*, vol. 222, no. 11, pp. 1810–1819, Jun. 2011, doi: https://doi.org/10.1016/j.ecolmodel.2011.02.011.

[112] “ArcGIS Desktop | Desktop GIS Software Suite,” *www.esri.com*. https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview.

[113] Posit team (2024). RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA. URL http://www.posit.co/.

[114] A. Farashi and M. Alizadeh-Noughani, "Basic Introduction to Species Distribution Modeling," in *Ecosystem and Species Habitat Modeling for Conservation and Restoration*, S. Dhyani, D. Adhikari, R. Dasgupta, and R. Kadaverugu, Eds. Singapore: Springer, 2023, pp. 21–40. DOI: 10.1007/978-981-99-0131-9_2.

[115] S. J. Phillips, M. Dudík, and R. E. Schapire, “A maximum entropy approach to species distribution modeling,” *Twenty-first International Conference on Machine Learning - ICML ’04*, pp. 655–662, 2004, doi: https://doi.org/10.1145/1015330.1015412.

[116] B. Naimi and M. B. Araújo, “SDM: a Reproducible and Extensible R Platform for Species Distribution Modeling,” Ecography, vol. 39, no. 4, pp. 368–375, Mar. 2016, doi: https://doi.org/10.1111/ecog.01881.

[117] S. Vignali, A. G. Barras, R. Arlettaz, and V. Braunisch, “SDMtune: an R Package to Tune and Evaluate Species Distribution Models,” *Ecology and Evolution*, vol. 10, no. 20, pp. 11488–11506, Sep. 2020, doi: https://doi.org/10.1002/ece3.6786.

[118] R. J. Hijmans, “Terra: Spatial Data Analysis” R Package Version 1.7-78, May 2024. [Online]. Available: https://cran.r-project.org/web/packages/terra/terra.pdf

[119] H. Liu, H. Gong, X. Qi, Y. Li, and Z. Lin, “Relative importance of environmental variables for the distribution of the invasive marsh species Spartina alterniflora across different spatial scales,” *Marine and Freshwater Research*, vol. 69, no. 5, p. 790, 2018, doi: https://doi.org/10.1071/mf17100.

[120] S. Vignali, A. G. Barras, and V. Branuisch, “SDMtune – hyperparameter tuning” CRAN.r-project.org. https://cran.r-project.org/web/packages/SDMtune/vignettes/hyper-tuning.html (Accessed: Jun. 17, 2025)

[121] R. G. Pearson, T. P. Dawson, and C. Liu, “Modeling Species Distributions in Britain: a Hierarchical Integration of Climate and land-cover Data,” *Ecography*, vol. 27, no. 3, pp. 285–298, May 2004, doi: https://doi.org/10.1111/j.0906-7590.2004.03740.x

[122] E. Pineda and J. M. Lobo, “Assessing the Accuracy of Species Distribution Models to Predict Amphibian Species Richness Patterns,” *Journal of Animal Ecology*, vol. 78, no. 1, pp. 182–190, Dec. 2008, doi: https://doi.org/10.1111/j.1365-2656.2008.01471.x.

[123] J. A. Hanley and B. J. McNeil, “The Meaning and Use of the Area under a Receiver Operating Characteristic (ROC) curve.,” *Radiology*, vol. 143, no. 1, pp. 29–36, Apr. 1982, doi: https://doi.org/10.1148/radiology.143.1.7063747.

[124] A. Naqibzadeh, J. Sarhangzadeh, A. Sotoudeh, M. Mashkour, and J. Thomalsky, “Goitered Gazelle’s (*Gazella Subgutturosa*) Habitat Desirability Modeling by Using Maximum Entropy (Maxent) Method,” Feb. 2022, doi: https://doi.org/10.1101/2022.02.10.479956.

[125] X. Robin et al., "pROC: an open-source package for R and S+ to analyze and compare ROC curves," *BMC Bioinformatics*, vol. 12, no. 1, p. 77, Mar. 2011.

[126] H. R. Sofaer, J. A. Hoeting, and C. S. Jarnevich, "The Area under the Precision-recall Curve as a Performance Metric for Rare Binary Events," *Methods in Ecology and Evolution*, vol. 10, no. 4, pp. 565–577, Feb. 2019, doi: https://doi.org/10.1111/2041-210x.13140.

[127] W. Li and Q. Guo, "Plotting Receiver Operating Characteristic and Precision–recall Curves from Presence and Background Data," *Ecology and Evolution*, vol. 11, no. 15, pp. 10192–10206, Jun. 2021, doi: https://doi.org/10.1002/ece3.7826.

[128] J. M. Kass *et al.*, "Achieving higher standards in species distribution modeling by leveraging the diversity of available software," *Ecography*, vol. 2025, no. 2, Nov. 2024, doi: https://doi.org/10.1111/ecog.07346.

[129] R. G. Pearson *et al.*, "Model-based Uncertainty in Species Range Prediction," *Journal of Biogeography*, vol. 33, no. 10, pp. 1704–1711, Oct. 2006, doi: https://doi.org/10.1111/j.1365-2699.2006.01460.x.

[130] N. Raes and H. ter Steege, "A null-model for Significance Testing of presence-only Species Distribution Models," *Ecography*, vol. 30, no. 5, pp. 727–736, Sep. 2007, doi: https://doi.org/10.1111/j.2007.0906-7590.05041.x.

[131] E. O. Wiley, K. McNyset, T. Peterson, R. Robins, and A. Stewart, "Niche Modeling Perspective on Geographic Range Predictions in the Marine Environment Using a Machine-learning Algorithm," *Oceanography*, vol. 16, no. 3, pp. 120–127, Jan. 2003, doi: https://doi.org/10.5670/oceanog.2003.42.

[132] K. Baral *et al.*, "Impact of Climate Change on Distribution of Common Leopard (Panthera pardus) and Its Implication on Conservation and Conflict in Nepal," *Heliyon*, vol. 9, no. 1, p. e12807, Jan. 2023, doi: https://doi.org/10.1016/j.heliyon.2023.e12807.

[133] A. McIntosh, "The Jackknife Estimation Method," *arXiv.org*, Jun. 01, 2016. https://arxiv.org/abs/1606.00497 (accessed Mar. 28, 2025).

[134] T. Newbold, “Applications and Limitations of Museum Data for Conservation and ecology, with Particular Attention to Species Distribution Models,” *Progress in Physical Geography: Earth and Environment*, vol. 34, no. 1, pp. 3–22, Jan. 2010, doi: https://doi .org/10.1177/0309133309355630.

[135] C. Liu, M. White, and G. Newell, “Selecting Thresholds for the Prediction of Species Occurrence with presence-only Data,” *Journal of Biogeography*, vol. 40, no. 4, pp. 778–789, Jan. 2013, doi: https: //doi .org/10.1111/jbi.12058.

[136] R. M. Navarro-Cerrillo, J. E. Hernández-Bermejo, and R. Hernández-Clemente, “Evaluating models to assess the distribution of Buxus balearica in southern Spain,” *Applied Vegetation Science*, vol. 14, no. 2, pp. 256–267, Nov. 2010, doi: https://doi .org/10.1111/j.1654-109x.2010.01112.x.

[137] D. Zurell *et al.*, “A standard protocol for reporting species distribution models,” *Ecography*, vol. 43, no. 9, pp. 1261–1277, Jun. 2020, doi: https://doi .org/10.1111/ecog.04960.

[138] A. T. Peterson, “Predicting Species’ Geographic Distributions Based on Ecological Niche Modeling,” *The Condor*, vol. 103, no. 3, pp. 599–605, Aug. 2001, doi: https://doi .org/10.1093/condor/103.3.599.

[139] B. D. Todd, D. E. Scott, J. H. K. Pechmann, and J. W. Gibbons, “Climate Change Correlates with Rapid Delays and Advancements in Reproductive Timing in an Amphibian Community,” *Proceedings of the Royal Society B: Biological Sciences*, vol. 278, no. 1715, pp. 2191–2197, Dec. 2010, doi: https://doi .org/10.1098/rspb.2010.1768.

[140] D. Laurencio and L. A. Fitzgerald, “Environmental Correlates of Herpetofaunal Diversity in Costa Rica,” Journal of Tropical Ecology, vol. 26, no. 5, pp. 521–531, Jul. 2010, doi: https://doi .org/10.1017/s0266467410000222.

[141] D. S. Pilliod and R. D. Scherer, “Managing Habitat to Slow or Reverse Population Declines of the Columbia Spotted Frog in the Northern Great Basin,” *The Journal of*

Wildlife Management, vol. 79, no. 4, pp. 579–590, Mar. 2015, doi: https://doi.org/10.1002/jwmg.868.

[142] J. Eric Wallace, R. J. Steidl, and D. E. Swann, "Habitat Characteristics of Lowland Leopard Frogs in Mountain Canyons of Southeastern Arizona," *Journal of Wildlife Management*, vol. 74, no. 4, pp. 808–815, May 2010, doi: https://doi.org/10.2193/2009-207.

[143] V. H. Zero and M. A. Murphy, "An Amphibian Species of Concern Prefers Breeding in Active Beaver Ponds," *Ecosphere*, vol. 7, no. 5, p. e01330, May 2016, doi: https://doi.org/10.1002/ecs2.1330.

[144] "Range Extent," *Natureserve.org*. https://help.natureserve.org/biotics/content/record_management/Element_Files/Element_Ranking/ERANK_Range_Extent._Rating.htm (accessed Jul. 06, 2025).

[145] IUCN, *IUCN Red List Categories and Criteria: Version 3.1.* Gland, Switzerland: IUCN, 2001.

[146] M. Kearney and W. Porter, "Mechanistic niche Modeling: combining physiological and spatial data to predict species' ranges," *Ecology Letters*, vol. 12, no. 4, pp. 334–350, Apr. 2009, doi: https://doi.org/10.1111/j.1461-0248.2008.01277.x.

[147] C. Elverici, A. T. Peterson, and U. Perktaş, "Hotspots in transition: Mediterranean amphibian diversity under different climate scenarios," *Biodiversity and Conservation*, vol. 34, no. 2, pp. 589–604, Dec. 2024, doi: https://doi.org/10.1007/s10531-024-02988-6.

[148] Y. Boussalim and Y. Dallahi, "Future Shifts in Climatic Conditions Promoting Northward Expansion of the Mediterranean Climate in the circum-Mediterranean Region," *Environmental Monitoring and Assessment*, vol. 196, no. 11, Oct. 2024, doi: https: //doi.org/10.1007/s10661-024-13286-7.

[149] S. Wang, Y. Mei, Q. Liu, and W. He, “The Impacts of Global Warming on Climate Zones over China Based on CMIP6 Models,” *International Journal of Climatology*, vol. 44, no. 11, pp. 4046–4061, Jul. 2024, doi: https://doi.org/10.1002/joc.8567.

[150] A. Tuel and E. a. B. Eltahir, “Why Is the Mediterranean a Climate Change Hot Spot?,” *Journal of Climate*, vol. 33, no. 14, pp. 5829–5843, Jul. 2020, doi: https://doi.org/10.1175/JCLI-D-19-0910.1.

[151] R. D. Loyola, P. Lemes, F. T. Brum, D. B. Provete, and L. D. S. Duarte, “Clade-specific Consequences of Climate Change to Amphibians in Atlantic Forest Protected Areas,” *Ecography*, vol. 37, no. 1, pp. 65–72, Jun. 2013, doi: https://doi.org/10.1111/j.1600-0587.2013.00396.x.

[152] U. B. Shrestha and K. S. Bawa, “Impact of Climate Change on Potential Distribution of Chinese Caterpillar Fungus (Ophiocordyceps sinensis) in Nepal Himalaya,” *PLoS ONE*, vol. 9, no. 9, p. e106405, Sep. 2014, doi: https://doi.org/10.1371/journal.pone.0106405.

[153] N. C. Coops and R. H. Waring, “A process-based approach to estimate lodgepole pine (Pinus contorta Dougl.) distribution in the Pacific Northwest under climate change,” *Climatic Change*, vol. 105, no. 1–2, pp. 313–328, Aug. 2010, doi: https://doi.org/10.1007/s10584-010-9861-2.

[154] M. Ojaghlou and E. Uğurlu, “Urbanization and Climate change: Environmental Kuznets Curve (EKC) and STIRPAT Analysis for Turkey,” *Economics & Sociology*, vol. 16, no. 1, pp. 259–270, Jan. 2023, doi: https://doi.org/10.14254/2071-789x.2023/16-1/16.

[155] M. G. D. Carraça and C. G. Collier, “Modeling the Impact of high-rise Buildings in Urban Areas on Precipitation Initiation,” *Meteorological Applications*, vol. 14, no. 2, pp. 149–161, 2007, doi: https://doi.org/10.1002/met.15.

[156] M. A. Çelik and M. Karabulut, “UYDU VE İSTASYON TABANLI KURAKLIK İNDEKSLERİ KULLANILARAK AKDENİZ BÖLGESİNDE KURAKLIK ANALİZİ (2000-2014),” *the Journal of Academic Social Sciences*, vol. 44, no. 44, pp. 341–370, Jan. 2017, doi: https://doi .org /10.16992 /asos.12077.

[157] M. Topuz and R. Geçen, “The Effect of Silifke and Erdemli Distrcit Centers on Land Surface Temperature,” *Çukurova Araştırmaları Dergisi*, vol. 7/3, no. 14, pp. 439–453, 2021, doi: https://doi .org/ 10.29228 / cukar.54129.

[158] C. Dufresnes, S. Dubey, K. Ghali, D. Canestrelli, and N. Perrin, “Introgressive Hybridization of Threatened European Tree Frogs (Hyla arborea) by Introduced H. Intermedia in Western Switzerland,” *Conservation Genetics*, vol. 16, no. 6, pp. 1507–1513, Jun. 2015, doi: https://doi .org/ 10.1007 /s10592-015-0745-x.