ENVIRONMENTAL DISTRIBUTION MODELING OF RESIDENT AND MIGRATORY PASSERINE BIRDS FROM TURKEY IN A CLIMATE CHANGE PERSPECTIVE

by

Moris ABOLAFYA

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ABSTRACT

The effects of changing climate have been studied extensively on various species and in different parts of the world. The objective of this thesis is to predict the effect of climate change on the distribution of 20 resident and nine summer breeding migratory Passerines in the Turkey. Potential geographic distribution of Passerine species have been analyzed by using a maximum entropy modelling approach for the years 2020, 2050 and 2080, and appropriate bioclimatic data from two different increasing economic activity level climate change scenarios (A2a and B2a) of Intergovernmental Panel on Climate Change. The results indicate that most of the resident species will maintain or expand their presence areas. On the other hand climate change will affect summer migratory Passerines more negatively than the resident species. These migratory species are predicted to lose significant portions of their presence areas during three study periods. The species whose breeding areas are restricted to the more northern and western parts of the Turkey will progressively lose suitable climate space. In addition, species that have restricted breeding areas in the southern parts of the country will have the potential to expand their range to the northern and western parts of Turkey. It should be noted that the results symbolize the best case scenarios, since only bioclimatic variables are used as the main limiting factors and any variable related to availability of suitable habitats and/or roosts are not considered. Future research should incorporate species data from a wider geographic area and more fine-tuned analyses using subspecific distribution information.

ÖZET

İklim değişikliğinin farklı türler üzerine etkileri dünyanın farklı bölgelerinde yoğun olarak incelenmektedir. Bu tezin amacı, iklim değişikliğinin Türkiye'deki 20 yerleşik ve dokuz yaz göçmeni ötücü kuş (Passerine) türüne etkisini tahmin etmektir. Ötücü kuş türlerin 2020, 2050 ve 2080 yıllarına göre potansiyel coğrafi dağılımı, Intergovernmental Panel on Climate Change (IPCC)'nin iki farklı ekonomik ilerlemeye bağlı olarak geliştirilen iklim değişikliği senaryolarına (A2a ve B2a) uygun iklim verileri kullanılarak maksimum entropi modelleme yaklaşımıyla analiz edilmiştir. Sonuçlar yerleşik türlerin varlık alanlarını genişlettiklerini, oysa her üç çalışma periyodunda da iklim değişikliğinin göçmen türler üzerindeki olumsuz etkisinin daha fazla olacağını ve bu türlerin bulundukları bölgelerdeki varlık alanlarının önemli miktarda azalacağını göstermiştir. Üreme alanları çoğunlukla Türkiye'nin kuzey ve batı kesimleriyle ile sınırlı bulunan türler giderek uygun iklimsel alanlarını kaybetmişlerdir. Buna ek olarak, üreme alanları ülkenin güney kesimiyle kısıtlı olan türler yayılım alanlarını Türkiye'nin kuzeybatı bölgelerine doğru genişletecek potansiyele sahip olacaklardır. Çalışmada ana sınırlayıcı faktör olarak sadece iklim değişkenlerinin kullanılması ve buna bağlı herhangi bir uygun yaşam alanı verisinin değişken olarak kullanılmaması nedeni ile sonuçların en iyi durum senaryoları yansıttığı göz önünde bulundurulmalıdır. Gelecekteki araştırmalar daha geniş bir coğrafi alandan tür dağılım verileriyle yürütülmeli ve alttür bazında daha detaylı analizler yapılmalıdır.

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LIST OF SYMBOLS/ABBREVIATIONS

Abbreviation	**Explanation**
AUC	Area Under Curve
BBS	Breeding Bird Survey
CART	Classification and regression tree
CDIAC	The Carbon Dioxide Information Analysis Center
GAM	General Additive Models
GARP	Genetic Algorithm for Rule-set Prediction
GIS	Geographic Information Systems
GLM	General Linear Models
HADCM3	Hadley Centre Coupled Model, Version 3
IPCC	Intergovernmental Panel on Climate Change
ROC	Receiver Operating Characteristics
WWF	World Wild Fund for Nature

1. INTRODUCTION

The structure and function of the Earth as a supplementary system is being shifted by several interacting components, such as human population growth and consumption of resources. Thus, inevitably, changes in the global environment will occur. Currently one of these modifications at the forefront is global warming (climate change) and many scientists have studied the possible effects of climatic change on natural organisms, populations, and ecosystems (Lovejoy and Hannah, 2005). The common consensus of the studies of ecologists is that climate change comprises a potential threat to the earth's biodiversity (Kappelle *et al.*, 1999). The continuous effects of human population growth, such as widespread poverty, economic globalization, land-use change, and climate change have deep impacts on biological diversity, whose effects will only become more severe when the pace of environmental change quickens. Projections of human-induced climate change and evidence of past rapid climate change show that biological diversity will be affected drastically in a short time period (Peter and Lovejoy, 1992; Hughes, 2000; Intergovernmental Panel on Climate-Change 2001 [IPCC]). Therefore, the challenges to conservation and environmental management become important.

1.1. What Are The Facts About Climate Change?

There are many factors that influence the Earth's climate. The main factor is the amount of energy coming from the sun, but other factors such as the amount of greenhouse gases and aerosols in the atmosphere, and the properties of the Earth's surface, all come into effect in the determination of how much of this solar energy is kept or reflected back to space. Climate change has both natural and human-induced causes. Natural factors can be summarized as volcanic eruptions, variations in the sun's intensity, or very slow changes in ocean circulation and land surfaces. However, these natural factors are not as detrimental as the human effects, because for thousands of years, the Earth's atmosphere has changed very little, temperature and the amount of greenhouse gases have remained balanced for humans, animals, plants and other organisms to survive (Crowley, 2000). However, since the beginning of the industrial revolution, the atmospheric concentration of greenhouse gases has raised considerably (IPCC, 2007).

Large-scale climatic changes have been observed and documented since mid-twentieth century. Since the mid-1800s, the average atmospheric temperatures have considerably increased already, by about 0.6 ^{o} C (Houghton *et al.*, 1990). The increases in carbon dioxide (CO_2) and other greenhouse gases seem to be raising the temperature of the planet at a rapid rate, and computer models predict an average global temperature increase of 1.4 to 5.8 ^{o}C by the year 2100 (IPCC, 2001; Hegerl *et al.*, 2007). However, projected rises in temperature are not expected to be equally distributed over the earth, which means that the mean temperatures at the poles are expected to increase more (around 0.8^{o}C *per* decade) than in equatorial regions (around 0.1^{o}C *per* decade). According to those changes, global mean sea levels are expected to rise approximately 6 cm per decade, and this will have many adverse effects, such as salt water intrusion, and loss of land and natural resources in coastal regions (McNeely *et al.*, 1995). Predicted effects of these temperature increases are already being observed and are expected to continue frequently and intensively, as heat waves, droughts, floods and hurricanes. All of these changes have significant impact on biodiversity, including changes in species distribution, population sizes, the timing of reproduction or migration events, and increases in the frequency of pest and disease outbreaks. In fact, a recent research shows that current temperature-related shifts are already affecting more than 100 species, ranging from molluscs to mammals and from plants to vegetation, which indicate the current and visible impact of climate change (Root *et al.*, 2003).

1.2. Greenhouse Effect and Greenhouse Gases

The greenhouse effect is a natural phenomenon and is due to the absorption of infrared radiation, as it is converted from solar (short wave) radiation by greenhouse gases and reradiates towards surface of the earth. The concentration of these greenhouse gases [water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3)] has been increasing significantly since 1750s (current Greenhouse Gas concentrations, ttp://cdiac.esd.ornl.gov/pns/current_ghg.html). The current and pre-industrial concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and their rates of increase are shown in Table 1. In a parallel manner, the average global temperatures have increased by 0.3°C - 0.6°C over the last 100 years (Houghton *et al.,* 1990). Since 1905, the average temperature of the planet, then at 14°C, has increased by 2.5%, at an unusually rapid rate (a 0.35°C rise). In the period between 1970 and 2005, it went up by 4% (0.55°C). IPCC scientists indicate that "the warming trend over the last 50 years (1955 to 2005) is nearly twice that for the last 100 years" (Le Treut *et al*., 2007; www.cdiac.esd.ornl.gov/pns/current_ghg.html).

Table 1. Current and pre-industrial time Greenhouse Gas concentrations (CDIAC).

GAS	**Pre-1750 tropospheric concentration**	**Current tropospheric concentration**	**Increase (%) over pre-industrial era (1750)**
Carbon dioxide (CO_2)	280 ppm*	384 ppm	37%
Methane (CH_4)	700 ppb**	1857/1735 ppb	165%
Nitrous oxide (N_2O)	270 ppb	321/320 ppb	50%

*ppm-parts per million, **ppb-parts per billion.

This warming trend is expected to continue in the future, as a result of increases in the amount of infrared radiation that is kept on earth by increased quantities of greenhouse gases. This is likely to affect living organisms substantially. For example, plant species living in hot and dry regions are likely to suffer from higher evapotranspiration rates, and thus drought, increase. In addition, in plants there is evidence that the photosynthesis will start earlier than usual in spring, in the colder parts of the earth (Badeck *et al*., 2004).

Although variations in solar radiation, deviations in the Earth's orbit, continental drifts, mountain formation, and volcanic eruptions are known natural reasons for the global climate change, today we know that anthropogenic factors, in other words human activities, have a crucial impact on the change of the environment. Human activities like increased use of fossil fuels in industry and agriculture generate large amounts of greenhouse gases (Crowley, 2000). Especially the burning of fossil fuels causes the emission of carbon dioxide (CO_2), which is a gas that decreases the extent of heat escape into space. Thus, it could be concluded that human activities are responsible for most of the global warming by enhancing earth's natural greenhouse effect (Vitousek, 1994). Since economic development and human activities are strictly connected with each other, the limits of climate change in the future will be set by the rate of economic development.

1.3. IPCC Future Climate Scenarios

Climate models are used to project how quantities like global mean air temperature and sea level may be expected to change due to the anthropogenic perturbations ofthe Earth's radiation budget. Rahmstorf *et al.* (2007) claim “The data now available raise concerns that the climate system, in particular sea level, may be responding more quickly than climate models indicate”. In the light of this information, IPCC scientists suggested a set of scenarios which based on most recent observed climate trends for carbon dioxide concentrations, global mean air temperatures, and global sea levels (Rahmstorf *et al.,* 2007).

Based on these estimates, IPCC scientists developed and published long term scenarios first time in 1990 and then in 1992 to be used for forecasting future climate change (Houghton *et al.*, 1990; Houghton *et al.*, 1992). In 2000 they developed a set of emission scenarios for radioactively important gases up to year 2100. These scenarios include four scenario “families” covering a total of 40 scenarios. The worst-case scenarios generate the most dramatic projections, with annual average temperatures rising up to 5.8ºC by the end of the 21th century, whereas the projections of the other scenarios are less severe. None of the scenarios projects any decrease in present average temperatures. These scenarios include many factors affecting greenhouse gas emissions; such as economic development and increase in population. These four illustrative marker scenarios can be summarized as A1, A2, B1 and B2 (Joos *et al.*, 2001).

The A1 family scenario represents a world with rapid economic growth and high energy, rapid technological change but low population growth. On the other hand the A2 family scenario symbolizes a future with slow economic growth, and fast population growth. In other words, A2 group of scenarios focus on a heterogeneous world with regional economic development. The B1 scenario family describes a future with low population growth as it is in A1, but with rapid changes in economic structure toward a service and information economy and the introduction of clean technologies. The B2 family scenario defines a future world with moderate population growth, intermediate levels of economic development, and less rapid technologic change than in A1 or B1.

1.4. Climate Change and Biodiversity

Climate change has strong implications for biodiversity. It affects a wide variety of organisms with diverse geographical distributions. Studies of the fossil records and pollen distributions show that species are very sensitive to climate change. When the climate changes, species often disappear from their present areas of distribution and/or may colonize in new areas. Therefore, as the climate changes in the future, the disruption of natural communities and extinction of populations and species can be expected (Davis and Shaw, 2001; Walther *et al.*, 2002).

Most species track the optimum climatic conditions suitable for them, and modify their home ranges if conditions are unsuitable. This shift in geographic distributions may results in changes in the physiology, phenology and interspecific interactions of species. For example, an increase in heat and a decrease in moisture can have direct effect on plant survival and reproduction (Badeck *et al.*, 2004). As another example, based on 35 years of data, Field Skipper butterfly (*Atalopedes campestris*) that seemed restricted to northern California reacted to global warming and expanded its range to central Washington State and Idaho (Wolterbeek, 2010). It is unlikely that all species will be able to evolve new tolerances with changes in climate, and this will affect not only the ranges of species themselves, but also the ecosystem dynamics (Thomas *et al.*, 2004).

Assessments based on paleoecological studies of past climate change, small-scale experiments, and computer models indicate that the effects of global climate change are expected to be even more drastic, in the mid- and late 21st century, when the global temperatures are predicted to increase by as much as 5.8 °C (Heger *et al.*, 2007). The potential impact of these changes on species distributions has been investigated for various organisms by using a modelling approach involving the construction of a "climate envelope" (Willis and Bhagwat, 2009). The function of a climate envelope is to outline the bioclimatic variables such as temperature and humidity, that particular species or groups of species are found in. It shows the ecological conditions a species requires for its survival without taking into account any biotic interactions, such as competition, predation, and food availability (Thomas *et al.*, 2004). This envelope subsequently can be projected on the climate scenarios for the 21st century, giving an outline of the potential distribution of the species in the future.

It is important to model several future scenarios, in order to predict how each species responds to climatic change (Kappelle *et al.*, 1999). The results of these model projections indicate significant changes for many species throughout the world, with the more tolerant species shifting, and even expanding, their ranges by moving towards higher latitudes. On the other hand, species with limited climatic tolerances, and therefore narrower climatic envelopes, cannot shift their ranges, culminating in decreases in their distributions. To illustrate these potential changes; research on the birds, mammals and butterflies of Mexico show a 40% predicted turnover ratio in local communities by 2055 (Peterson *et al.*, 2002). In Europe, Huntley *et al.* 2008 discovered that the average number of bird species breeding on the continent would decrease by 6.8–23.2% between the years 2070-2099.

1.5. Objective of The Study

Mounting evidence indicates that the global climate is currently changing and is having an impact on biological species. It is becoming urgent to develop predictions of how this change in the earth's environment will affect the abundance and distribution of species. This study mainly examines the relationship and possible consequences of a changing environment on species distribution in Anatolia during the 21th century. In geographic terms Anatolia is located at the intersection of Asia and Europe and various climate types and a wide variety of habitats are observed within. As such Anatolia is one of the most important biodiversity areas in the world, and hosts a diverse bird fauna of approximately 464 species (Kirwan *et al*., 1998). Birds have been documented to be a class that is shifting their elevation ranges and colonizing new localities as a result of climate change (Jetz *et al*., 2007; Peh, 2007; Sekercioglu *et al*., 2008; Peterson *et al*., 2002). Besides, long term future projections estimate that up to 30% of the landbird species will be extinct according to worst estimate of surface warming of 6.4° C in the western hemisphere by 2100 (Sekercioglu *et al*., 2008).

In this study, songbirds (Passeriformes) are selected as an example animal class of species to examine the potential impact of climate change on Anatolian fauna. Two major IPCC scenarios (A2 and B2) are chosen for future climatic projections. The results will facilitate the prediction of possible distributional changes in the studied resident and migratory species ranges over time. This will also highlight effective strategies to maximize conservation efforts for these birds and help evaluate existing ones in the study region.

2. LITERATURE REVIEW

2.1. Concepts of Species Distribution Models

In the last two decades, as factors like habitat loss and global climate change started to impact and threaten the survival of many species, there has been, therefore, an increase of interest in species distribution models. This was possibly due to the growing need for information on the geographical distribution of biodiversity (Guisan and Zimmermann, 2000). Distribution models are currently being used routinely to predict species richness and changes in biodiversity. In recent years, predictive modelling of species distribution has become an important method to address various issues in ecology, biogeography, evolution, and more recently, in conservation biology and climate change research. Species distribution modelling is currently being used to understand species-environment relationships (Guisan and Zimmermann, 2000), to assess habitat suitability (Hirzel and Le Lay, 2008), to determine the influence of global climate change on species (Parmesan *et al*., 1999; Walther *et al*., 2002; Parmesan and Yohe, 2003), to project species extinction risk under climate change scenarios (Araújo *et al*., 2005), to evaluate impact of landscape management (Paegelow *et al.,* 2008), and site selection for species reintroduction (Broennimann, *et al*., 2007), among others.

Species distribution models try to provide detailed predictions of distributions by relating presence or abundance of species to environmental data. In this context, distribution models have provided a new tool to explore different questions in ecology, evolution, and conservation. Conceptions of modelling methodologies consist of input variables and outputs at the end of the analysis. The selection of the input variables depends on the purpose of model. Thence, terrestrial conditions such as elevation, soil type, land use, vegetation type, precipitation, temperature and productivity are significant variables in predicting species distribution and richness (Rotenberry *et al*., 2006). In distributional modelling, species distribution models require the occurrence data of species and environmental spatial data layers. These are combined to obtain a predictive projection model which describes the availability of an area for any species (Graham *et al*., 2006). The projection of modelled relationships between species and alternative climates (past or future) is also becoming increasingly popular.

Distributional modelling has been used to predict species ranges (even with limited data) and also the effects of environmental change. It is a good way to assess potential geographic distributions of species derived from their climatic niches, and in some cases it provides additional information for conservation planning strategies and delimiting of protected areas (Guisan and Thuiller, 2005; Rosenzweig and Tubiello, 1996). Distribution models have also been used to predict the invasive potential of non-native species (Ficetola *et al*., 2007). In this approach, climatic tolerances of species are the primary determinants of their current distributions.

Mapping and modelling species distribution is increasingly used in the management of biodiversity, species protection, prediction of possible effects of land use, and climate change. To identify and map suitable habitat for species over large spatial regions, distribution modelling combines species' occurrence data and environmental variables with a powerful tool, the Geographic Information Systems (GIS). Using improved GIS softwares makes it possible to calculate the value of selected environmental variables for each map point in the study area and for each species location, and design and refine future monitoring and sampling strategies to see how populations respond to changing environmental conditions. Some of the GIS layers used to derive environmental variables include temperature, precipitation, digital elevation models, vegetation type, land use, soils, and hydrology (Rotenberry *et al*., 2006). Since GIS derived climate layers are created by spatially interpolating records from climate stations in combination with digital elevation models (Hijmans *et al*., 2005), species distribution models with this GIS-based climate change perspective have become increasingly important. There are quite a few software available for modelling distribution, many of them which can be easily integrated with GIS. Range maps can be created with species distribution models, and in this approach known occurrences of a species and spatially continuous environmental data layers are used to understand the ecological requirements of a species (Graham and Hijmans, 2006). Besides, GIS softwares can be also used to develop predictive models of species distribution, once species distribution and environmental data are integrated within a GIS environment.

Using climate envelopes (or the climatic niche concept) is the most preferred current method for the prediction of species distributions under climate change and they are being used commonly in many areas of ecology. Climate envelope models describe the conditions under which populations of a species persist in the presence of other biota as well as climatic constraints. They enable the ecological conditions which a species requires for its survival without taking into account any biotic interactions, such as competition with other species or other individuals, predation, and changes in food availability. Future distributions are projected based on the assumption that the current envelopes reflect species' environmental preferences. Therefore, species’ future distribution patterns will possibly be modified as the environmental conditions themselves change due to climate change. Newbold *et al.* (2009) suggested that climate-based models of species richness can provide a rapid method for detecting species richness changes in a given area, and therefore can have important implications for biodiversity conservation. The evolutionary conservation of species, the phylogenetic situation of species over time and comparative biogeographical change can be demonstrated in the studies with the support of this principle (Martinez-Meyer *et al.*, 2004, Higgins *et al.*, 2003). For instance Waltari *et al.* (2007), by comparing environmental niche modeling predictions with traditional molecular genetics and phylogeographic predictions for 20 terrestrial vertebrate species in North America showed that environmental niche modeling and phylogeographic studies gave highly similar results.

2.2. Comparison and Evaluation of Various Modeling Methods

While developing distribution modelling techniques, researchers have focused on creating models using three types of biotic data on the area of interest: abundance data, presence/absence data and presence-only data. However, only two of them have been used extensively in recent years, those using presence and absence species occurrence data, and those which use presence-only data.

In the former group, presence/absence, general linear models (GLM) and general additive models (GAM) have been used most frequently. Aspects such as their sensitivity of prediction, robustness to violations of model assumptions (e.g., independence of errors, non-normality) were extensively examined in the literature (Neter *et al*., 1996; Ferrier *et al*., 2002). The main problem of the methods with presence/absence point data is that, most of the time, absences cannot be inferred with certainty. When modelling the distributions of species, absence data are often unavailable, but pseudo-absence data can be used in place of true absence (Zaniewski *et al*., 2002). Pseudo-absence data do not come from actual observation records. Those points are assigned as true absences in the areas where the environmental conditions are compatible with the area of actual presence records (Graham *et al.* 2004). In order to model using the GLM methods, a good strategy is to set pseudo-absence points when true absence data are not available (Hosmer and Lemeshow, 2000; Chefaoui and Lobo, 2008). While applying pseudo-absence method, it is also essential to identify habitats unsuitable for species by profile techniques; this helps us to produce reliable pseudo-absence points for presence–absence modelling. However, in a recent study which tested a range of niche models parameterized with presence only data, GLMs and GAMs performed as well or worse than some commonly used presence only models (Elith *et al*., 2006). Additionally, absences from an inappropriate time interval may make the model predictions less accurate. For instance, if a species has not had the opportunity to disperse to a new area (e.g., an invasive species in a new area) or if current land use restricts occupation of a site, using current absence in model development could lead to poor predictions of potential distribution (Bond *et al*., 2006).

On the other hand, presence-only data are the subject matter of bulk of the current studies, and the results are important for practical implications of modelling for climate change and conservation evaluation. Presence-only methods are comparatively more accurate when compared to presence/absence methods because it is hard to demonstrate absence of species, and false absences can decrease the reliability of predictive models (Chefaoui *et al*., 2005; Guisan and Thuiller, 2005). Moreover studies indicate that the presence-only data are effective for modelling species' distributions for many species and regions. According to results which are integrated with produced area under curve scores (AUC), the predictions based on presence-only data can be accurate enough to be used in conservation planning (Pearce and Ferrier, 2000a; Elith, 2006; Hernandez *et al*., 2006a). However, it is the common consensus that if absence data is available, modelling with presence/absence data should be prioritized as they give better predictions (Brotons *et al*., 2004; Segurado and Araújo, 2004).

The studies of presence only ecological niche modelling have seen growth in recent years measured by the number of publications utilizing these techniques. A recent review in which predictions from numerous presence only datasets across the globe, using a variety of statistical methods illustrated how presence only datasets can provide accurate predictions of species distributions (Elith *et al.,* 2006). There are several modelling methods which have been used for presence-only modelling of species distributions such as, BIOCLIM (Busby, 1986; Nix, 1986) and DOMAIN (Carpenter *et al*., 1993). These models estimate the suitability in a "bioclimatic envelope" by computing the minimum distance in any environmental area with any presence records. Another model, Genetic Algorithm for Rule-set Prediction (GARP) can be defined as a genetic algorithm that produces sets of rules that create ecological niches in an artificial-intelligence-based approach with test presence data and a set of 'pseudo-absence' points (Anderson *et al*., 2003). Probably one of the most popular algorithms now, MAXENT, finds the probability distribution of maximum entropy to predict target probability distribution which are the closest to uniform (Phillips and Dudik, 2004).

These distinct modelling techniques were compared in different studies. Kumar *et. al.* (2009) evaluated two presence/absence methods GLM and classification and regression tree (CART), and two presence-only methods, MAXENT, GARP. They studied bioclimatic and environmental variables for models prediction. Their results showed that MAXENT model gave the most precise predictions, followed by GLM, CART, and lastly GARP.

Elith *et al.* (2006) compared effectiveness of four presence-only models; BIOCLIM, DOMAIN, GARP, and MAXENT to predict distributions of species based on bioclimatic variables. In this study, researchers showed that MAXENT performed better than the other models. Hernandez *et al.* (2006b) evaluated the performance of these presense-only models using species with different environmental preferences and different sample sizes. The results again showed that among the four modeling methodologies MAXENT performed near maximum accuracy levels even with small species occurrence data sets, with as small as five, 10 and 25 data points. They also concluded that the accuracy of the projection is better when species with small geographic ranges are evaluated. In many comparative studies, Maxent performed well even with small sample sizes (Grundel and Pavlovic, 2007; Guisan *et al.*, 2005; Guisan *et al.,* 2007). In another comprehensive comparative study, Phillips *et al.* (2006) demonstrated that based on AUC measures, MAXENT can perform regularly better than GARP in predicting the spatial distribution of two species. In addition MAXENT was more successful in producing detailed predictions. Thus MAXENT seems to be a generally better algorithm than others, for the purposes of distributional modelling, especially in regions where absence data are not recorded for species.

2.3. Methodological Problems of Species Distribution Models

Data for developing species distribution models are distributed irregularly across a species' range based on area, time, and environment (Thuiller *et al.*, 2004; Phillips *et al.*, 2009). These types of spatial biases are characteristic of many biological survey data sets, and these problems of data quality and availability need to be overcome by having higher sampling rates at accessible locations. Besides, improving data sharing and increasing structural integration of data sources are needed to have reliable predictions. If the data that are not representative of the appropriate area, time, and environment are used, big portion of the suitable areas for occupancy may be ignored or not identified in current and projected future climate scenarios by species distribution models (Cayuela *et al.*, 2009). Even though some studies have faced this problem, in order to reduce the impact, some other studies selected species in a limited study area (Wiens *et al.*, 2009). However, Lewis (2006) states that if species with limited ranges are selected for most species distribution modeling studies, the results of collective data will probably cause biases themselves.

Austin (2002) mentioned that ‘strong correlation does not require causation’. Climate data can be associated with many other environmental phenomena (such as, spatial proximity and mutual correlation with other variables). Strong correlations between variables may allow climatic data to predict species presence, even if climate has little to do with a species’ dispersal (Lozier *et al.*, 2009). Unfortunately, the relative influence of current climate in the distribution of many species is unknown or not well known.

Most models which are used to predict species’ distribution under future climates require modelled future climate scenarios as inputs (Brereton *et al.*, 1995). Future climate scenarios stem from mathematical models. Some elements of climate are carefully parameterized (such as, temperature, ocean acidification) than others (such as, precipitation patterns), and their resolution and certainty have important effects on the results of species–climate predictions (Beaumont and Hughes, 2002; Watson, 2008).

Also some species have specific small-scale habitat preferences that are likely to be ignored by species distribution models. Topographic, geomorphic features and the distributions of other species will be crucial for many species. Most of the species distribution models use large grid cells to apply climate scenarios, often tens kilometers across or more (Erasmus *et al.*, 2002). Some of them are capable of representing small grid cells, however this makes it difficult to capture elements such as temperature and precipitation (Williams *et. al.,* 2003). In addition some other critical environmental variables are not available extensively in spatial format (e.g. groundwater resources). Unexpected climatic events such as storms and droughts are also difficult to predict or represent spatially (Hannah *et al*., 2002). Therefore, there are issues that make interpretation of species distribution models complex and cause high levels of uncertainties.

2.4. Effects of Climate Change on Species

Recent rapid climate change is already affecting a wide variety of organisms and its effects on natural systems have been studied to understand its impact for potential geographic distributions of species. In this regard, distribution modelling techniques have become particularly important, because they provide one of the few predictive approaches to understand geographic dynamics of species. Several studies have modelled future distributions of species at regional and local scales. A general conclusion is that species' potential distributional areas will shift poleward, as well as upward in elevation in areas where the conditions will likely be more convenient for them to survive (Martínez-Meyer, 2005; Sekercioglu *et al*., 2008). Nevertheless, alarming extinction risks have been predicted for some species in the next century (Thomas *et al*., 2004).

The changes in climate can impact species either directly or indirectly through many different impact mechanisms. The evidence from long-term data indicates that the climate of the past half-century is already affecting the physiology, the range and distribution, and phenology of some species (Crick, 2004) and the composition and dynamics of communities (Walther et al., 2002), as predicted theoretically. However, in many studies researchers have mainly focused on two phenomena: range and abundance shifts, and phenological changes.

Evidence from the fossil records (Davis and Shaw, 2001) and from recently observed trends show that changing climate has a strong influence on species' ranges (Walther *et al*., 2002). Range and abundance shifts can be explained as a form of adaptation in terms of moving to more suitable geographical habitats. Many studies provide evidence that changing climate has a profound influence on range expansion and contraction of species, particularly for the migratory species such as birds and butterflies that can disperse easily. Parmesan and Yohe (2003) analyzed 1700 species including trees, shrubs, herbs, butterflies, birds, amphibians and fish, and they indicate that more than half of these species display statistically significant, nonrandom pattern changes in the range of the direction predicted by regional changes in climate. They also summarized that 99 species including birds, butterflies, alpine herbs have changed their ranges northward with an average limit of 6.1 km/decade, or higher their altitudes by an average of 6.1 m/decade. Recent research conducted by Root *et al*. (2003) shows temperature-related geographical shifts affecting around 1500 species, ranging from mollusks to mammals and from grasses to trees. They indicate the current and visible impact of climate change on species, and conclude that the shifts are observed even in minor (<1°C) temperature changes.

Due to habitat alterations, direct human activity can be considered as the main reason of changes in bird distribution and abundance. However, recent climate warming is reported as the putative reason (Parmesan *et al*., 1999). Climate change is predicted to cause shifts in bird distributions along latitudinal and/or altitudinal gradients because species are expected to follow climate as a function of their physiological tolerances. In mountains, climate changes more rapidly with elevation than it does with latitude, so rapid altitudinal shifts by bird species have been predicted (Mccarty, 2001; Sekercioglu *et al*., 2008). Climate change has been also shown to affect the geographic distribution and/or abundance of bird species in different parts of Europe, Middle East, and Australia (Harrison *et al*., 2006; Duncan *et al*., 2001). For example, it was observed that British bird species extended their breeding ranges north by an average of 18.9km in response to increasing mean annual temperatures at the northern extent of their distribution over the period 1972-1991 (Thomas and Lennon, 1999).

Although in terms of expansions and contractions some studies indicate evolutionary responses of some species to climate change, the generality of evolutionary responses aren't well understood. Recent studies have shown that a significant change in environmental dynamics (e.g. deforestation, natural reforestation, fire risk, agriculture, urbanism, biodiversity, and climate change) can have effects on mutations in particular genes or genomic regions which provide either adaptation of species to changing environments or cause them to go extinct (Thomas *et al.*, 2004). To understand the effect of climate change on extinction risk, Thomas *et al.* (2004) used a species level approach, in contrast to the more traditional community-level approach that uses the species and area relationship. Their overall conclusion is that between 20 and 30 percent of species will go extinct if temperatures rise by 1.5 to 2.5^{o}C over the next 50 years period.

Another major impact of climate change may involve the movement of species' populations from their actual locations to new and unoccupied areas. In this process, local extinctions may occur and populations may become highly fragmented. For example, Sinervo *et al.* (2010) have observed lizard populations in Mexico since 1975, and in 2009 they saw that 12% of local lizard population has gone extinct. With the help of climatic data, they found a correlation between the change in maximum temperature and local extinctions.

As another phenomenon, phenology can be defined as periodic life cycle events influenced by seasonal and inter-annual variations in climate. Phenological phases are important indicators for detecting the impact of a changing climate on organisms and ecosystems. A large number of different types of datasets demonstrate that changes in the timing of life cycle events are obvious on different spatial scales from all over the world. Menzel (2002) summarized the significant impact of earlier spring activities on biological species, including changes in species distribution, population sizes, and the timing of reproduction or migration events on diverse organisms such as trees, shrubs, herbs, butterflies, birds, amphibians and fish.

Phenological differences are evident mostly for plants and bird species. The changes in the spring period reflected by the altered phenology of flowering, breeding, or first singing of birds, and earlier arrival of migrant birds have been observed in conjunction with climate change (Both *et al.*, 2005). Parmesan and Yohe (2003) also summarized a mean of 2.3 days/decade earlier spring timing of various life-history events (95% CI of 1.7–3.2 days/decade) across all 172 species including herbs, shrubs, trees, birds, butterflies, and amphibians. For plants, strong seasonal variation is reported with the highest advances in early spring and almost no response in summer and early autumn. Similarly, short distance migrating birds, which tend to migrate early in the season, show earlier arrival times (Sparks, 2001). Short-distance migrating birds spend the winter close to their breeding areas, as a consequence they are able to adjust the timing of migration easier as a response to local climate change, which correlates to the conditions on their breeding areas. However long distance migrants show a more complex response, with many species not changing their arrival times or even delaying them (Walther *et al.*, 2002; Root *et al.*, 2003). This is just because of the fact that the effects of climate change are not homogeneously observed over the world and results in heterogeneous shifts in local climate conditions in different parts of the world. Therefore, when a long distant migrant species starts migrating and arrive its final destination, the onset of spring which has a crucial ecological impact on the population of species might have already past and which may results in poorer conditions for feeding and breeding (Both *et al.*, 2005). For example, in Poland, the earlier arrival of short-distance (European) migrants was observed more than that for long distance (African) migratory birds (Tryjanowski *et al.*, 2002). Marra *et al.* (2005) also stated that North American, short-distance migrant passerines have advanced their arrival date into their breeding areas; this is probably because of faster spring migration at higher temperatures on their flyway.

Other researches indicate the indirect effects of climate change on phenology of species, through food abundance. Both and Visser (2005) indicated that food abundance is one of the crucial factors to which birds should adapt their timing of reproduction, therefore food availability in changing environments directly affects their phenology. In their study Both and Visser (2005) show that when there is not enough food for *Ficedula hypoleuca* there is a delay on the time of egg-laying, and this effects some other life characters, such as earlier incubation in the clutch and decreases the interval between laying of the last egg and hatching of the first egg. In Netherlands, Both and Visser (2001) also reported earlier in-nesting times for a long-distance migrant, small passerine bird pied flycatcher, *Ficedula hypoleuca*. As a mechanism they proposed that earlier in-nesting time was constrained by the arrival time, because of the insufficient food supply at the time they arrive. They argued that these birds, when wintering in Africa, are also not able to predict when spring starts on their breeding ground. Other studies show that arrival and breeding times depend on temperatures at their wintering grounds, as well as on temperature at the breeding grounds (Both *et al.,* 2005).

In terms of plants, Ahas and Aasa (2006) showed that the spring period starts four weeks earlier in western and central Europe and were delayed for up to two weeks in the Eastern Europe. Another study, which is based on pollen data by Van Vliet *et al*. (2003), indicates that the start of flowering in the Netherlands has begun up to 19 days in advance in the 1990s, when compared with the 1970s. Beaubien and Freeland (2000) have studied the first flowering time of the Aspen Poplar, *Populus tremuloides*, between 1900 and 1997 in Canada. The results of their study showed that flowering date started 26 days earlier between study periods. In another study, Menzel and Fabrian (1999) have reported a prolonged growing season by examining the plant data from the International Phenological Gardens.

Understanding how species will respond to projected future climate change is of fundamental importance for effective management and conservation of biodiversity (Hannah *et al*., 2002). Environmental variability can cause the strength and direction of selection to change over time. For instance many species show little or no match between their current and predicted ranges. Such species possibly have high extinction risk, especially those with limited climatic tolerance (Huntley *et al*., 2008). Hence when environmental conditions, which populations are currently adapted to change drastically over time, there will either be probable migration towards new areas with suitable conditions or extinction (Martinez-Meyer *et al*., 2004). Thomas *et al*. (2004) mention that around 400 species may lose their ranges and go extinct by the end of the 21st century.

In conclusion, it can be seen that climate change affects the populations of birds and behavior of other organisms negatively, including range changes, population dynamics, phenology and extinction risk. Many species move closer to the poles and many species' life cycle events are changed as a response to the rise in global temperatures. Using long-term data sets is essential to understand the relationships between survival rates, breeding success, abundance, distribution and phenology of bird species and a range of climatic variables. Thereby, these relationships can be used to predict the effects of future climatic change on bird populations.

3. MATERIALS AND METHODOLOGY

The objective of this study was to understand how bird species respond to climatic changes. In principle, species can respond to climatic changes in one of the two ways either they can adapt, through evolutionary process to the new climatic conditions in which they find themselves, or else they can change their area of distribution so that it continues to correspond to those regions where the species' climatic conditions tolerances and/or requirements are met (Huntley, 1999). Therefore the main aim of this study was to predict possible changes of species distributions in the future (2020, 2050, and 2080) and present richness maps. The steps of the modelling technique are described below in Figure 1.

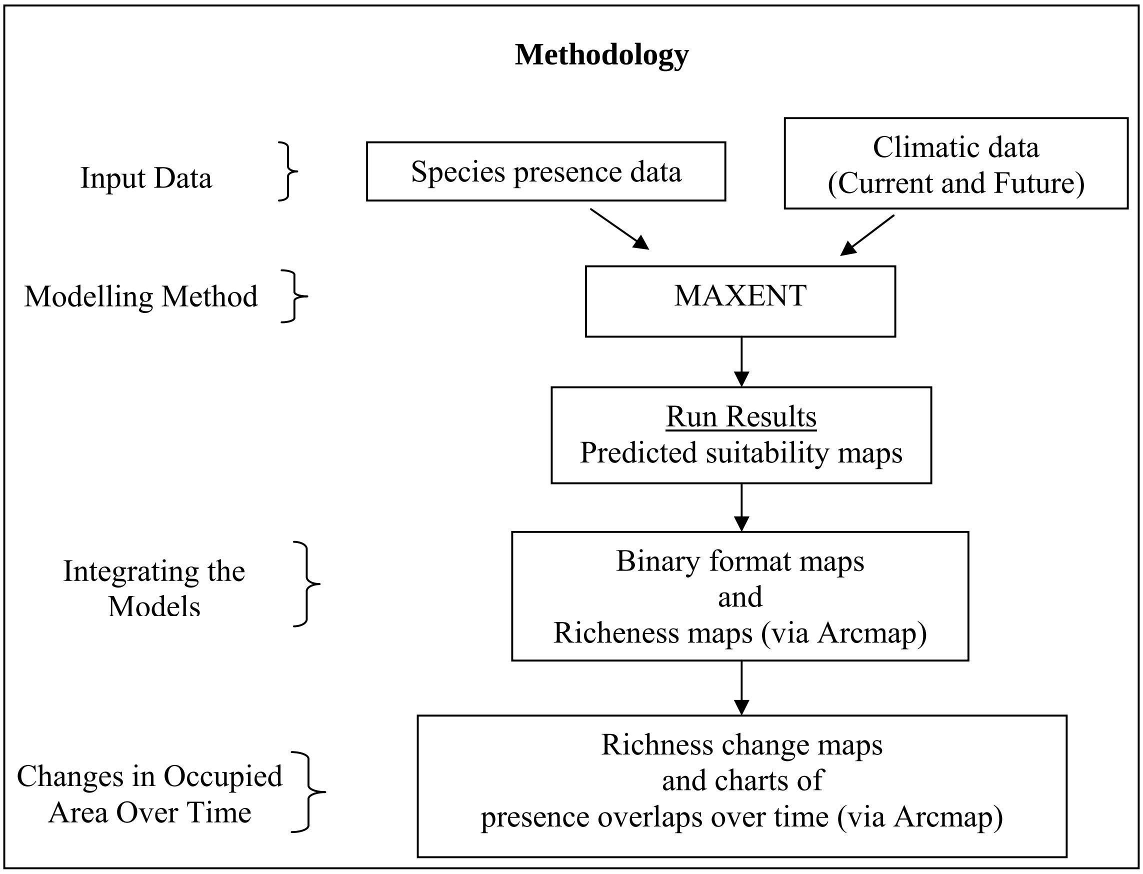


Figure 1. The steps of the research methodology.

3.1. Geographical Area, Species and Time Horizon

3.1.1. Study Area

Turkey, whole Anatolian Region, was selected as geographical area for the study. The country of Turkey has a surface area of 783,562 km^2 and is found between eastern meridians 26° and 45° and northern parallels 36° and 42°. Overall, Turkey is the intersection point of Asia and Europe and consists of seven regions with diverse climates and complex topography. Hence, it is not possible to talk about a homogeneous, single overall climate pattern for Turkey. Around the Sea of Marmara (the Marmara Region) the climate is moderate, though in winter the temperature can drop below zero. In western Anatolia (Aegean Region) there is a mild Mediterranean climate with average temperatures of 9°C in the winter and 29°C in the summer. On the southern coast of Anatolia (the Mediterranean Region), a similar kind of climate is observed. In the climate of the Anatolian Plateau (the Central Anatolian Region), there are great temperature differences between day and night and between seasons; the average temperature is 23 °C in summer and -2 °C in winter. The climate in the Black Sea Region is wet, warm and humid, with the average temperature summer being 23°C, and the winter 7°C. In eastern Anatolia and southeastern Anatolia there is a long hard winter, where year after year snow lies on the ground from November until the end of April. The average temperature in winter is -13°C and in the summer it is 17 °C (Sensoy *et al.*, 2008).

Because of it being in the temperate zone and hosting regions with a wide spectrum of climatic patterns, Turkey is quite rich in habitat diversity due to the variety in its natural resources such as soil, water, geology, geomorphology, climate, flora and fauna (Kaya *et al.*, 1997). Turkey has several natural habitats, such as marshes and thick forests of the Northeast, wetlands and the dry arid areas of the Southwest, coastal parts of the Mediterranean, Aegean, and Black Sea Regions and various mountain chains. The presence of such different habitat types contributes to the high levels of plant and animal species diversity observed in Turkey.

Water is essential for living organisms to maintain their basic functions, and wetlands are especially important for the survival of many species found in Turkey. They have basic functions, such as playing an essential part in the regulation of river flow, filtering pollutants and fertilizers, providing habitats for water birds, wild animals and plants. In terms of wetlands, Turkey is one of the most important countries around the region, due to its geographical position between Europe, Asia and Africa, its geographical features, and climate. According to the International Ramsar list, there are 135 internationally important wetlands in Turkey, and 12 of them are designated as Ramsar Sites (WWF-Türkiye, 2008). These wetlands are of great importance for migrant, nonmigrant bird species, and also for many breeding species of waterbirds.

3.1.2. Study Species

In this study, resident (non migratory) and migratory passerine bird species which are common and regular in the Turkey throughout the year are examined. The Passerines, known as songbirds, belong to the largest order of class Aves which has nearly 5700 species (Sibley and Monroe, 1990). They consist of a diverse group of tiny to fairly large land birds. They are named as songbirds because they have larger brains and learning ability, especially with respect to vocalizations.

Resident and migratory Passerines are commonly observed in Turkey, and this provides a big database of presence point records that are necessary for modelling. This big number of species enables us to undertake a comprehensive biodiversity analysis. The availability of species' presence point records with geographical coordinates (latitude and longitude) in sufficient number can be counted as the one of the biggest limitations for preparing biologically meaningful biodiversity maps. In this study we used a web database on Turkish birds (www.kusbank.org) to gather presence point records for a number of different Passerine species.

3.2. Input Data

3.2.1. Species Presence Data

Passerine species, presence only, data was obtained from www.kusbank.org. A full checklist consists of 472 Turkish bird species. Among all, 20 resident (nonmigratory) and nine summer migratory (breeding) Passerine species were selected to represent the diverse climatic features present in the study area with the help of Roselaar (1995), and for which sufficient occurrence data was available to undertake modelling. After the selection of species, the reliability of the records was examined for each species separately. In order to avoid bias;

First, local Breeding Bird Survey (BBS) - Atlas studies (especially in GAP and Gediz Delta regions) and records from ringing stations were eliminated in order to obtain homogeneous recorded data. Therefore biases, which may have been caused by a relatively excessive number of records in those regions, were reduced for the model. Second, for migratory species, time of observation in the records was taken into account and records which belong to the breeding season (April 15 – July 30) were kept and the others were eliminated because of the fact that those records out of this time interval may represent the records made during the actual migration of the species, not the data at the exact breeding locality. Third, some resident bird species made small-scale changes in their exact living locality with respect to excessive climatic conditions during wintertime and stay temporally in other locations showing other climatic conditions than those species prefer to be during breeding time. Therefore all the bird observations recorded during wintertime especially between December and January were excluded from the analyses. Finally, the elimination of cryptic species was done based on the observers’ experience. The term of cryptic is used to describe species that are not easily identified and require adequate experience.

The data on the distribution of species was obtained at least in the form of species name, name of location observed, and geographic coordinates of an observed species (latitude and longitude). At the end of the performed analyses, a total number for species presence point records were obtained as number of unique locations. The lists of bird species included in the analyses are presented with an alphabetical order in the Tables 2a and 2b. The distribution of species presence points in the study area is shown in Figures 2a and 2b.

Table 2a. Resident species names and number of presence records.

Scientific name	**Common name**	**Presence Records**
Calandrella brachydactyla	Greater Short-toed Lark	262
Carduelis carduelis	European Goldfinch	3275
Corvus monedula	Eurasian Jackdaw	2237
Corvus corone palescens	Hooded Crow	4234
Corvus corax	Common Raven	936
Galerida cristata	Crested Lark	2922
Garrulus glandarius	Eurasian Jay	2407
Melanocorypha calandra	Calandra Lark	794
Passer montanus	House Sparrow	177
Petronia petronia	Rock Sparrow	533
Pica pica	Black-billed Magpie	3904
Parus ater	Coal Tit	890
Parus caeruleus	Blue Tit	1479
Passer domesticus	House Sparrow	5097
Parus major	Great Tit	3590
Pycnonotus xanthopygos	White-spectacled (Yellow-	415
Sitta neumayer	Western Rock-nuthatch	1024
Sitta tephronota	Eastern Rock-nuthatch	198
Sitta europaea	Wood Nuthatch	388
Turdus merula	Eurasian Blackbird	3685
Total		**38447**

Table 2b. Migratory species names and number of presence records.

Scientific name	**Common name**	**Presence Records**
Carpodacus erythrinus	Common Rosefinch	260
Emberiza caesia	Cretzschmar's Bunting	141
Erythropygia galactotes	Rufous-tailed Scrub-robin	669
Hippolais olivetorum	Olive-tree Warbler	65
Hirundo daurica	Red-rumped Swallow	700
Lanius nubicus	Masked Shrike	411
Phylloscopus sindianus	Phylloscopus sindianus	29
Phylloscopus trochiloides	Greenish Warbler	25
Sylvia cantillans	Subalpine Warbler	35
Total		**2335**

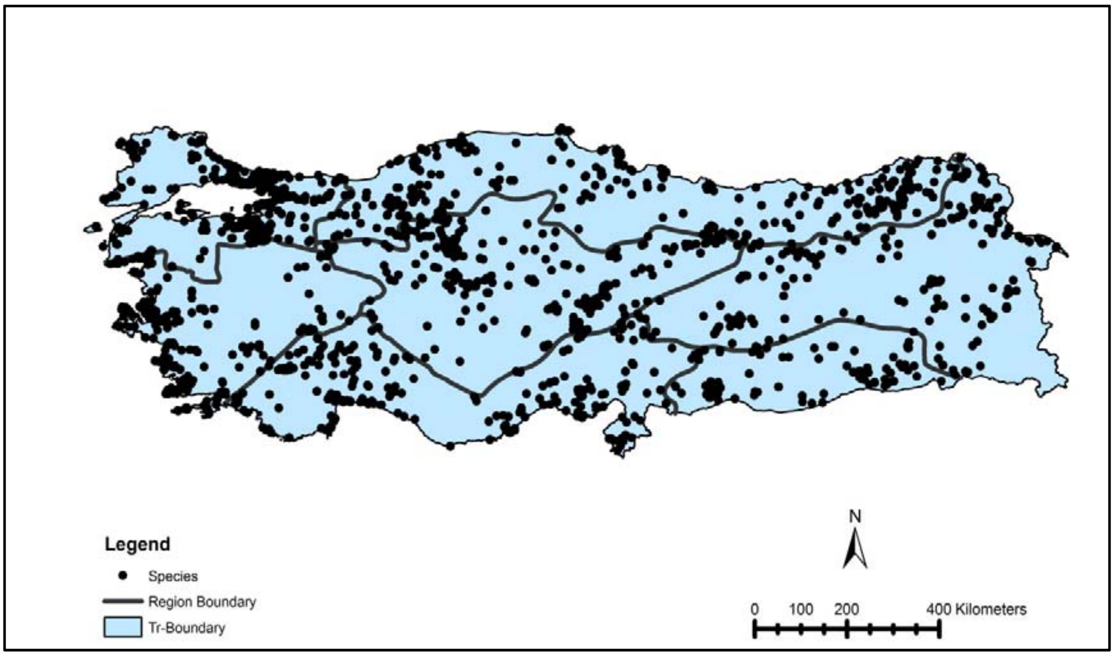


Figure 2a. The presence records of resident species in the study area.

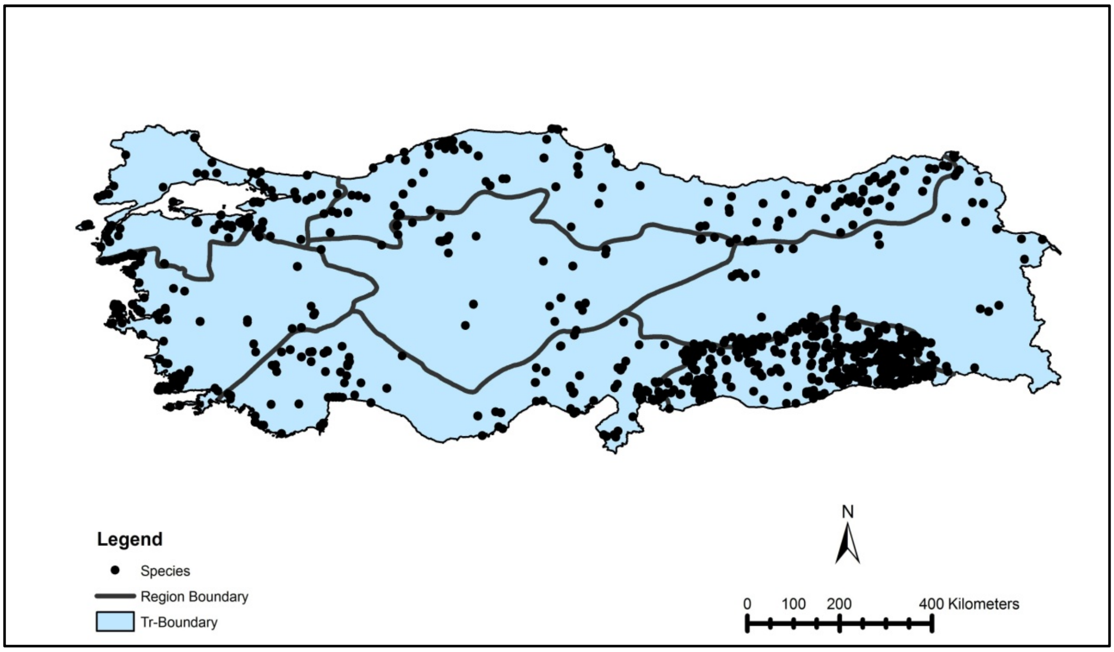


Figure 2b. The presence records of summer migratory species in the study area.

3.2.2. Climatic Data (Current and Future)

The worldclim.org was used as the source for both past and future climate data. Climatic data were retrieved at a 2.5 arc-minutes grid resolution (~ 5 km x 5 km resolution). It was created by interpolation using a thin-plate smoothing spine of observed climate at weather stations, with latitude, longitude and elevation as independent variables (Hutchinson, 1995; Hutchinson, 2004). Movements of species over time were tracked over different time periods (2020, 2050, and 2080).

For current and future conditions, 19 bioclimatic variables were generated with the help of specific software, ArcMAP and DivaGIS, by using average monthly climate data (precipitation, minimum, and maximum temperature) obtained from weather stations on a 2.5 arc-minutes grid resolution (~ 5 km x 5 km resolution) (Ramírez and Bueno-Cabrera, 2009; Hijmans *et al*., 2005). As a global climate model, HADCM3 (Hadley Centre

Coupled Model version 3) was used to simulate the impact of the A2a and B2a scenarios on future climate conditions. These two scenarios were based on IPCC's different scenarios (Collins *et al.*, 2001). In total 19 layers of topographical and environmental bioclimatic variables were used as listed on Table 3. All these layers were masked to an area circumscribed between eastern meridians 26° and 45° and northern parallels 36° and 42°, which included the territory of Turkey with all its seven regions.

Table 3. Codes for 19 environmental and topographic bioclimatic variables layers used to model birds' distribution.

Variable	**Variable Type**	**Source**
BIO1	Annual Mean Temperature	WorldClim
BIO2	Mean Diurnal Range: Mean of monthly (max temp -	WorldClim
BIO3	Isothermality: (P2/P7)* 100	WorldClim
BIO4	Temperature Seasonality (standard deviation *100)	WorldClim
BIO5	Max Temperature of Warmest Month	WorldClim
BIO6	Min Temperature of Coldest Month	WorldClim
BIO7	Temperature Annual Range (P5-P6)	WorldClim
BIO8	Mean Temperature of Wettest Quarter	WorldClim
BIO9	Mean Temperature of Driest Quarter	WorldClim
BIO10	Mean Temperature of Warmest Quarter	WorldClim
BIO11	Mean Temperature of Coldest Quarter	WorldClim
BIO12	Annual Precipitation	WorldClim
BIO13	Precipitation of Wettest Month	WorldClim
BIO14	Precipitation of Driest Month	WorldClim
BIO15	Precipitation Seasonality (Coefficient of Variation)	WorldClim
BIO16	Precipitation of Wettest Quarter	WorldClim
BIO17	Precipitation of Driest Quarter	WorldClim
BIO18	Precipitation of Warmest Quarter	WorldClim
BIO19	Precipitation of Coldest Quarter	WorldClim

3.3. Modelling

In the model, the climate envelope was built by using the species and climate data mentioned above. The geographic location that particular species are found in was used as the dependent variable, and various climatic data as independent variables. Subsequently, the relationship between a species' known distribution and various climatic variables were quantified.

MAXENT version 3.2.19 (www.cs.princeton.edu/~schapire/MAXENT), a maximum entropy modelling method, was used to estimate species geographic distributions based on presence data. Maxent is a general-purpose algorithm that can generate predictions or inferences from an incomplete set of information. The Maxent approach is based on a probabilistic framework. The main assumption is that the incomplete empirical probability distribution (determined by occurrence data) can be approximated with a probability distribution of maximum entropy (the Maxent distribution) subject to certain environmental constraints, and that this distribution approximates the potential geographic distribution of the group of interest (Phillips. *et al.*, 2006.). The input data consist of a set of environmental layers for the study region and the observed presence localities within that region. Maxent then uses these data to generate a distribution of the niche space observed at the presence localities, and estimates the environmental properties that are suitable for the species studied. Predictive maps generated by Maxent express suitability of each grid cell as a function of the environmental variables at that grid cell.

The models were run with default settings of Maxent: auto features; 10,000 background points, regularization multiplier = 1.0, maximum iterations = 1000 and convergence threshold = 0.00005. To assess the importance of each predictor variable, the jackknifing procedures were implemented in Maxent. The area under the receiver operator curve (AUC) was used to assess overall model performance, where an AUC score of 0.5 indicates random prediction, and a score of 1 a perfect prediction. In order to assess the robustness of the model to sampling variation, 25% of the presence data from the original dataset were chosen randomly to test the model while the remaining 75% were used in training it.

To understand which variables are most important in the model, MAXENT keeps track of how much the overall model gain improves when small changes are made to each variable by running a jackknife test. MAXENT performs three separate models by using a set of bioclimatic variables repeatedly:

- Each bioclimatic variable is excluded, and a model generated using all other variables.
- A model is generated using each bioclimatic variable alone.
- A model is generated with all bioclimatic variables.

The results are presented in html format and include these three models' gain. The gain is a measure of the likelihood of the samples. At the end of the run, the gain indicates how closely the model is concentrated around the presence samples; for example, if the gain is 2, it means that the average sample likelihood is exp (2) ≈ 7.4 times higher than that of a random modelled area. The uniform distribution has a gain value of 0, increasing towards an asymptote during the run. Therefore the higher the gain, the better is the model's predictive power. It should be known that Maxent does not directly calculating probability of occurrence. The probability it assigns to each pixel is typically very small, as the values must sum to 1 over all the pixels in the grid (Phillips *et al.*, 2006).

In order to eliminate insignificant bioclimatic variables that include redundant information from the model, a series of a correlation tests were conducted. For these purposes correlation matrices were generated (Appendix A) for all 19 bioclimatic variables using the software ENMTools (Warren *et al.*, 2008). This software helps assessing identity and similarity of ecological niches, or variables. In this study, a Pearson correlation coefficient of 0.75 was used as a threshold to pair highly correlated bioclimatic variables (Rissler *et al.*, 2006). By the help of paired bioclimatic variables and an examination of MAXENT results, eight biologically meaningful variables were chosen and used in all subsequent analyses. These included BIO1: annual mean temperature; BIO2: mean diurnal range in temperature; BIO3: isothermality (monthly/annual); BIO4: Temperature Seasonality (standard deviation *100); BIO8: mean temperature of wettest quarter of the; BIO12: Annual Precipitation; BIO14: Precipitation of Driest Month; BIO15: precipitation of seasonality (coefficient of variation). On the other hand, in order to use variables which indicate warmer summer seasons when the migratory species are actually present, instead of variables BIO1 and BIO14 their correlated variables BIO10: Mean Temperature of Warmest Quarter and BIO18: Precipitation of Warmest Quarter, respectively, were used. MAXENT software can be used to predict species' distribution in the future with a model developed using current bioclimatic variables. Hence using these eight bioclimatic variables, projections for 2020, 2050, and 2080 were produced.

3.4. Integrating The Models

The output data from MAXENT model show the prediction of probability of occurrence with a range from 0 to 1, for each cell in the analysis area. In order to develop binary state predictions and produce binary maps, and define suitable and unsuitable areas for each species, a threshold was determined to convert these occurrence probabilities to discrete presence/absence values. By the help of "10 percentile training presence logistic threshold" values, the presence probabilities in each pixel of the geographic area were determined for each species. In these binary maps, species were considered to be absent in a cell if their probability of presence was lower than the 10-percentile threshold, and present if it was higher (Raes *et al.*, 2009).

The binary presence maps of each species were produced for four time periods. Then, in order to produce species richness (biodiversity) maps for each modelled scenario and time period all binary maps from each species' biogeographic group were combined. ArcGIS 9.3 software and the help of scripts prepared in Python programming language (Keşişoğlu, 2010) were used while combining the maps. This makes it possible to obtain biodiversity change maps to observe possible loss or gain of biodiversity in the same area over time.

3.5. Changes in Occupied Area Over Time

As mentioned above, in the output data, presence is indicated by 1, and absence is indicated by 0. In order to create presence overlap maps for the different time periods, current data were multiplied by predicted future data, for each cell. In these maps, the location where a species was present both in current and predicted time periods is indicated by 1. The percentage of presence overlap was calculated by dividing the count of locations marked by 1 in predicted future presence maps by that in current maps. Python scripts in ArcGIS were used for making these calculations (Keşişoğlu, 2010).

4. RESULTS

4.1. Results for Resident Species

ROC plots predicted very similar AUC values between training and test data even though the values were slightly lower for the latter (0.89). All AUC values, which determine model performance, were higher than 0.88 or higher (Table 4), and these indicate that the model had a good predictive power, with average AUC values of 0.91 in all 20 models. Besides the average training, AUC values of the model including all eight variables are higher than that excluding one of the eight variables. This comparison also shows that the predictive ability of the model decreases if any of the eight variables are excluded.

Table 4. The order of AUC values, variable contributions, and indication times for each variable that show the most relevancy for a species.

Bioclimatic variables	Average AUC without	Sum of Contribution	Number of species
Temperature Seasonality (BIO4)	0.88	491.25	7
Annual mean temperature (BIO1)	0.88	460.52	8
Precipitation of seasonality (BIO15)	0.88	260.72	1
Annual Precipitation (BIO12)	0.88	228.61	3
Precipitation of Driest Month (BIO14)	0.88	203.26	1
Mean temperature of wettest quarter (BIO8)	0.88	167.64	0
Mean diurnal range in temperature (BIO2)	0.89	108.02	0
Isothermality (monthly/annual) (BIO3)	0.89	79.98	0

Temperature seasonality and annual mean temperature were the most relevant variables in all models. The former was seen to be the most relevant to be for seven species, while the later was for eight species. The order of contribution for the other six variables are, precipitation of seasonality, annual precipitation, precipitation of driest month, mean temperature of wettest quarter, mean diurnal range in temperature and isothermality (Table 4).

The model for each species was calculated using these eight variables as references and projecting current and future distribution maps, where each pixel in the maps is the dependent variable and climatic data are independent variables. Figure 3 shows distribution maps of *Pycnonotus xanthopygos*, for current and future (A2a-2020, A2a-2050, and A2a-2080) time periods as an example. Warmer colors show areas with better predicted conditions. Dots on the maps show the presence locations; white dots used for training, violet dots used for test locations. The occurrence probabilities of this species show a clear shift from the Mediterranean Region to the Aegean part of the country.

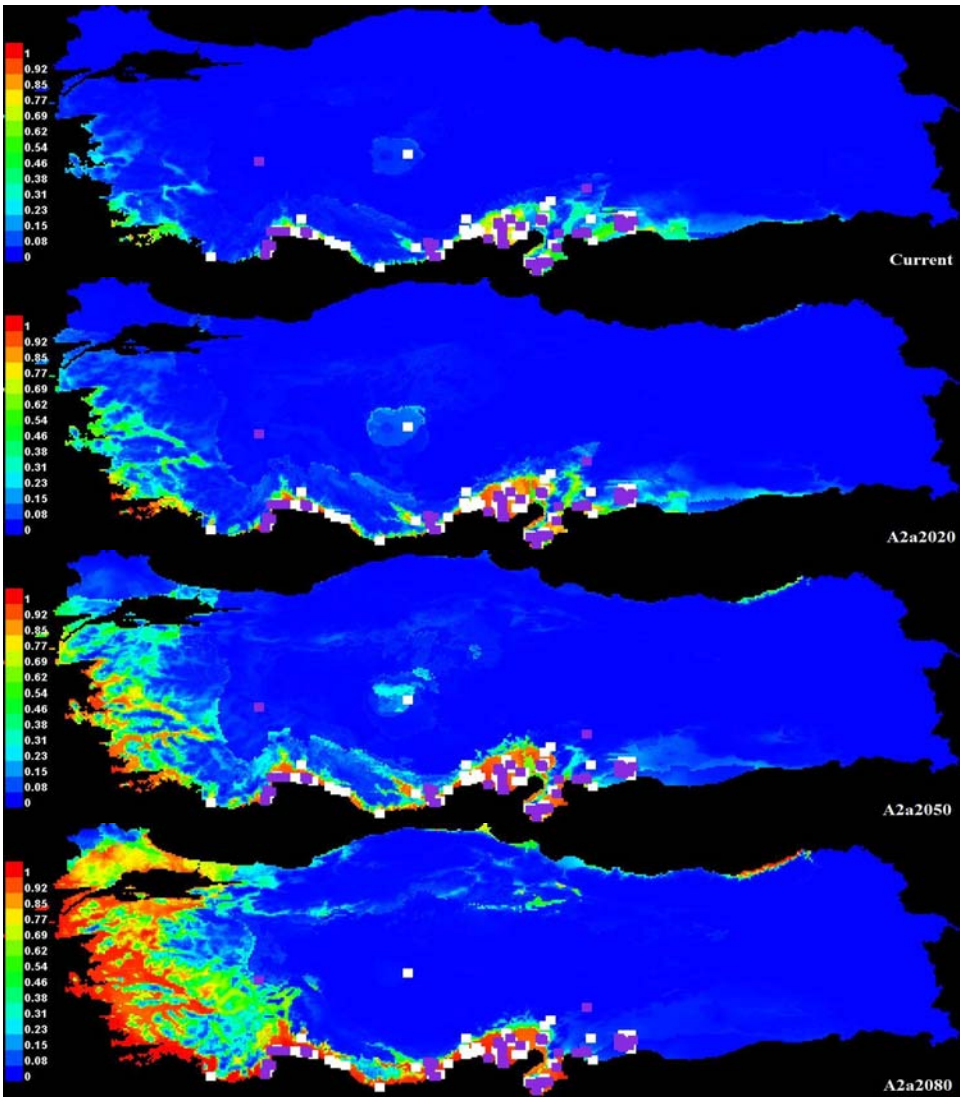


Figure 3. Maxent output, the probability of occurrence maps for *Pycnonotus xanthopygos* for current and future scenarios (A2a2020, A2a2050, A2a 2080).

In order to show a quick overview of current species distribution patterns, the projection output of every species were analyzed and overlaid one over another, and then the species richness map was created in Figure 4. As it can be seen from the map, presence of different species is aggregated in inland of the Aegean and Mediterranean Regions, and almost all of the eastern and southeastern parts of the country (warmer colors). In the coastal areas the species richness is relatively lower. Figure 5 shows the species richness map, which enables us to see the results in greater detail; about 1% of the studied areas do not have presence of any species, and 15% of studied area contains all the 20 species together.

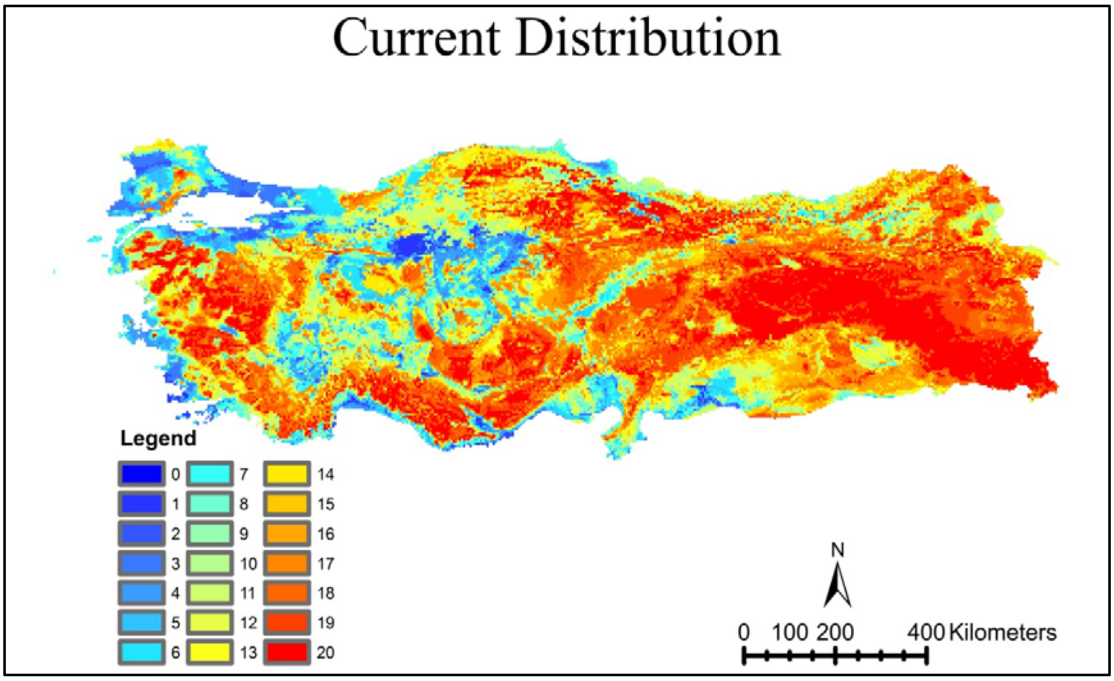


Figure 4. Current distribution patterns of 20 resident species.

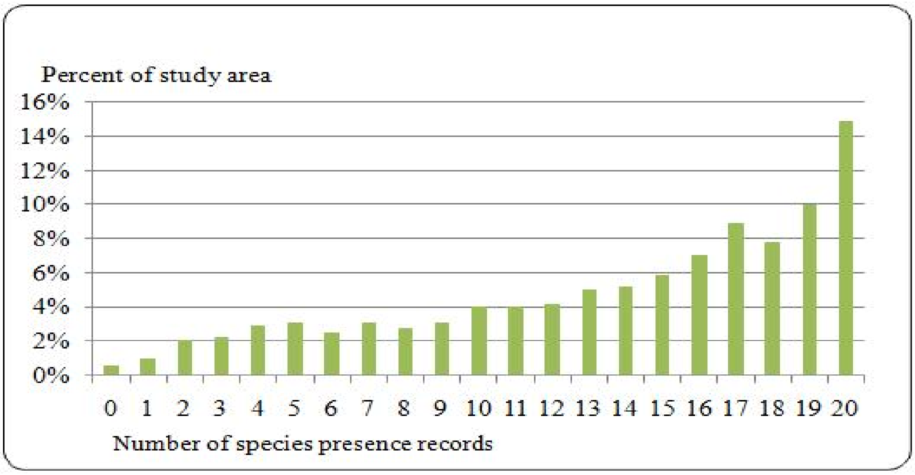


Figure 5. Current species richness chart.

A numeric representation of overall distribution can be seen in Table 5. The data show that there are not any obvious changes in the areas with no presence between the current period and future periods. The areas, which do not contain any species currently, hold 1% of the total area and these values decrease to 0% in all story lines in both scenarios. The summaries of species presence records distribution over time were graphed in Figure 6a and 6b for the scenarios A2a and B2a, respectively, in terms of the percentages. In both scenarios (A2a and B2a) there are no significant changes in the areas that have no species presence. Areas occupied with 1-5 species decline in both scenarios, but the decline is more severe in A2a. Under this scenario, an increase to 23% from 11% is seen in 2020, and then a serious decline to 2% is calculated by 2080. For the same species richness interval (1-5), under B2a, a more gradual decrease is observed from 11%, 10.6%, and 8.5% to 6.2% for current, 2020, 2050 and 2080 time periods, respectively. A big step increase is predicted in the areas occupied by 6-10 species from 15% in the current time period, to 27% and 28%, under scenarios A2a and B2a, in 2080, respectively. On the other hand, in both scenarios, the areas with 11-20 species are observed to decrease. In scenario A2a a decrease is seen from 73% to 61% until 2050, but a recovery to 71% is observed in 2080. In scenario B2a, a slight decrease is observed. The percentage of occupied area with

11-20 species declines to 68% in 2020 and stays around that value in 2050. In 2080, there is a further 3% decrease to 65%.

Table 5. Changes in percent occupied area over the different time periods and scenarios.

Scenario	**Year**	**Area with no species presence**	**Area with 1-5 species presence**	**Area with 6-10 species presence**	**Area with 11-20 species presence**
	Current	0.6%	11.2%	15.2%	73.0%
A2a	2020	0.1%	23.4%	10.0%	66.5%
	2050	0.1%	7.9%	31.5%	60.6%
	2080	0.0%	2.2%	27.2%	70.6%
B2a	2020	0.1%	10.6%	21.3%	67.9%
	2050	0.1%	8.5%	23.2%	68.2%
	2080	0.2%	6.2%	28.3%	65.3%

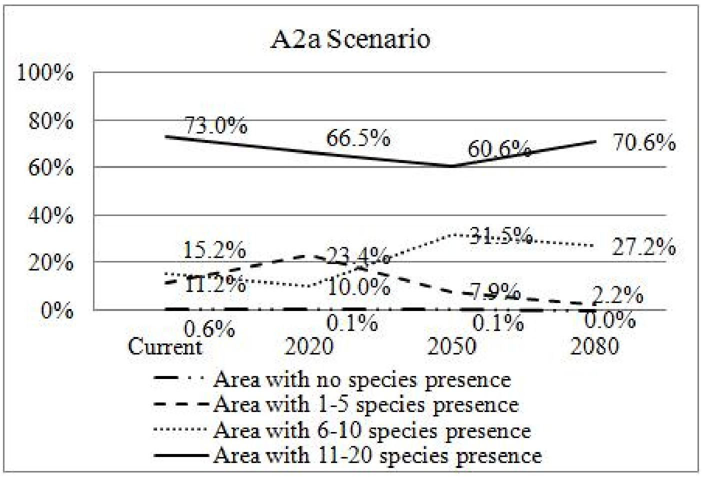


Figure 6a. Proportional changes in species distribution in time for the scenario A2a.

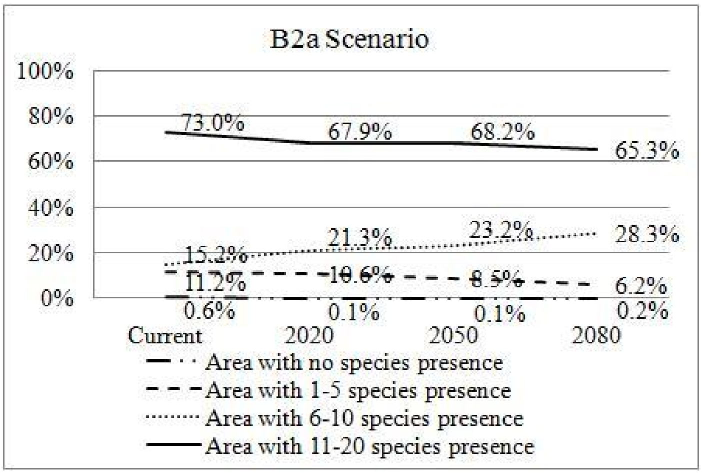


Figure 6b. Proportional changes in species distribution in time for the scenario B2a.

The species distribution maps (Figure 7) indicate that in both future climate change scenarios and species richness patterns increase in Central Anatolia on every timeline. In 2020, eastern regions of the country and the Central Anatolian Region stay relatively more occupied (more than 15 species) in terms of the quantity of species presence, while western regions, especially coastal lines of the Turkey are expected to have less than seven species in 2050. The Eastern Anatolia Region is observed to lose some of its species, whereas the Marmara Region gains some species and the Central Anatolia Region stays the same, in terms of its species richness in this time period. Finally in 2080, it is predicted that the Aegean Region gains some more species and a recovery of up to 19 species is also predicted in some parts of the Eastern Anatolia Region. The general pattern for 2080 is that there is a species range shift from eastern Anatolia to the west.

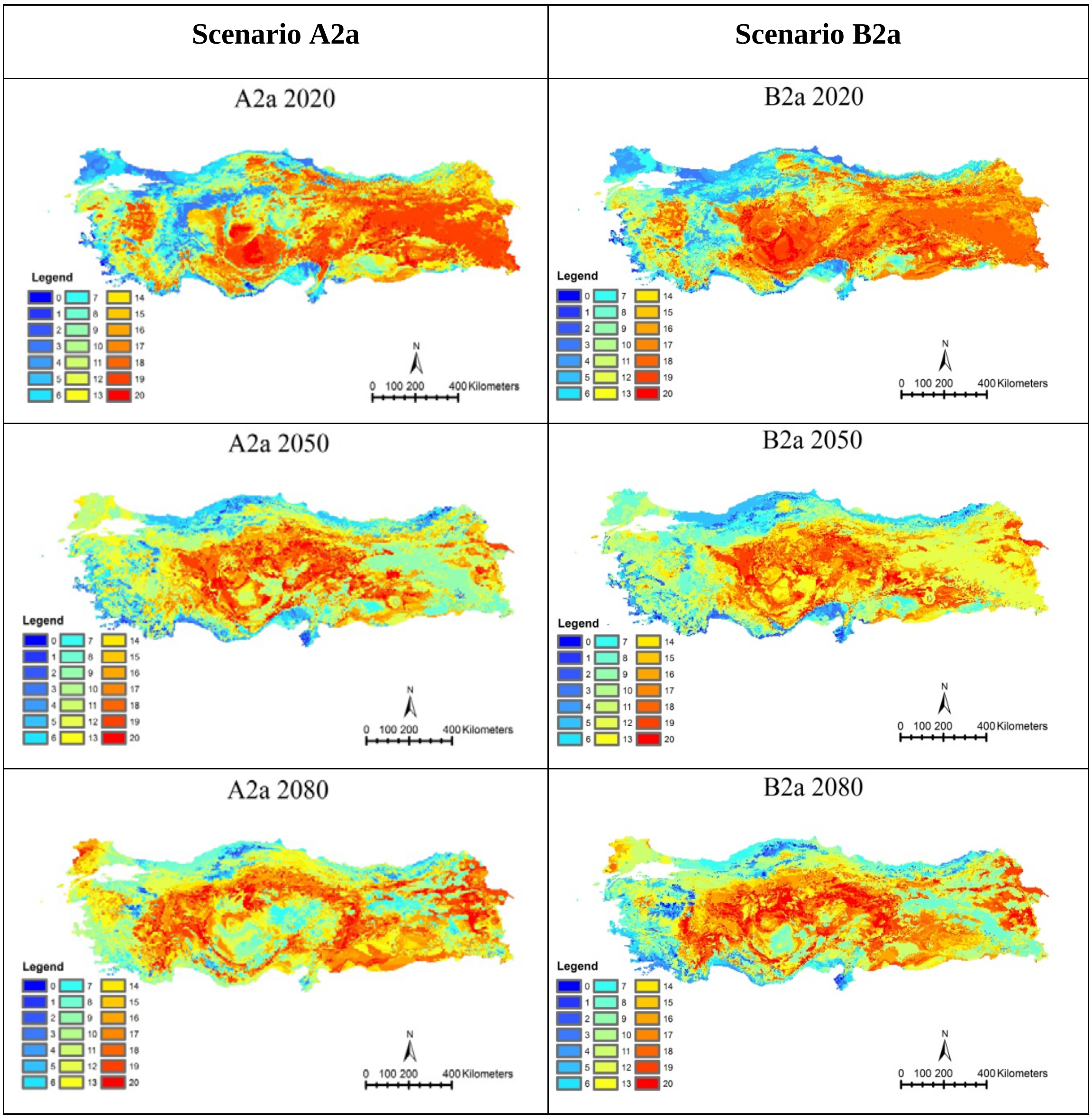


Figure 7. Modelled species richness maps by period and future scenarios.

To understand the model better, visually, changes in species richness were calculated and mapped in Figure 8. If we look at the changes by geographic regions of Turkey, in both scenarios the greatest decrease in species numbers is observed in the Eastern Anatolia Region at the end of the study period, 2080. In the first time period, 2020, there is some rise in the species richness mostly in the Central Anatolia, Southeastern Anatolia and partly in the Marmara and the Eastern Black Sea Regions in both scenarios. Specifically in the

Eastern Anatolia Region a decrease is the dominant pattern. This decrease is mostly low (0-(-8)) in 2020. In A2a scenario, this loss reaches up to (-) 15 species in 2050. Again under the A2a scenario, in 2080 a recovery is expected to happen in this area. On the other hand, in scenario B2a the species decrease is gradual without any recovery; there is no species loss in eastern Anatolia between 2020 and 2050 and the areas which lose species get larger in eastern Anatolia in 2080. In the Marmara Region the gain and loss maps are expected to show similar patterns in both A2a and B2a scenarios. At the beginning, in 2020, there is an increase around Marmara Sea up to nine species. This increase spreads through the Thrace Region incrementally up to 16 species in 2050 and in 2080. In the Aegean and the Mediterranean Regions, in each time period, there is a low gain (around one to nine species) in the coastal areas, but in the inland parts of these regions, there is a loss, up to eight species in 2020, and up to 15 species in 2050 and 2080. The Central Anatolian and Southeast Anatolia Regions, on the other hand, show an increase in the number of species in all time periods and under both scenarios. In 2020 this increase is up to nine species, and the areas which have higher number of species increase westward and reach eastern part of the Aegean and northern part of the Mediterranean Regions from Central Anatolia in 2050. This increase reaches up to 17-20 species in certain areas, in 2080.

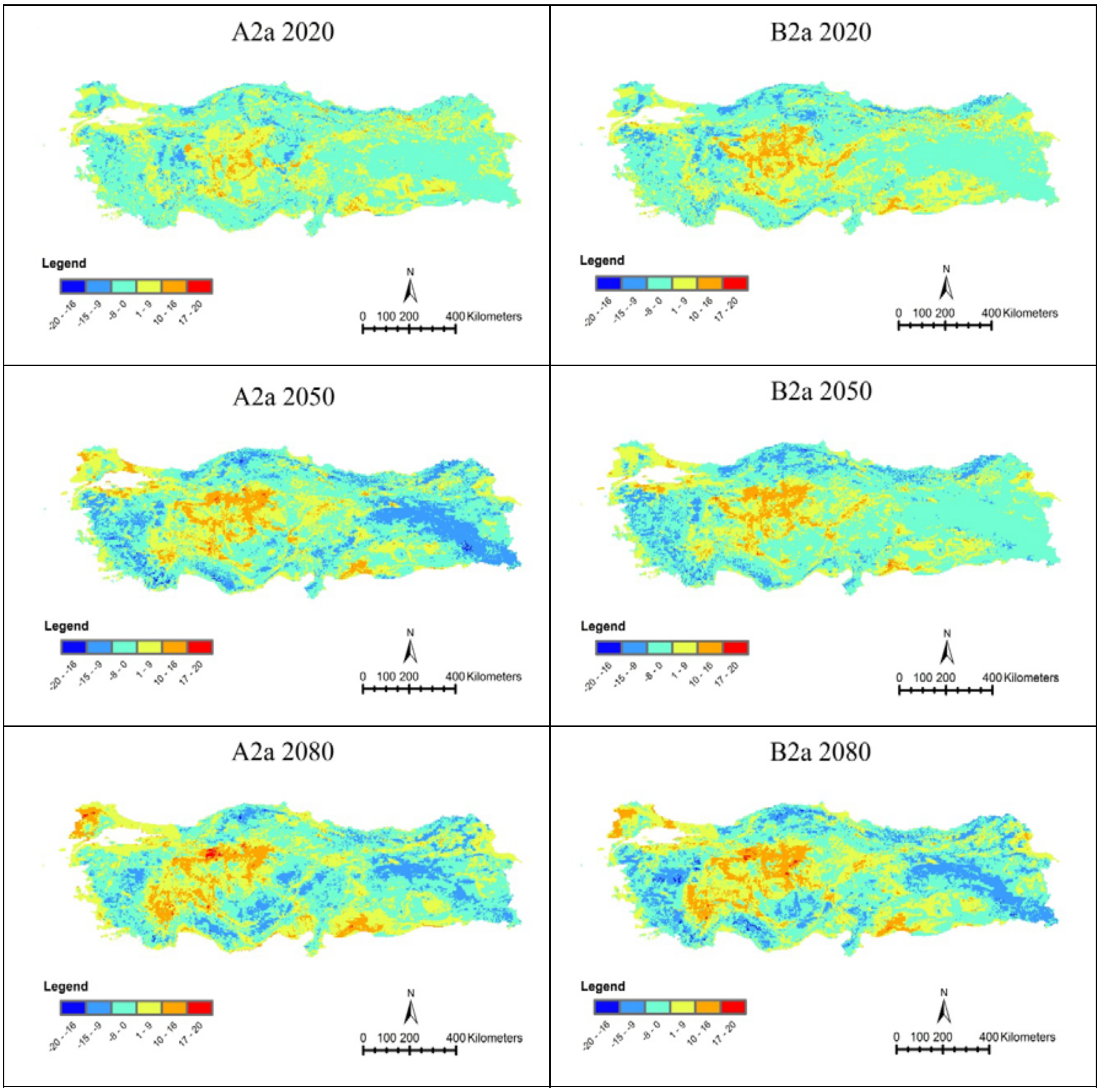


Figure 8. Maps of species richness change (negative values indicate grids with species lost; positive values indicate grids with species gained).

Up to now united results of the modelled species have been analyzed. The evaluation of species by species expansion and contraction patterns comprises a final presentation of the results of the modelling. Table 6 shows the gained or lost area in terms of grid cells by calculating the difference of the grid cell numbers, which are predicted to be occupied in the present and future time periods. Figures 9a and 9b show the percentage of gained or lost area for each species. Bar heights are determined by calculating the total grid area of a species' predicted presence for both the current and future time periods. When zero is considered as a reference point for current distribution, the bars above that point show the expansion in the area for the species, or alternatively the bars below the zero line show the contraction of the area for a particular species.

Model predictions with Maxent and different scenarios showed high variability in the projection of species range shifts, with some species being projected to lose and most species being projected to gain suitable habitat, depending on the scenario. When the ensemble model results were analyzed separately (Table 6), it is found that in scenario A2a only one species (*Sitta tephronota*) is consistently predicted to have a smaller distribution and 14 of the 20 species are consistently predicted to have larger distributions. On the other hand, in scenario B2a, three of the 20 species (*Corvus corax, Parus ater, Sitta tephronota*) are consistently predicted to have smaller distributions and 16 of the 20 species are consistently predicted to have a larger distribution. The remaining species show increases and decreases depending on the time period and scenario. For example, *Parus major* and *Sitta europaea* is predicted to have a smaller distribution until 2020 and then increase their distribution by 2080 in A2a and B2a scenarios, respectively. On the other hand, *Carduelis carduelis* are predicted to have a larger distribution until 2050 and then have a smaller distribution in 2080, under scenario A2a.

If we focus on specific regional patterns, some species, like *Pycnonotus xanthopygos,* have a high tendency to expand their ranges in both story lines (Figures 9a and 9b). *Pycnonotus xanthopygos* is firmly restricted to the southern coastlands, generally in the Mediterranean Region. Model results show that this species will move westward by following coastal line starting in 2020 and reach to the Marmara Region in 2080. In scenario A2a, where the increase in the species presence area is higher, a range shift is seen even into the Thrace Region (Appendix C, Figure C16). This species shows a significant gradual increase in A2a scenario with 141%, 332% and 992% and in B2a scenario with 191%, 304% and 510% for the time periods 2020, 2050, 2080, respectively.

Other species which show a general movement to the west and north, from mainly south, southeastern, eastern and central regions of Anatolia to the Aegean, Marmara, Western Central Anatolia, and Western Black Sea Regions are *Carduelis carduelis, Parus ater, Parus caeuralus, Parus major, Petronia petronia, Pica pica, Sitta tephronota,* and *Turdus merula*. Now an overview of species by species movements, under the different scenarios and time-frames will be given for this general pattern. *Carduelis carduelis* is common throughout Turkey, but not found extensively in the treeless parts of central Anatolia, southeastern and eastern Anatolia. A total increase of 39-40% in the Black Sea, the Aegean and the Mediterranean Regions is expected in both scenarios, and gradual decrease in central Anatolia is seen in both scenarios (Appendix C, Figure C2). *Parus ater,* is widespread in the western and eastern parts of the Black Sea Regions, Thrace, southern coastlands and northern central plateau. A small increase is observed in 2020 under scenario A2a; later an area loss of 8% and 40% is expected to happen in 2050 and 2080, respectively. In B2a scenario, decrease starts in the year 2080 with 5% and ends in 2080 with 10% of total area loss. This species is expected to move completely to the western Anatolia from their locations in inlands portions of the regions. This species will maintain its distribution in the Black Sea Region (Appendix C, Figure C10). *Parus caeuralus* is a widespread species but largely absent from Cukurova area and eastern and southeastern regions. An area gain is expected in the years 2020 and 2050, but those areas will be lost in 2080, and the loss will be more severe in A2a scenario (26% of gained area) than B2a scenario (8% of gained area). Area losses are also expected from the Central Anatolia with time and Mediterranean Region and aggregate intensely on the west and north of the country (Appendix C, Figure C9). *Parus major,* in terms of its current distribution is generally very common in Turkey, but rare in the Central Anatolia plateau, eastern and southeastern regions. This species is also expected to move from central Anatolia gradually by time and aggregate extensively in the Aegean, Marmara and Western Black Sea Regions. The increase rate is gradual (up to 38%) in scenario B2a, but in scenario A2a, a habitat loss is expected in 2020 (-13%), followed by a 50% increase in 2050, and finally an 8% of area loss is expected in 2080 (Appendix C, Figure C11). *Petronia petronia,* is widespread in midlands of Turkey, but found intermittently in coastal areas of Black Sea, Marmara, Aegean and Mediterranean Regions. According to the model this species moves westward from eastern part of the country. Firstly, it increases its range in the Central Anatolia Region in 2020 almost 50% in both scenarios and aggregate in Aegean, Mediterranean and Thrace Region with a total gain of 71% and 89% in scenario A2a, and 57% and 78% in scenario B2a for the years 2050 and 2080, respectively. But in both scenarios there is no predicted spread to the Black Sea Region (Appendix C, Figure C14). *Pica pica* can be seen all over the country, but is generally absent along the coastal line of the Black Sea and southern parts of southeastern Turkey. A gradual increase in presence area is expected in their current range and also a spread to the Black Sea Region is expected in 2050 and 2080 (Appendix C, Figure C15). *Sitta tephronot* is a species restricted to a very limited area and is seen intensely in the southeastern region. It is expected to move westward towards the Mediterranean Region, with decreasing areas in all study periods (Appendix C, Figure C19). Finally *Turdus merula* is common and widespread in the Thrace, western Anatolia, and Black Sea Regions. It will gradually expand its presence area to 54% for the scenario A2a and to %10 for the scenario B2a in 2080. However a gradual area loss in central Anatolia and intense aggregation in the Aegean Region is expected in the future for this species (Appendix C, Figure C20).

As another pattern, aggregation of species presently found in Central Anatolia, Marmara, Southeastern Anatolia, and Western Black Sea into Central Anatolia and Eastern Aegean Regions in the future (especially in 2080) is observed in the species *Corvus corone*, *Corvus monedula*, and *Sitta europaea*. *Corvus corone* is common in Marmara, southeastern Anatolia and northern half of the country. This species is expected to expand and increase its area up to 92 -93% of its current distribution in central and western Anatolia, in both scenarios at the end of the study period (Appendix C, Figure C4). Another species in the same genus, *Corvus monedula* has a wide distribution in much of the country and mostly in Marmara and Central Anatolia Regions, but it is generally absent in the coastal zones of the Black Sea and southern regions. In 2050 more than 100% increase is predicted in the range of the species and 184% and 160% total increase is calculated according to model in the scenarios A2a and B2a, respectively, by 2080. This area increases mostly in the north and the species is predicted to expand its range even into the coastal zones of Black sea and southern regions (Appendix C, Figure C5). The final species in this pattern, *Sitta europrea* is widespread in Thrace, Marmara, western part of the Black Sea and inlands of the Aegean Regions. The species is expected to spread into the entire Black Sea Region, and north and coastal parts of the Aegean Region, by expanding its range 28% and 34% at the end of the study period (Appendix C, Figure C17).

Calandrella brachydactyla, Galerida cristata, Garrulus glandarius, and *Sitta neumayer* are four species that show a tendency to expand their current ranges, mainly from the Central Anatolia and Aegean Regions, to Marmara, Black Sea, and Southeastern Anatolia Regions. Calandrella brachydactyla is widespread in central Anatolia and locally seen in western Anatolia. It expands its range up to 91% and 64% in the scenarios A2a and B2a, respectively, from the Central Anatolia to the Aegean and Black Sea Regions, gradually in each time period. An increase is also predicted in southeastern Anatolia (Appendix C, Figure C1). *Galerida critada* is more common in Central Anatolia and Southeastern Anatolia Regions and is expected to expand to the Black Sea, Marmara, Aegean and Mediterranean Regions. However, under scenario A2a, a loss is predicted in 2080 in central Anatolia. The total area gain is 107% for scenario A2a and 95% for scenario B2a (Appendix C, Figure C6). *Garrulus glandarius* is commonly widespread in the northern part of the country because they cannot use in treeless semi desert areas (Roselaar, 1995). The increase of this species is not significant; in 2050 12% and 13% increase is expected for the scenarios A2a and B2a. But in 2080, a decrease to 6 % in gained area is calculated in scenario A2a while this decrease is 12% in scenario B2a. The increase is seen in the northern Anatolia, Mediterranean Region and southeastern part of the Anatolia. Also a decrease in the Central Anatolia Region is expected (Appendix C, Figure C7). *Sitta neumayer* is widespread over the Turkey excluding the Thrace Region and coastal zone of the Black Sea Region, and is scarce and local in southeastern Anatolia. This species expands its range northward in the Thrace Regions and western part of the Anatolia, by 35% and 22% for the scenarios A2a and B2a in 2080. In both scenarios there is a loss in central Anatolia but the extent of the loss is higher under scenario A2a (Appendix C, Figure C18).

A few species are expected to expand their ranges to almost entire Turkey. *Paser domesticus* and *Paser montanus* have current ranges in parts of Marmara, central Anatolia, and southeastern Anatolia and expand their ranges up to 250% of its current area. *Melanocorypha calandra* is seen mostly in central Turkey, and this species' range has been projected to expand significantly to cover the entire country up to 95% and 77% in 2080 in scenarios A2a and B2a, respectively.

Finally, *Corvus corax* is generally common in western part of the country and eastern part of the Black Sea Region. A range increase is not predicted for this species, instead some loss is expected. In scenario A2a up to 6% of expansion is predicted in 2020, but this value decreases 5% and 11% in 2050 and 2080, respectively. In scenario B2a, on the other hand, 9% area loss is foreseen in 2020, this loss will be 2% in 2050 and 6% in 2080 (Table 6, Appendix C, Figure C3).

Table 6. Resident species list and the number of gained or lost area in terms of grid cells (T: tendency, C: contraction, E: expansion).

		A2a				B2a			
Species	**Current**	**2020**	**2050**	**2080**	**T**	**2020**	**2050**	**2080**	**T**
Calandrella brachydactyla	13795	5715	7442	12618	E	6894	8579	8848	E
Carduelis carduelis	17915	4554	7186	-2173	E/C	4626	6163	6892	E
Corvus monedula	11650	6874	16751	21394	E	8768	15009	18659	E
Corvus corone	18920	9317	15030	17521	E	9890	13584	17389	E
Corvus corax	16913	950	232	-1171	E/C	-1479	-408	-1075	C
Galerida cristata	12392	5681	11939	13259	E	7708	10601	11828	E
Garrulus glandarius	18111	425	2188	1119	E	10	2382	2216	E
Melanocorypha calandra	16678	5416	12308	15806	E	7797	10899	12780	E
Passer montanus	9094	5716	13001	22744	E	7374	10743	16872	E
Petronia petronia	15371	7700	10944	13744	E	7299	8690	11944	E
Parus ater	13986	905	-1166	-4883	E/C	-663	-879	-1340	C
Parus caeruleus	13250	2745	2591	-856	E/ C	1847	3105	1985	E
Passer domesticus	18263	5804	12240	20047	E	7781	10656	15157	E
Parus major	17066	-2256	6341	4956	C/E	4613	5557	6422	E
Pica pica	14553	4502	10196	10819	E	5510	8316	10538	E
Pycnonotus xanthopygos	645	912	2139	6396	E	1234	1961	3292	E
Sitta neumayer	21659	180	8541	7489	E	5162	6308	4839	E
Sitta tephronota	2882	-550	-593	-137	C	-1212	-726	-1279	C
Sitta europaea	16167	2161	4845	4487	E	-159	3601	5556	C/E
Turdus merula	16278	1616	2585	8741	E	1788	2021	1658	E

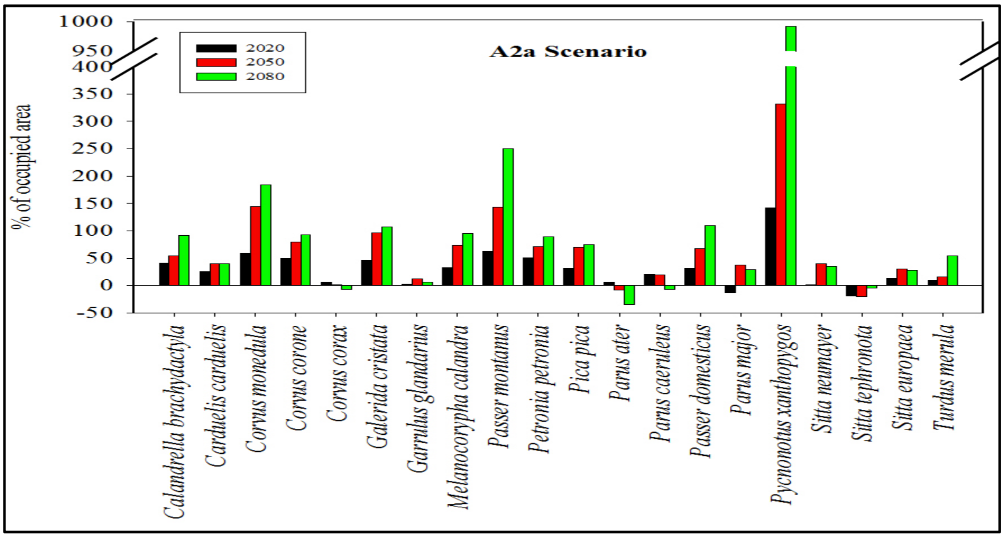


Figure 9a. Expansion/contraction pattern of the resident species by years in scenario A2a (the bars above zero point indicate expansion of species).

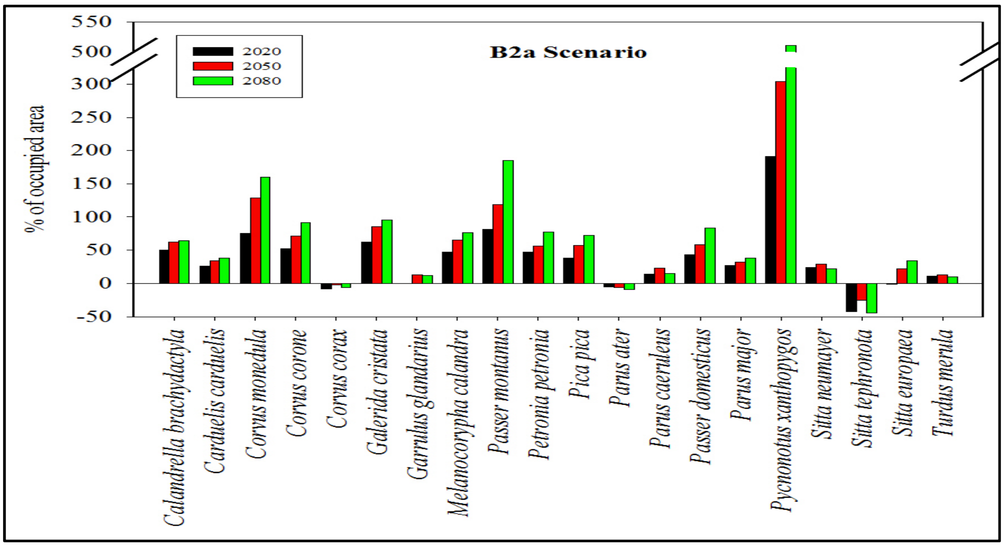


Figure 9b. Expansion/contraction pattern of the resident species by year in scenario B2a (the bars above zero point indicate expansion of species).

After these species by species accounts, now some overall pattern evaluations will be made. The range shift trend for all species is seen in Figure 10. The range shift portions indicate that an increase in the ranges is expected with the median values of 28%, 47%, and 56% in A2a scenario and 31%, 45%, and 51% in B2a scenario by the years 2020, 2050 and 2080, respectively. The outliers show the species which shows the highest range expansion, *Pycnonotus xanthopygos* (Appendix B, Table 9).

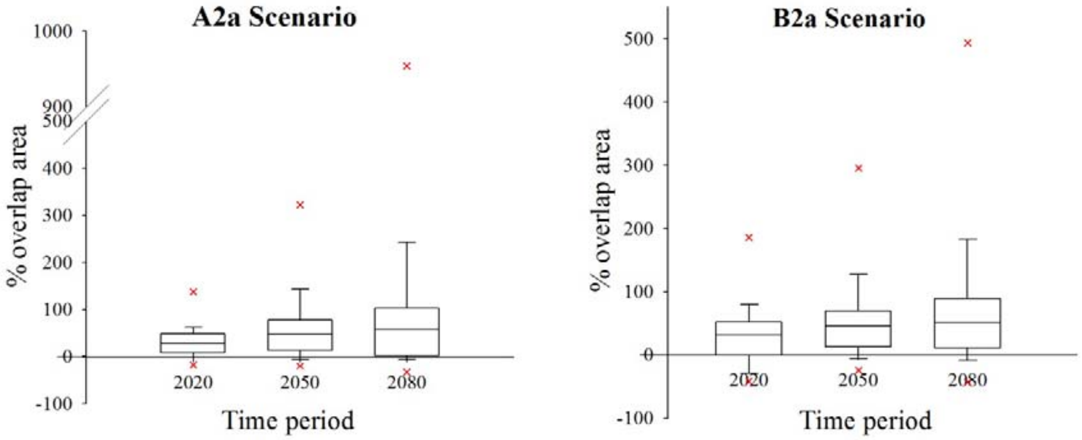


Figure 10. Proportional range shift area between projected models and the current potential distribution (the vertical bar indicates maximum and minimum values registered for a bird species within each group; outliers show the portion of maximum expansion shift for a species).

For the different species, the extent of their current occupied area that will still be occupied in the future projections varies according to scenario. Figure 11 represents the expected percentage of area that will continue to be occupied by the same species in each future time period when compared to the current period. As it can be seen in this figure, the areas which will still be occupied by the same species gradually decreases under the scenario A2a by 2020, whereas a small recovery in 2050 is seen in scenario B2a. In A2a scenario, in all time periods, the highest area loss is observed with *Sitta tephronota*. It will occupy the lowest percentile of its current area, 53%, 49%, and 33% for 2020, 2050, and

2080, respectively (Appendix B, Table10). *Pycnonotus xanthopygos* is the species which keeps most of its current occupied area in 2020 with the value of 89%; that species is *Corvus corone* with a value of 90% in 2050, and *Passer domesticus* with a value of 93% in 2080. For the B2a scenario, in all time periods, the highest area loss is observed again in *Sitta tephronota*. It will occupy 38%, 48%, and 28% of its current area for 2020, 2050, and 2080, respectively. *Pycnonotus xanthopygos* is again the species which keeps most of its current area occupied in 2020, with a value of 88%. In 2050 two species occupy the greatest percentage of their current areas, *Corvus corone* and *Passer domesticus* with 89%, and in 2080 *Passer domesticus* maintains most of its current distribution with 93%. Other species' percentages for maintaining their current distribution in the future time periods stay within these mentioned values.

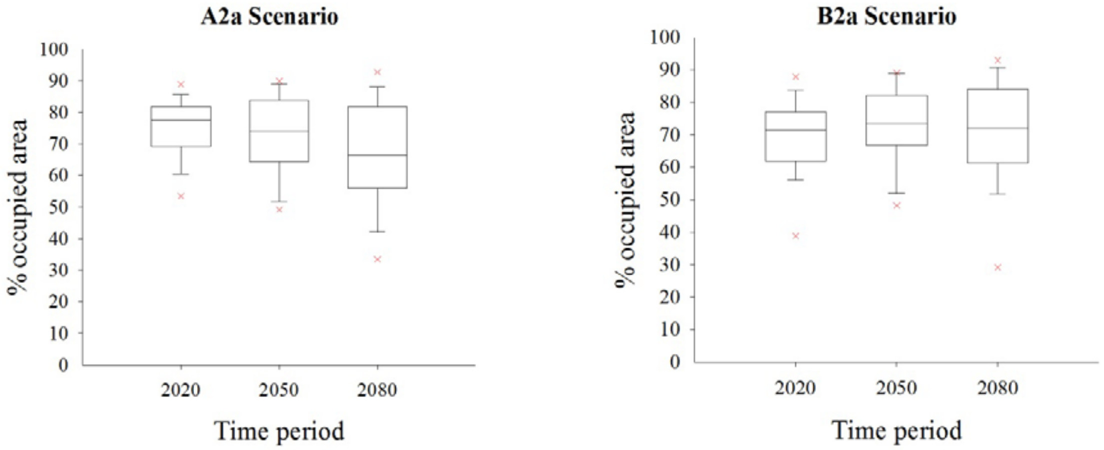


Figure 11. The change of occupied area throughout the time periods in relation to area currently occupied by species (the vertical bar indicates maximum and minimum values registered for a bird species within each group).

Finally, Figure 12 shows average percentage of the areas that are expected to continue to host the same species in each time period compared to the previous one (2080 compared to 2050, 2050 to 2020 and 2020 to current) for the resident species. It represents that only 53% and 58% of the areas will keep the same species in all time periods at the end of the study period in the scenarios A2a and B2a, respectively.

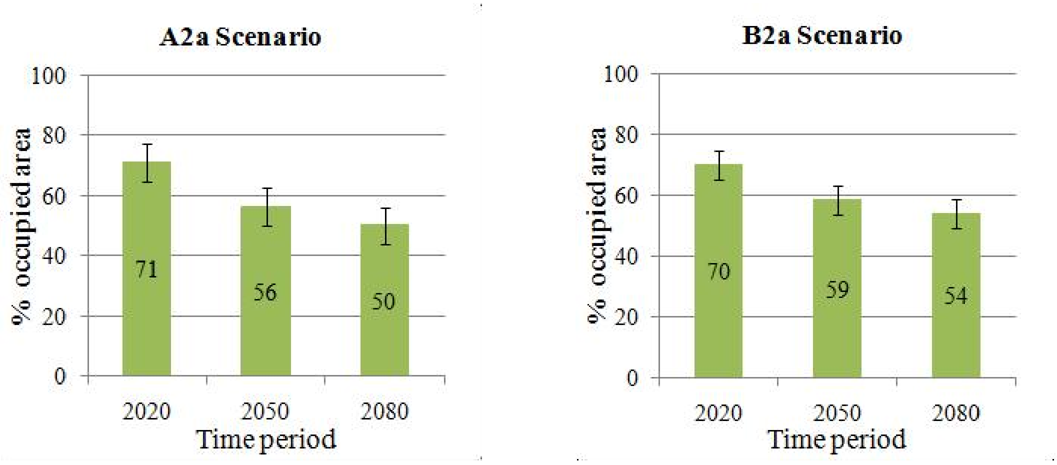


Figure 12. Average percentage of occupied area that is expected to host the same species in all timelines (the vertical lines indicate standard deviation).

4.2. Results for Migratory Species

While evaluating the results of summer migrant species, it was observed that ROC plots predicted were very similar and even higher than AUC values between training (0.95) and test data (0.93), when compared to the resident species' AUC values. Even though the values were slightly lower for the latter, all AUC values were higher than 0.92, and these indicate that the model had a good predictive power, with an average AUC values of 0.95 in all nine models. Besides, the average training AUC values of the model including all eight variables is higher than that excluding one of the eight variables. This comparison also shows that the predictive ability of the model decreases if any of the eight variables are excluded (Table7).

Table 7. The order of AUC values, variable contributions, and indication times for each variable that show the most relevancy for a migratory species.

Bioclimatic variables	**Average AUC without**	**Sum of Contribution**	**Number of species**
Mean Temperature of Warmest Quarter(BIO10)	0.93	231.6765	3
Precipitation of seasonality (BIO15)	0.93	221.5304	3
Precipitation of Warmest Quarter (BIO18)	0.93	144.4614	3
Temperature Seasonality (BIO4)	0.93	106.7725	0
Mean temperature of wettest quarter (BIO8)	0.92	33.1505	0
Annual Precipitation (BIO12)	0.93	23.3341	0
Mean diurnal range in temperature (BIO2)	0.93	22.4841	0
Isothermality (monthly/annual) (BIO3)	0.93	16.5903	0

Mean temperature of warmest, precipitation of seasonality, and precipitation of warmest quarter were the most relevant variables in all models. These three variables were seen to be the most relevant for three species each. The order of contribution for the other five variables is, temperature seasonality, mean temperature of wettest quarter, annual precipitation, mean diurnal range in temperature and isothermality (Table 7).

Figure 13 shows a quick overview of today’s summer migratory species’ distribution patterns. The map indicates that almost none of the species have any presence in the Central Anatolia and Eastern Anatolia Regions. Different species are possibly seen at the same periods in southeastern Anatolia with up to five species, in the coastal zones of the Mediterranean with up to six species, and in the Marmara and Black Sea Regions with up to three species. Figure 14 shows the numeric results of the species richness map; nearly 44% of the studied areas do not have presence of any species, and there are no areas which host seven, eight, or nine summer migratory species at the same time.

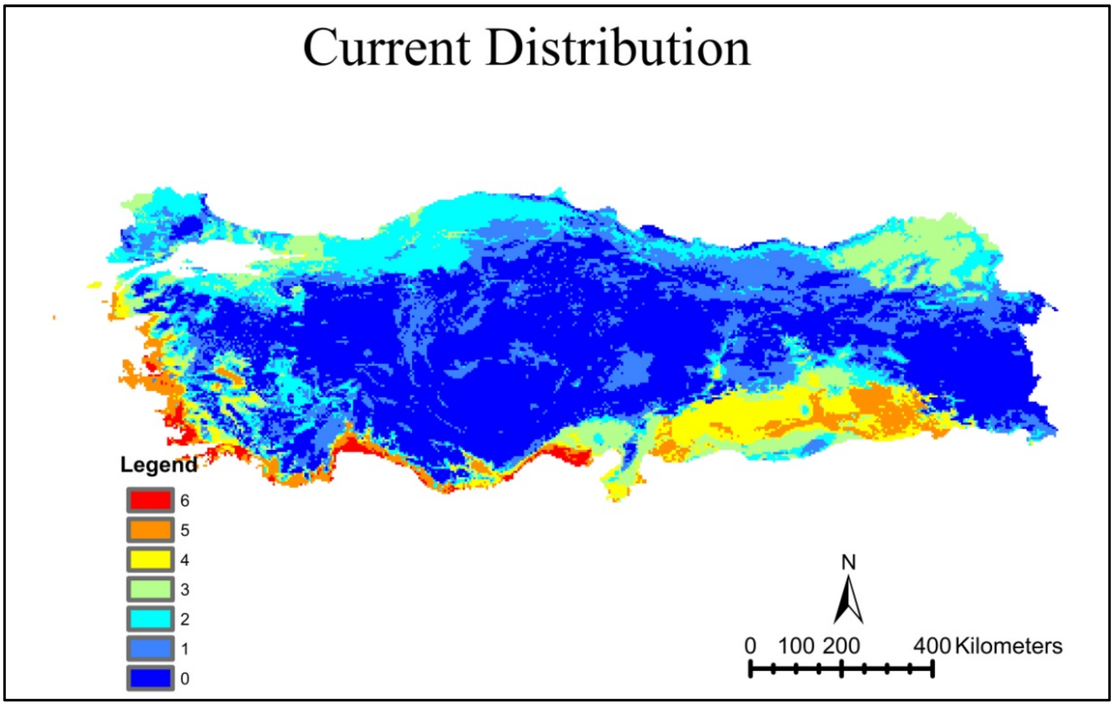


Figure 13. Current distribution patterns of selected nine summer migrant species.

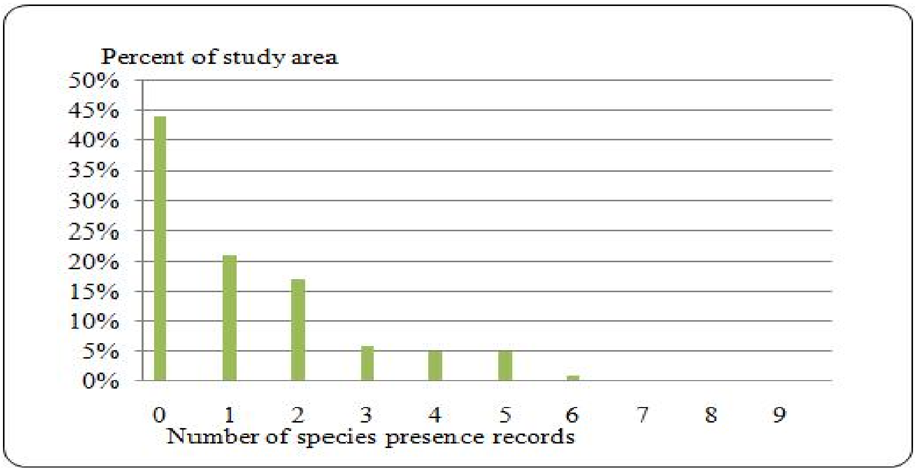


Figure 14. Current species richness chart.

Table 8, and Figures 15a and 15b show the proportional change of the distribution summer breeding migrant species in future time periods, 2020, 2050, 2080. There is a gradual decrease in the areas with no species presence in both scenarios. The percentage of the areas with zero species presence is predicted as 44% presently and is expected to be 30%, 26%, and 18% in scenario A2a and 34%, 29%, and 20% in scenario B2a for the time periods 2020, 2050, and 2080, respectively. This decrease in areas with no species means that the species will move into areas which they do not occupy currently. The areas which contain one to four species will increase to 26% and 27% in A2a and B2a scenario respecively, by the end of the study period. The biggest jump between any two consecutive time periods is seen between current and 2020, from 50% to 66% in scenario A2a and to 62% in scenario B2a. Subsequently, those areas will continue to expand further, gradually, until 2080. On the other hand, areas hosting five to nine species will decrease from 6% to 4% and 3% in 2020 and 2050, and there will be a recovery to 6% in 2080 under scenario A2a, but the value stays the same at 3% in scenario B2a for the year 2080.

Table 8. Changes in percent occupied area over the different time periods and scenarios.

Scenario	**Year**	**Area with no species presence**	**Area with presence of 1-4 species**	**Area with presence of 5-9 species**
	Current	44%	50%	6%
A2a	**2020**	30%	66%	4%
	2050	26%	71%	3%
	2080	18%	76%	6%
B2a	**2020**	34%	62%	4%
	2050	29%	68%	3%
	2080	20%	77%	3%

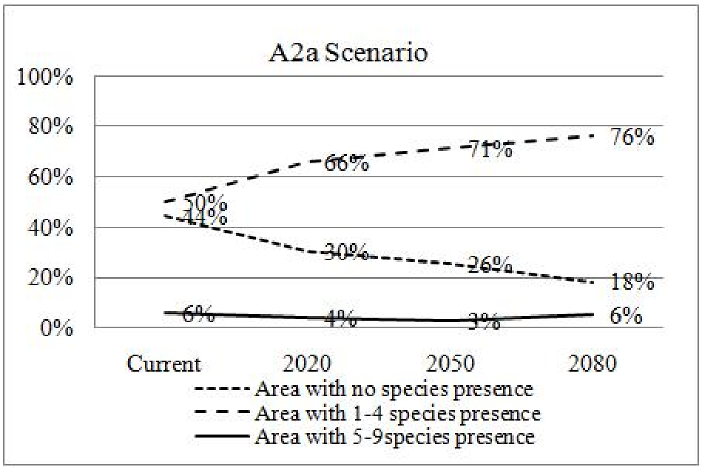


Figure 15a. Proportional changes in summer migratory species distribution in time for the scenario A2a.

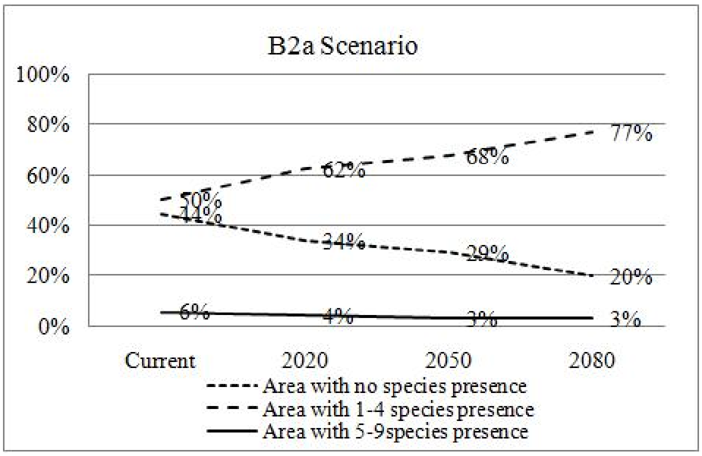


Figure 15b. Proportional changes in summer migratory species distribution in time for the scenario B2a.

The maps in Figure 16 represent the species distribution patterns over the studied time periods based on scenarios A2a and B2a. In 2020 there is a species decrease in the east of the Southeastern Anatolia and Black Sea Regions. Species richness is maintained in the west of the southeastern Anatolia with up to four species, in the coastal zones of the Mediterranean with up to six species, and in some points it even reaches to seven species on the coast of the Aegean Region under scenario B2a. The Marmara and coastline of the Black Sea Regions are expected to host up to three species. Besides, west of the Central Anatolia starts to be occupied by some species in this time period, 2020. In 2050 a recovery is observed in the east of the southeastern Anatolia. There is also an increase in species richness, up to four species, in the northern Thrace, southern Marmara and also western part of the Black Sea Regions. In 2080 the area which is occupied by up to four species in the coastal zone of the Black Sea Region is expected to increase, another increase is also expected in the inland part of the Aegean Region. Furthermore, in 2080, central Anatolia will be occupied in the summer season with some migratory species, which come for breeding. On the other hand the amount of area that is occupied by six species at the same time will decline along the Aegean coast.

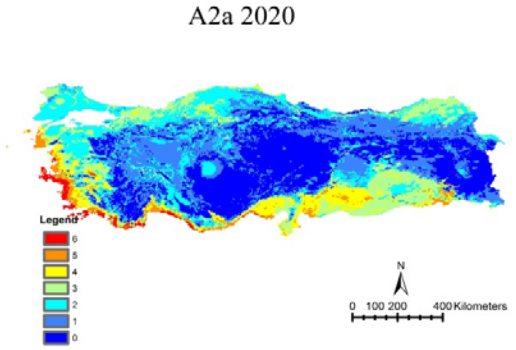
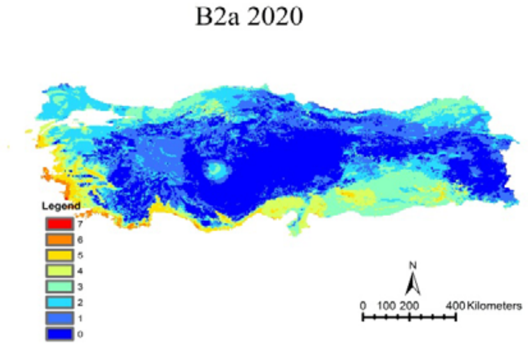
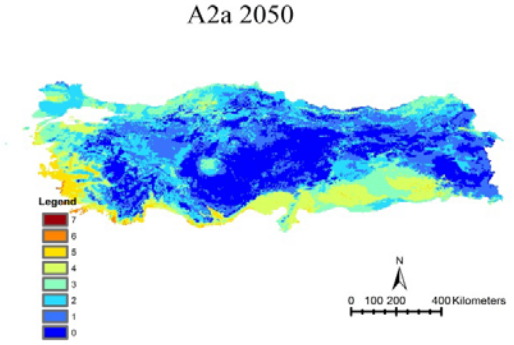
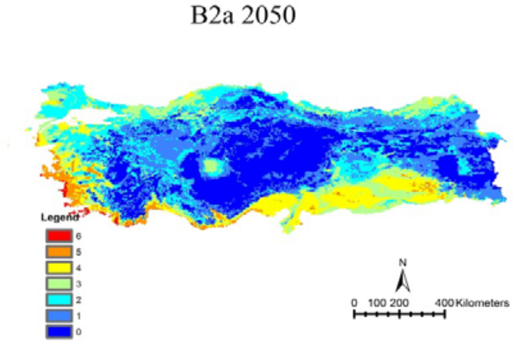
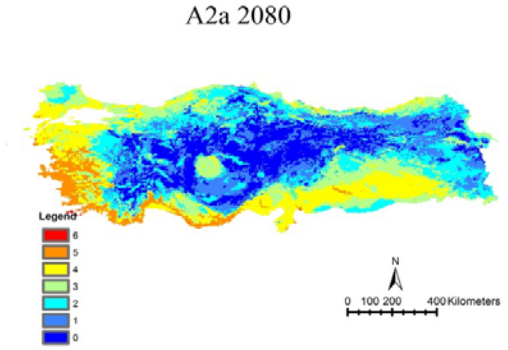
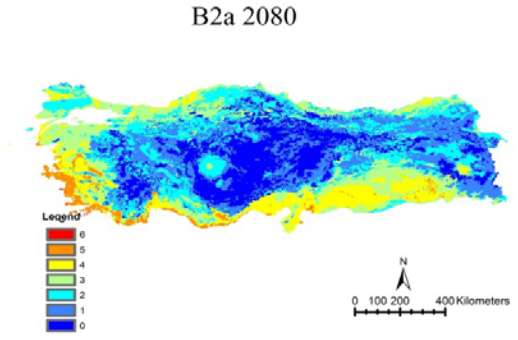
Scenario A2a	**Scenario B2a**
 A2a 2020 	 B2a 2020
 A2a 2050 	 B2a 2050
 A2a 2080 	 B2a 2080

Figure 16. Modelled species richness maps by period and future scenarios.

To understand the model better, the cumulative changes in species richness were calculated and mapped in Figure 17. These maps show species richness changes by scenarios for each time period. In 2020 there is a gain up to five species in the west of the country and the species loss is mostly seen in the Southeastern Anatolian Region and

Eastern Black Sea Region. The eastern part of Central Anatolia Region, which does not contain any of the summer migratory species currently (Figure 13), does not show any changes in term of potential area gain. In 2050 a relative increase can be seen in the Black Sea Region, and in 2080 there is an increase in the central Anatolia, in both scenarios.

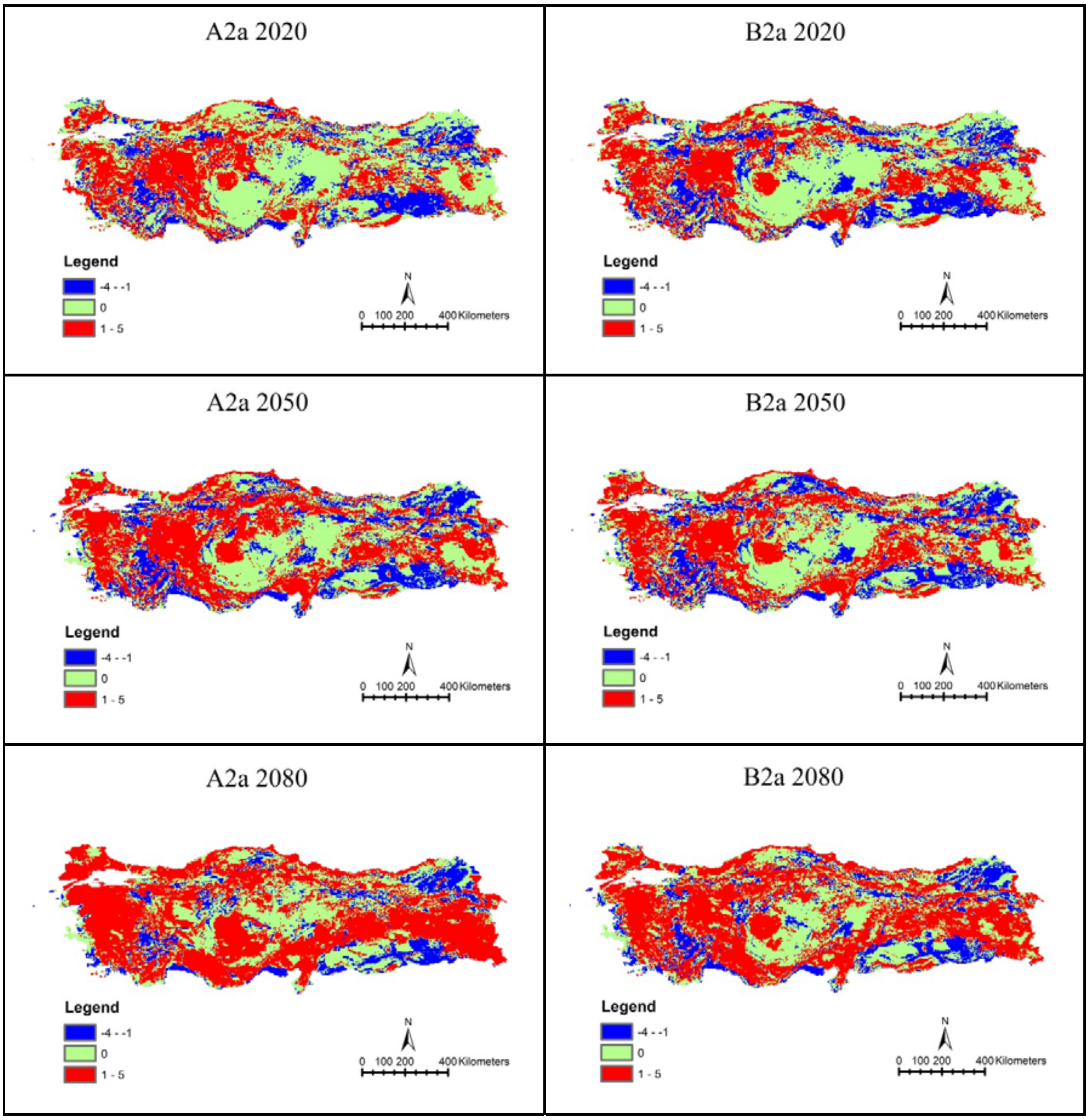


Figure 17. Maps of species richness change (negative values indicate grids with species lost; positive values indicate grids with species gained).

Up to now united results of the modelled species have been analyzed. The observation of species by species expansion and contraction is the final step of the modelling outcome. Table 9 summarizes the number of gained or lost area in terms of grid cells. First column indicates the number of current occupied grid cells per species. The next column was calculated to show expansion and contraction patterns by comparing future occupied grid cells to the present values. Figures 18a and 18b show clear contraction or expansion percentages for each species. Bar levels are determined, as outlined above for the resident species.

According to model predictions with Maxent, one of the nine migratory summer species *Sylvia cantillans,* which is generally seen along the coastal zone of the Mediterranean Region and south Thrace Region (Appendix C, Figure C29), will gradually lose all of its breeding habitat through 2020 and 2050, and in the year 2080 the species will have lost 96% and 99% of its breeding area in scenario A2a and B2a, respectively (Table 9 and Figure 18a and 18b).

Four other species, *Carpodacus erythrinus, Emberiza caesia, Phylloscopus sindianus* and *Phylloscopus trochiloides*, will loss more than half of their current areas used for breeding. *Carpodacus erythrinus* is common in the Black Sea coastlands and in some parts of the southeastern Anatolia in the breeding season. At the end of the modelled future time periods, in 2080, this species is expected to lose its breeding range in Southeastern Anatolia and Central Black Sea Regions (Appendix C, Figure C21). The total loss is 60% in scenario A2a and 43% in scenario B2a. *Emberiza caesia* is restricted to western Anatolia, coastal zone of Mediterranean Region and some parts of the Marmara Region. It will maintain its presence in their current breeding regions, but the area occupied will decline gradually to 21% in scenario A2a and to 26% in scenario B2a in 2050. In 2080 the decrease continues to 41% in scenario B2a, whereas 13% of recovery is predicted in scenario A2a (Appendix C, Figure C22). *Phylloscopus sindianus and Phylloscopus trochiloides* are restricted to the northern parts of Turkey. The former only can be seen in the eastern part of the Black Sea Region, while the latter is seen to colonize almost the entire Black Sea Region (Appendix C, Figures C27 and C28). These two species, which are recorded relatively rarely in Turkey, will lose most of their breeding presence at the end of the study period, 2080, and the total loss is 50% and 44% for *Phylloscopus sindianus* and that for *Phylloscopus trochiloides* is 85% and 73%, according to scenarios A2a and B2a, respectively.

Erythropygia galactotes, Hirundo daurica, Lanius nubicus, and *Hippolais olivetorum*, on the other hand, extend their breeding areas remarkably (Table 9). In 2080, under scenario A2a *Erythropygia galactotes*, which is locally common along the coasts of Mediterranean, and seen mostly in southeastern Anatolia, increases its current habitat three times (315%) and expands its range westward starting by 2020, and reaches to the Marmara and Thrace Region in 2080 (Appendix C, Figure C23). *Hippolais olivetorum* and *Hirundo daurica* are largely confined to southeastern Anatolia and coastal zones of the Mediterranean. In addition *Hirundo daurica* can be seen around the Sea of Marmara (Appendix C, Figures C24 and C25). In 2020 and 2050, *Hippolais olivetorum* is expeced to extend its range towards northwest of the country and in 2080 it is predicted to be found in the Marmara Region with 126% and 119% of total increase for the scenarios A2a and B2a, respectively. On the other hand, a gradual expansion of *Hirundo daurica* results in 134% and 90% increase in total breeding area in 2080 all around the Turkey, except for the Eastern Anatolia Region. *Lanius nubicus* is mostly found in western Anatolia, Mediteranian coastline and southeastern Anatolia. While it maintains most of its current range, this species will extend its range through northwest of the country increasingly in each time period, in scenario A2a 71%, 117%, and 137% and in scenario B2a 68%, 102%, and 130% in the years 2020, 2050 and 2080, respectively (Figures 18a and 18b) (Appendix C, Figure C26).

Table 9. Migratory species list and the number of gained or lost area in terms of grid cells (T: tendency, C: contraction, E: expansion).

Species	Current	A2a 2020	A2a 2050	A2a 2080	A2a T	B2a 2020	B2a 2050	B2a 2080	B2a T
Carpodacus erythrinus	12154	-2469	-5965	-7335	C	-4184	-5402	-5319	C
Emberiza caesia	4399	-311	-957	-382	C	-195	-1148	-1809	C
Erythropygia galactotes	4370	1758	3794	13786	E	2903	3637	7012	E
Hirundo daurica	10302	5288	9661	13071	E	5135	8495	12278	E
Hippolais olivetorum	8371	2162	4305	11232	E	2779	3738	7526	E
Lanius nubicus	11155	8016	13159	15386	E	7655	11452	14536	E
Phylloscopus sindianus	2262	-157	-931	-1132	C	-171	-932	-984	C
Phylloscopus trochiloides	5601	-1875	-3672	-4734	C	-2871	-3830	-4105	C
Sylvia cantillans	2530	-1184	-2391	-2420	C	-1872	-2320	-2510	C

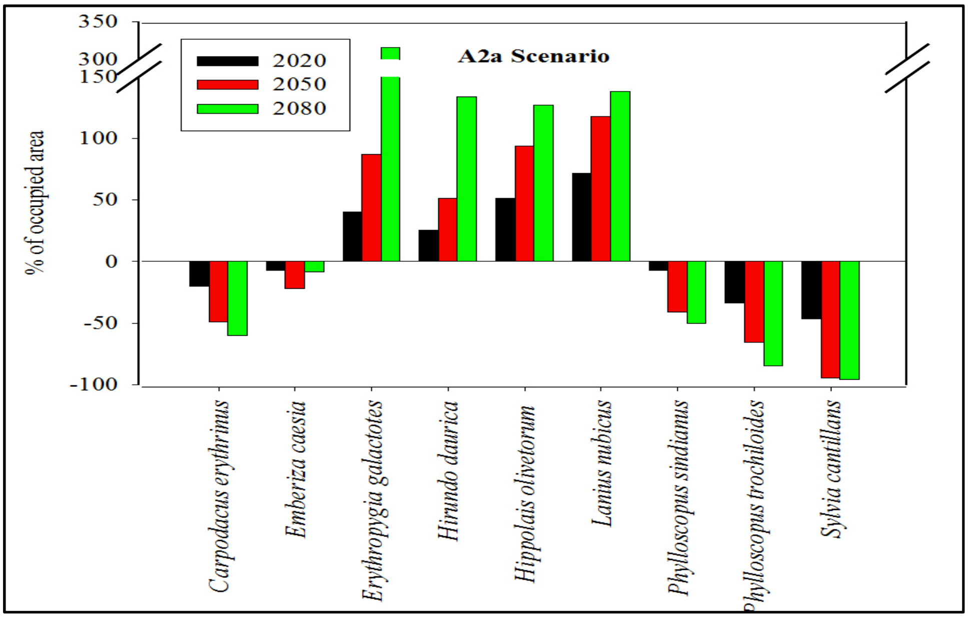


Figure 18a. Expansion/contraction pattern of migratory species by year in scenario A2a (the bars above zero indicate expansion of species).

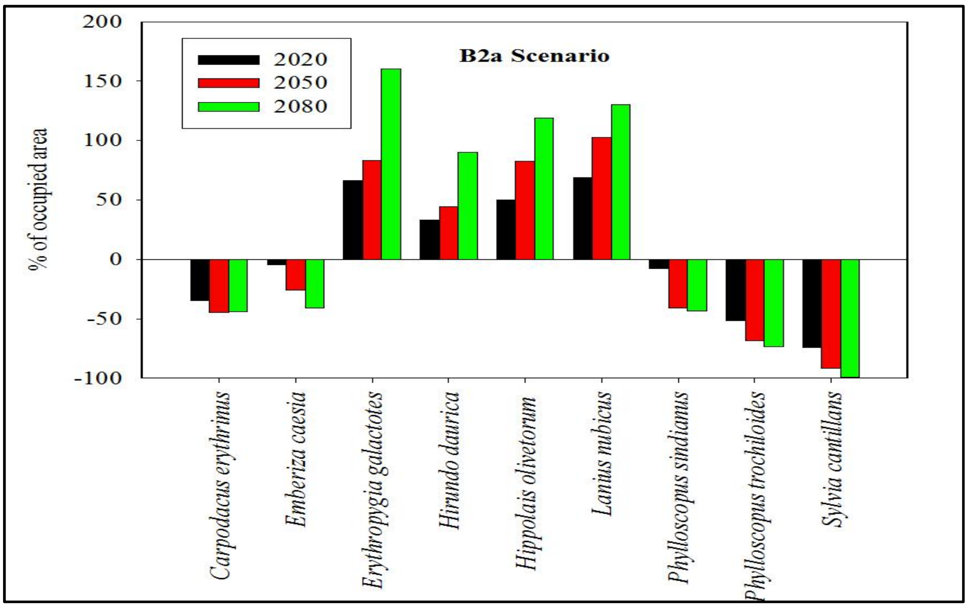


Figure 18b. Expansion/contraction pattern of migratory species by year in scenario B2a (the bars above zero indicate expansion of species).

The overall range shift trend is seen in Figure 19. The range shift portions indicate that an increase in the ranges is expected with the median values of -7%, -22%, and -9% in A2a scenario and -4%, -26%, and -41% in B2a scenario by the years 2020, 2050 and 2080, respectively. The range shift portions indicate that in both scenarios an increased range shift is expected by the years 2020, 2050 and 2080. As it can be guessed from the graph (Figure 19), the outliers symbolize the species which show the highest degree of range expansion (Appendix B, Table of Figure 18).

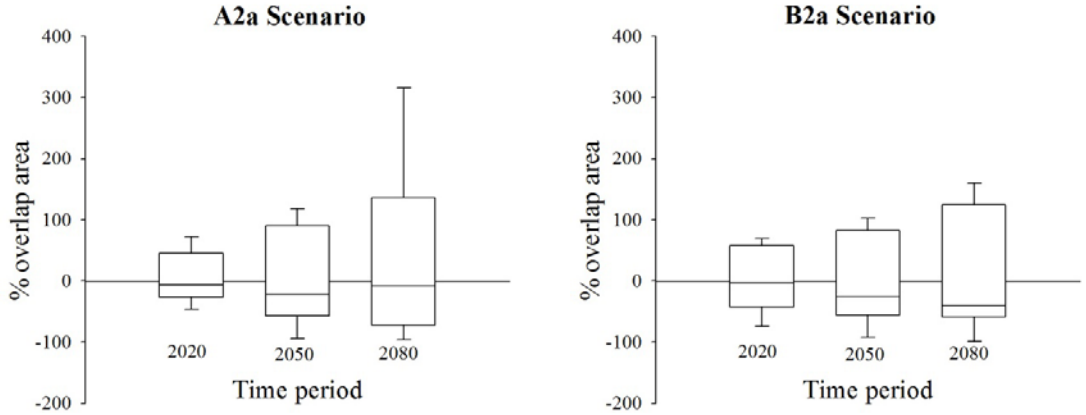


Figure 19. Proportional range shift area between projected models and the current potential distribution (the vertical bar indicates maximum and minimum values registered for a bird species within each group).

For the different species, the extent that their current occupied area still will be occupied in the future projections vary according to the related scenarios. Figure 20 represents the expected percentage of area that will continue to be occupied by the same species in each future time period compared to the current. The areas which will be occupied by the same species decreases gradually in both scenarios with time. In all the time periods, the highest area loss is observed in *Sylvia cantillans*. It will occupy the lowest percentile of its current area, 43%, 5%, and 1% for the scenario and 24%, 8%, and 1% for scenario B2a in the years 2020, 2050, and 2080, respectively. On the other hand

Hirundo daurica do not lost any of its current area in both scenarios and in all time periods (Appendix B, Table 19). Other species' percentages for maintaining their current distribution in the future time periods stay within these mentioned values.

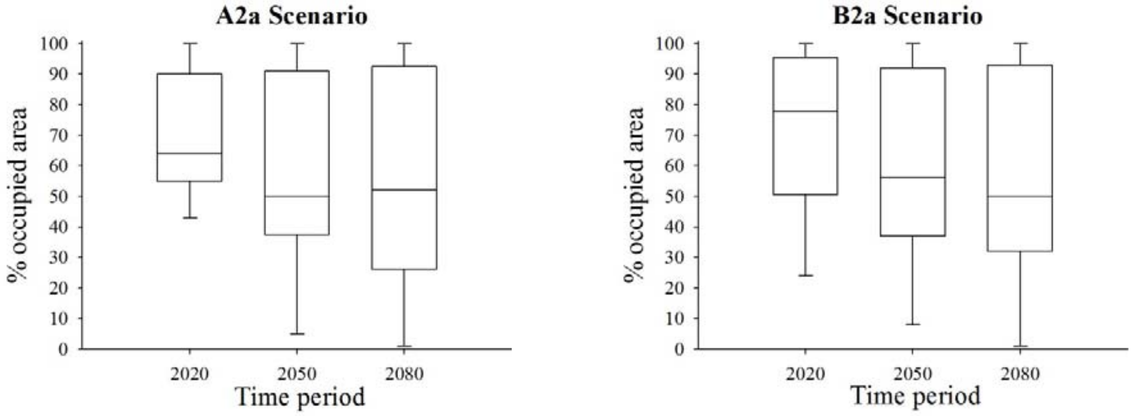


Figure 20. The change of occupied area throughout the time periods in relation to area currently occupied by species (the vertical bar indicates maximum and minimum values registered for a bird species within each group).

Finally, Figure 21 shows average percentage of the areas that are expected to continue to host the same species in each time period compared to the previous one. It represents that only 50% and 54% of the areas will still be occupied by the same species in all time periods at the end of the study period in the scenarios A2a and B2a, respectively.

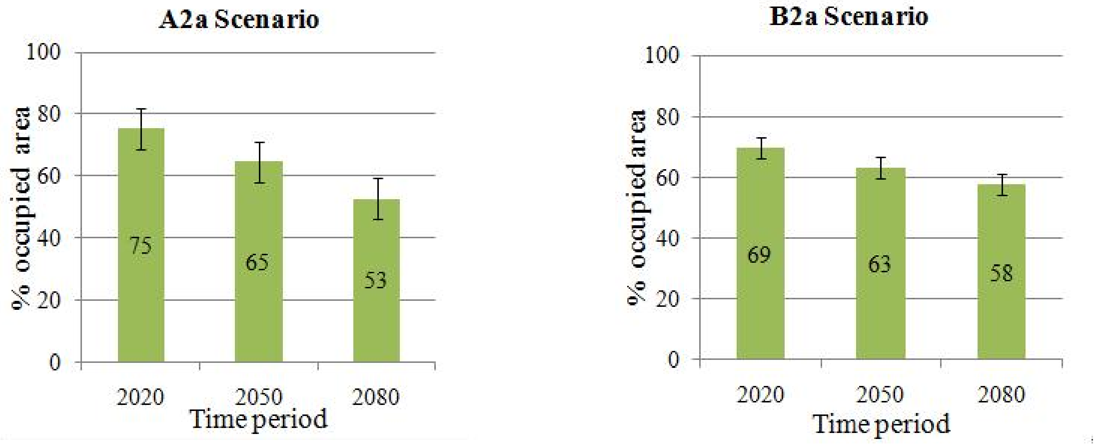


Figure 21. Average percentage of occupied area that is expected to host same species in all timelines (the vertical lines indicate standard deviation).

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5. DISCUSSION AND RECOMMENDATIONS

During the study, models that relate species' current breeding distributions to current climate have been used to explore their potential future distributions under two different climate scenarios for the years 2020, 2050 and 2080. To the best of our knowledge, this is the first species distribution modelling study including bird species in the Anatolia Region in a climate change perspective. As a result we have identified some of the potential impacts of climate change upon Anatolian resident and summer migrant breeding birds. The general conclusions that emerged from the study, showing similarities in both climate scenarios, are summarized in this chapter.

The study identified the most important factors that affect Passerines presence and/or absence in the country. These factors are temperature seasonality; annual mean temperature; precipitation of seasonality; annual precipitation; precipitation of driest month for resident species and mean temperature of warmest quarter; precipitation of seasonality; precipitation of warmest quarter for summer migratory species. These results are in good correlation with those in the literature which indicate that temperature, food and water source availability contribute significantly to Passerine migration and survival (Barbet-Massin *et al.*, 2009).

Most of the species analyzed within the scope of this study exhibit a clear tendency for overall displacements either in north, north-east or north-westward directions within Anatolia. However, the magnitude of the displacements varies amongst species and between the two climate scenarios examined. The greatest extent of range shift is observed, on the range of several hundred kilometers, for the species *Pycnonotus xanthopygos and Sitta tephronota.*

The model results suggest that some Passerine species might show different patterns than others and actually not all studied species are likely to reduce their niches, as was initially expected. This could be explained by two facts: First, the reaction of individual species to climate change depends on their adaptive potential and also the actual rate of change in climate that changes between regions. Second, Turkey is known to be a key area for the study of geographical variation, in terms of subpopulations, for the birds of the Western Palearctic because of the fact that species and subspecies occurring in European deciduous forests, Mediterranean scrub and wetlands, Arabian semi-desert, Caucasian Mountains and central Asia steppe all meet in Turkey (Roselaar, 1995). Moreover, most of the Passeriformes species in Turkey have more than one geographical subpopulation. Therefore Turkey is, perhaps, one of the most important countries around the region for studying geographical subpopulations. These geographical subpopulations are named as subspecies and they show differences in either morphology and/or genetics. These subpopulations are almost observed all over the country which spans a diverse range of climatic features. For example, Crested Lark *Galerida cristata* is one of the study species and it has five subspecies described or recorded within the region: *G. c. meridionalis* is observed in the Aegean and in the Mediterranean Coastline, *G. c. subtaurica* is observed in the Central Anatolia and Eastern Anatolia Regions, *G. c.caucasica* is observed in the coastal zone of the Black Sea, *G. c. cinnamomina* is observed around Hatay Province, and *G. c. zion* is observed in the Southeastern part of Turkey. All of these mentioned subspecies inhabit areas that have almost completely different bioclimatic features. If our objective in this study were to consider and identify possible dispersal changes at the subspecies level, instead of species level, under various climate scenarios and model their future distributions, we would have probably observed more changes than we detected in this study at the species level.

In terms of species richness, there is no change in the area with no-modelled presence for resident species (1% for current, 0% for future periods). This is probable due to the increase in the area which have six-ten species (15% for current, around 28% for future periods), which expands their areas. In migratory species, however, there is a decrease in no-modelled presence (from 44 % for current to 18-20% total decrease for future periods). A decrease is also predicted in the areas, which contain 15-20 resident species (from 73% to 65%) and five to nine migratory species (from six percent to three percent). This indicates a clear range shift for migratory species and is predictable as these birds look for specific bioclimatic features either for breeding or wintering. Therefore even small chances in local climate scenarios are expected to affect most of the migratory species.

Two (under B2a) or three (under A2a) of the 20 resident and five of the nine migratory studied species are predicted to contract in their total occupied area. Furthermore, nearly 42% and %46 of future modelled presence for resident and migratory species, respectively, will occur in an area that does not contain the same species today (Figures 12 and 21). These results show that passerine species will need to shift their ranges in order to maintain their existence. These changes probably will cause phenological changes as mentioned in the literature (Walther *et al*., 2002; Root *et al*., 2003, Both *et al*., 2005). In addition, it should be noted that an assumption of the analyses undertaken was that every species could migrate independently between different areas. Hence if an area is bioclimatically suitable for a species, the species is considered to be able to migrate into that new area, no matter its dispersal ability. On the flip side, if the climatic conditions are not ideal for a species, it will not be seen in a certain area. Whereas the opposite might not be true, for example, areas that fulfill all the necessary climatic conditions for a species might not exhibit crucial factors for a species' existence, such as food and roosts. Hence our models predict best-case scenarios in terms of species distributions.

The potential general reduction in the extent of some species' breeding distributions will put a number of species at the risk of extinction. Moreover, some species' potential future distributions do not overlap with the current distributions and this will cause more species to be at risk of extinction or more significant population decreases, especially if these species' dispersal capabilities are limited. These include species such as *Emberiza caesia, Phylloscopus sindianus, Phylloscopus trochiloides,* and *Sylvia cantillans.* On the other hand, some of the species' potential expected distributions show dramatic expansions. It should be noted that those species that extend their breeding distributions and colonize news areas will possibly comprise certain risks for other already resident species that show more or less stable distributions. These risks include availability of territorial areas with poorer quality and smaller breeding success due to increased competition and insufficient food abundance. Therefore, while the recessive or sensitive species will be affected negatively, the dominant ones are likely to benefit from these newly arising conditions.

As explained above, the results make it clear that climate change will not affect every species in the same direction. Overall, there is not a significant decrease in area occupied by resident species, and the maximum decrease portion is seen on the species *Sitta tephronota* with the value of -44% in scenario B2a. However, there are three summer migratory species with more than 50% modelled decrease in their presence area until 2080 (*Carpodacus erythrinus*, *Phylloscopus trochiloides, Sylvia cantillans*). Among these species, *Sylvia cantillans* suffers very drastic range reductions; it loses more than 90% its current breeding area by the year 2050 in both scenarios and the loss reaches 99% in 2080 in scenario B2a. If the roost/habitat limitations are taken into account, we can assume that the actual decrease in occupied areas will possibly be higher than the modelled ones, so for this species a local extinction is expected. On the other hand, three resident species (*Corvus monedula, Passer montanus, Pycnonotus xanthopygos*) and four migratory species (*Erythropygia galactotes, Hirundo daurica, Hippolais olivetorum, Lanius nubicus,*) are modelled to have more than 150 % and 100% increases in their presence areas, respectively. Specifically the highest increase in a resident species was seen in *Pycnonotus xanthopygos* with 992%, and in migratory species this was *Erythropygia galactotes* with 315% in scenario A2a. In other words, there is a low probability of local extinction for these species.

In the light of the study, although it is an undeniable fact that there is a negative impact of climate change on the species distributions, we cannot say all species will be negatively affected from this change. The outputs of the species models show that summer migratory species whose breeding areas are in northern (*Carpodacus erythrinus*, *Phylloscopus sindianus***,** and *Phylloscopus trochiloides)* and western *(Sylvia cantillans)* parts of the Turkey will progressively lose suitable climate space. Alternatively, species that have restricted breeding areas in the southern parts of the country will have the potential to expand their ranges to the north-west parts of the study area. The consequences of climate change in terms of movement between different geographic regions are, therefore, variable.

At the country level, some of the modelled species are highly sensitive to climate change. For these species, more detailed monitoring is required to verify predictions of our models. Conservation management and regulations may need to be strengthened for these species to continue their existence in Turkey. Enhancement of the size of habitats by expanding protected areas will help in maintaining a species in a specific area. Translocation may be another method to decrease the vulnerability of those species. However, translocation is unlikely to be feasible except in a few cases, and for the species in our study area with predominantly western and northern distributions, habitat availability will be a serious problem.

To summarise, by the end of the 21st century, the potential breeding ranges of most of the bird species in Anatolia will be changed and some species will face risk of extinctions due to significant decreases in population ranges. However certain species will also be increasing their ranges. In order to understand better the consequences of climate change on species distribution, further research is needed to explore the relationships between climate change and associated changes in habitats, and also biotic interactions and species' adaptive capacity. It is also important to identify habitat changes with dynamic global vegetation models (DGVM) in order to take appropriate measures for vulnerable species and to assist the movement of others (Harrison *et al*., 2006). The model results have produced consistent results even though it had some limitations. The most important limitation was the use of one group of variables, bioclimatic variables. Therefore, the best-case scenarios which do not make use of the variables that are related to habitat were created. Hence, as mentioned above, more optimistic results than actual have been obtained for all analyses periods. In addition, it should be noted that there is some uncertainty about the precision of the current and future magnitude of climate change due to the uncertainties about the levels of future emissions, and the results of the study should be interpreted with caution.

As a follow-up to this study, in order to understand the movement and range changes of the Passerine species better, the extent of the study area may be increased by including neighboring countries of Turkey. It is also important to project similar models with other different global climate models in order to evaluate models results more accurately. Another challenge for the study was obtaining reliable data sets for analyses. Although there is an available central database for birds of Turkey (http://www.kusbank.org), which includes presence data from many parts of the country, the reliability of these data should be well examined by experts because of the input of data by a fair number of amateur observers. Also, as it was mentioned above, Passerine subspecies are found in a diverse range of climatic features, so that it might be possible to get more accurate future climatic predictions if the analyses include subspecies level distribution data. In addition, further research is needed for the improvement of the conservation strategies. This would be achieved by a careful assessment of current species richness observations, making similar projections with other IPCC scenarios, and monitoring Passerine phenology in areas that indicate loss of species richness and range as a result of global climate change.

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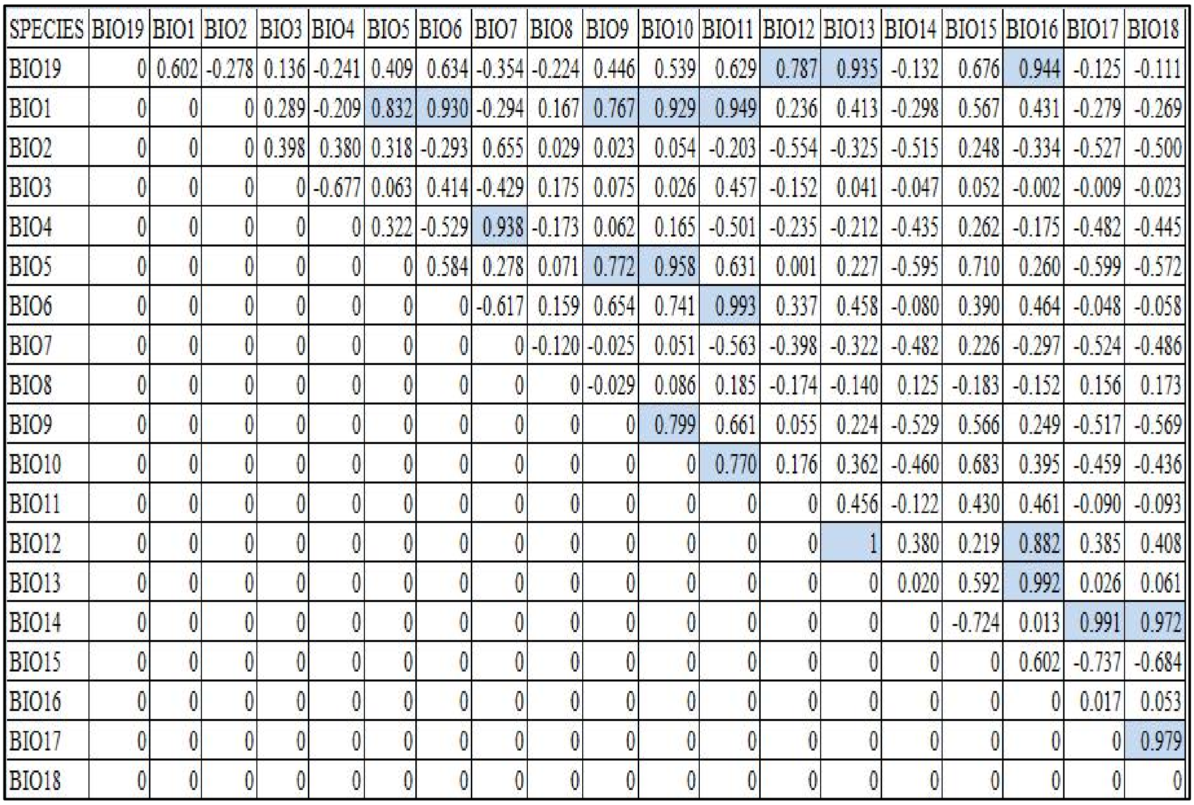
APPENDIX A: CORRELATION MATRIX

Table A1. Correlation matrix.



SPECIES	BIO19	BIO1	BIO2	BIO3	BIO4	BIO5	BIO6	BIO7	BIO8	BIO9	BIO10	BIO11	BIO12	BIO13	BIO14	BIO15	BIO16	BIO17	BIO18
BIO19	0	0.602	-0.278	0.136	-0.241	0.409	0.634	-0.354	-0.224	0.446	0.539	0.629	0.787	0.935	-0.132	0.676	0.944	-0.125	-0.111
BIO1	0	0	0	0.289	-0.209	0.832	0.930	-0.294	0.167	0.767	0.929	0.949	0.236	0.413	-0.298	0.567	0.431	-0.279	-0.269
BIO2	0	0	0	0.398	0.380	0.318	-0.293	0.655	0.029	0.023	0.054	-0.203	-0.554	-0.325	-0.515	0.248	-0.334	-0.527	-0.500
BIO3	0	0	0	0	-0.677	0.063	0.414	-0.429	0.175	0.075	0.026	0.457	-0.152	0.041	-0.047	0.052	-0.002	-0.009	-0.023
BIO4	0	0	0	0	0	0.322	-0.529	0.938	-0.173	0.062	0.165	-0.501	-0.235	-0.212	-0.435	0.262	-0.175	-0.482	-0.445
BIO5	0	0	0	0	0	0	0.584	0.278	0.071	0.772	0.958	0.631	0.001	0.227	-0.595	0.710	0.260	-0.599	-0.572
BIO6	0	0	0	0	0	0	0	-0.617	0.159	0.654	0.741	0.993	0.337	0.458	-0.080	0.390	0.464	-0.048	-0.058
BIO7	0	0	0	0	0	0	0	0	-0.120	-0.025	0.051	-0.563	-0.398	-0.322	-0.482	0.226	-0.297	-0.524	-0.486
BIO8	0	0	0	0	0	0	0	0	0	-0.029	0.086	0.185	-0.174	-0.140	0.125	-0.183	-0.152	0.156	0.173
BIO9	0	0	0	0	0	0	0	0	0	0	0.799	0.661	0.055	0.224	-0.529	0.566	0.249	-0.517	-0.569
BIO10	0	0	0	0	0	0	0	0	0	0	0	0.770	0.176	0.362	-0.460	0.683	0.395	-0.459	-0.436
BIO11	0	0	0	0	0	0	0	0	0	0	0	0	0	0.456	-0.122	0.430	0.461	-0.090	-0.093
BIO12	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.380	0.219	0.882	0.385	0.408
BIO13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.020	0.592	0.992	0.026	0.061
BIO14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.724	0.013	0.991	0.972
BIO15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.602	-0.737	-0.684
BIO16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.017	0.053
BIO17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.979
BIO18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX B: DATA TABLES

Table B1. Data Table of Figure 10.

	A2a			**B2a**		
Species	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Calandrella brachydactyla	41	54	91	50	62	64
Carduelis carduelis	25	40	40	26	34	38
Corvus monedula	59	144	184	75	129	160
Corvus corone	49	79	93	52	72	92
Corvus corax	6	1	-7	-9	-2	-6
Galerida cristata	46	96	107	62	86	95
Garrulus glandarius	2	12	6	0	13	12
Melanocorypha calandra	32	74	95	47	65	77
Passer montanus	63	143	250	81	118	186
Petronia petronia	50	71	89	47	57	78
Pica pica	31	70	74	38	57	72
Parus ater	6	-8	-35	-5	-6	-10
Parus caeruleus	21	20	-6	14	23	15
Passer domesticus	32	67	110	43	58	83
Parus major	-13	37	29	27	33	38
Pycnonotus xanthopygos	141	332	992	191	304	510
Sitta neumayer	1	39	35	24	29	22
Sitta tephronota	-19	-21	-5	-42	-25	-44
Sitta europaea	13	30	28	-1	22	34
Turdus merula	10	16	54	11	12	10

Table B2. Data Table of Figure 11.

	A2a			**B2a**		
Species	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Calandrella brachydactyla	69	61	56	64	66	62
Carduelis carduelis	79	77	69	73	77	77
Corvus corax	80	71	56	71	70	61
Corvus corone	86	90	88	84	89	91
Corvus monedula	74	79	81	66	76	78
Galerida cristata	83	85	72	75	85	84
Garrulus glandarius	74	72	64	69	74	72
Melanocorypha calandra	81	83	73	77	82	84
Parus ater	64	49	42	56	51	51
Parus caeruleus	69	62	43	61	65	59
Parus major	60	58	55	56	60	61
Passer domesticus	82	89	93	80	89	93
Passer montanus	80	80	82	77	80	85
Petronia petronia	83	72	61	75	69	66
Pica pica	70	73	59	61	71	71
Pycnonotus xanthopygos	89	88	88	88	88	88
Sitta europaea	76	74	69	68	72	72
Sitta neumayer	81	84	84	79	82	77
Sitta tephronota	53	51	33	38	48	28
Turdus merula	74	74	60	72	73	69

Table B3. Data Table of Figure 12.

	A2a			**B2a**		
Species	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Calandrella brachydactyla	69	53	41	64	56	49
Carduelis carduelis	79	68	50	73	68	63
Corvus corax	80	66	47	71	63	52
Corvus corone	86	82	76	84	81	79
Corvus monedula	74	65	56	66	60	56
Galerida cristata	83	76	62	75	72	68
Garrulus glandarius	74	63	57	69	65	59
Melanocorypha calandra	81	72	58	77	73	68
Parus ater	64	43	30	56	44	36
Parus caeruleus	69	53	34	61	54	46
Parus major	60	51	46	56	53	50
Passer domesticus	82	78	76	80	77	76
Passer montanus	80	72	66	77	71	69
Petronia petronia	83	66	50	75	63	53
Pica pica	70	58	44	61	55	49
Pycnonotus xanthopygos	89	88	88	88	88	88
Sitta europaea	76	66	55	68	62	57
Sitta neumayer	81	73	55	79	72	64
Sitta tephronota	53	34	12	38	23	14
Turdus merula	74	66	51	72	66	58

Table B4. Data Table of Figure 19.

	A2a			**B2a**		
Species	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Carpodacus erythrinus	-20	-49	-60	-34	-44	-44
Emberiza caesia	-7	-22	-9	-4	-26	-41
Erythropygia galactotes	40	87	315	66	83	160
Hippolais olivetorum	26	51	134	33	45	90
Hirundo daurica	51	94	127	50	82	119
Lanius nubicus	72	118	138	69	103	130
Phylloscopus sindianus	-7	-41	-50	-8	-41	-44
Phylloscopus trochiloides	-33	-66	-85	-51	-68	-73
Sylvia cantillans	-47	-95	-96	-74	-92	-99

Table B5. Data Table of Figure 20.

	A2a			**B2a**		
Species	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Carpodacus erythrinus	64	43	37	55	48	50
Emberiza caesia	60	43	52	55	43	39
Erythropygia galactotes	95	98	100	99	98	100
Hippolais olivetorum	82	84	85	79	86	86
Hirundo daurica	100	100	100	100	100	100
Lanius nubicus	85	83	82	78	81	84
Phylloscopus sindianus	50	50	41	92	56	50
Phylloscopus trochiloides	60	32	15	46	31	25
Sylvia cantillans	43	5	1	24	8	1

Table B6. Data Table of Figure 21.

	A2a			**B2a**		
Species	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Carpodacus erythrinus	64	40	30	55	43	38
Emberiza caesia	60	37	30	55	39	27
Erythropygia galactotes	95	95	95	99	97	97
Hippolais olivetorum	82	77	70	79	76	74
Hirundo daurica	100	100	100	100	100	100
Lanius nubicus	85	78	72	78	74	72
Phylloscopus sindianus	50	45	39	92	58	50
Phylloscopus trochiloides	60	32	15	46	31	23
Sylvia cantillans	43	5	1	24	8	1

APPENDIX C: DISTRIBUTION PATTERNS OF SPECIES

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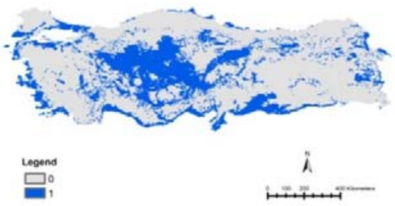
<tr><td>Current</td><td colspan="2">
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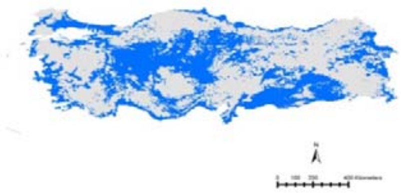
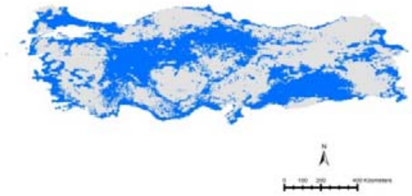
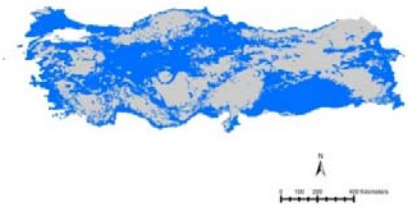
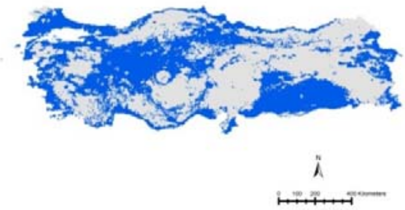
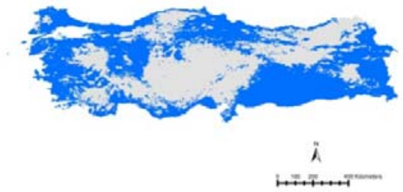
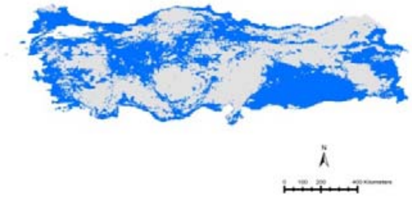
<tr><td>2020</td><td></td><td></td></tr>
<tr><td>2050</td><td></td><td></td></tr>
<tr><td>2080</td><td></td><td></td></tr>
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Figure C1. Distribution patterns of *Calandrella brachydactyla*.\

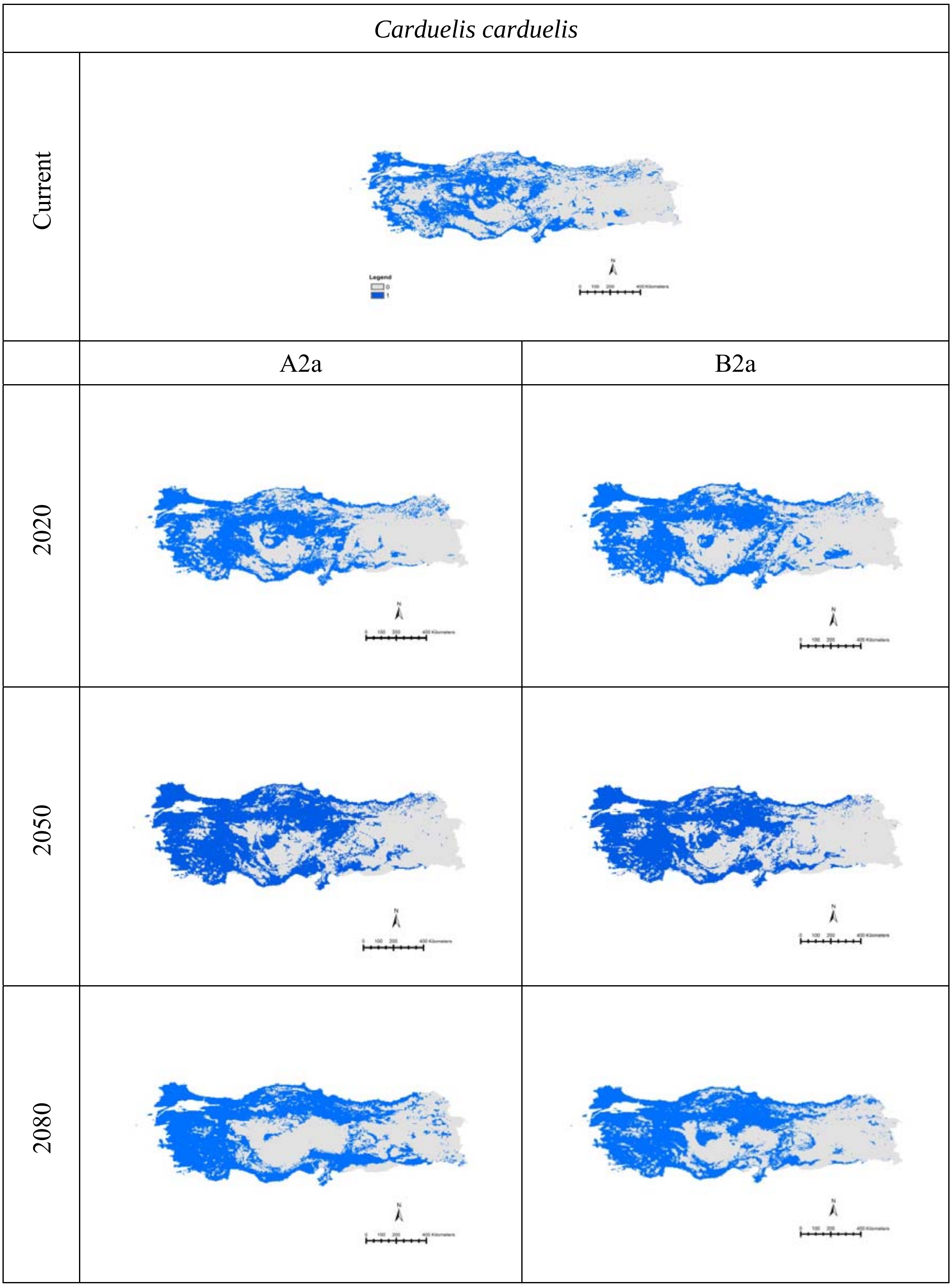

Figure C2. Distribution patterns of *Carduelis carduelis*.

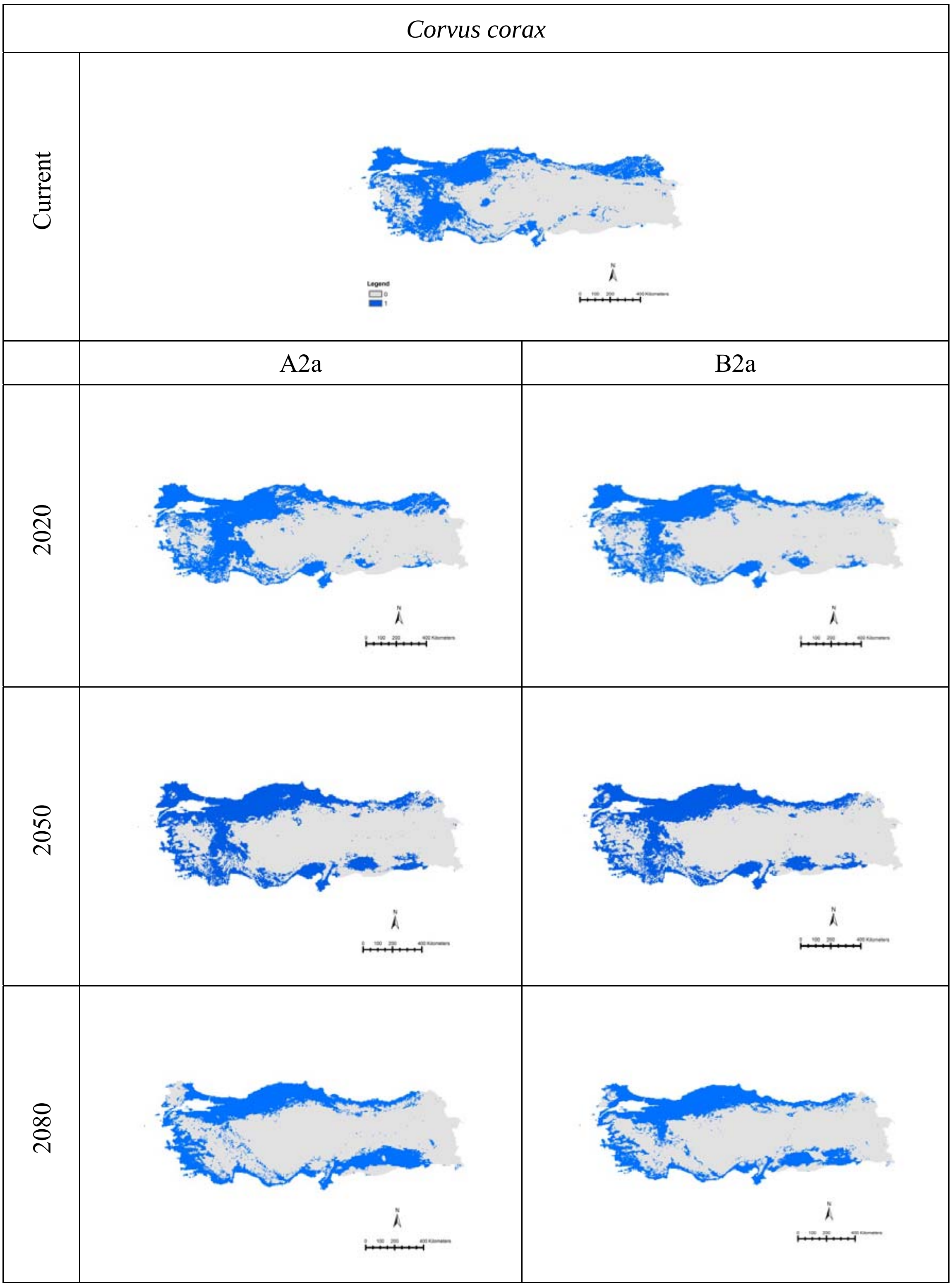

Figure C3. Distribution patterns of *Corvus corax*.

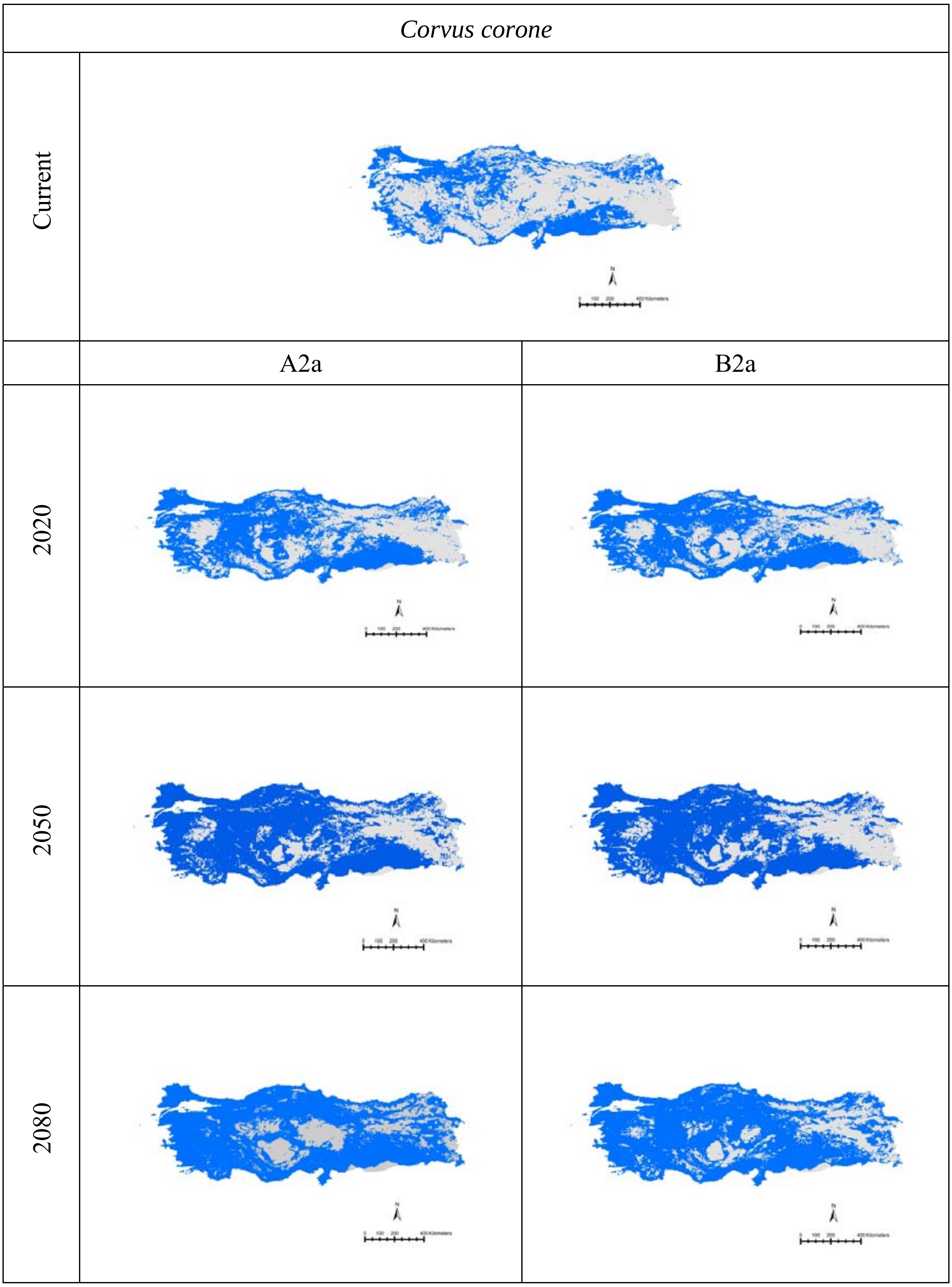

Figure C4. Distribution patterns of *Corvus corone*.

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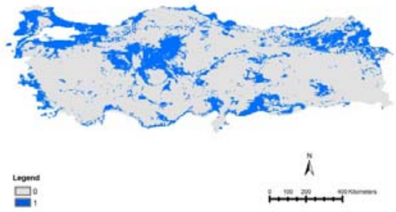
<tr><td>Current</td><td colspan="2"> </td></tr>
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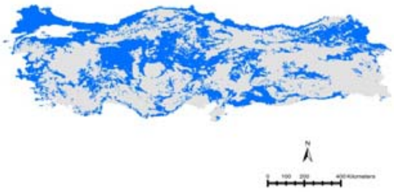
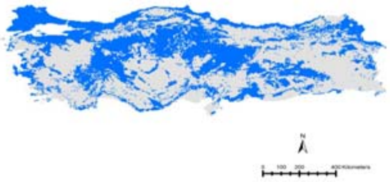
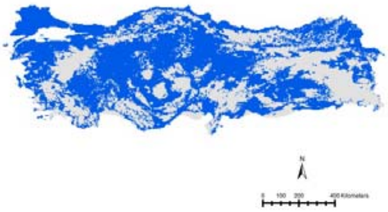
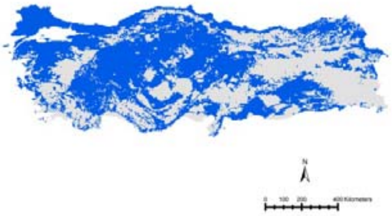
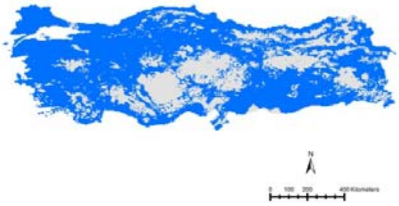
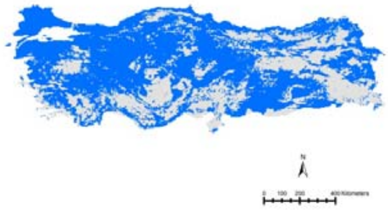
<tr><td>2020</td><td> </td><td> </td></tr>
<tr><td>2050</td><td> </td><td> </td></tr>
<tr><td>2080</td><td> </td><td> </td></tr>
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Figure C5. Distribution patterns of *Corvus monedula*.

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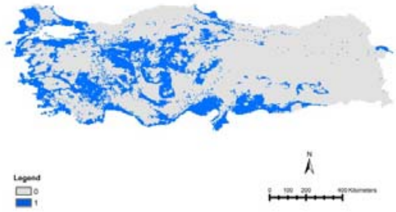
<tr><td>Current</td><td colspan="2">
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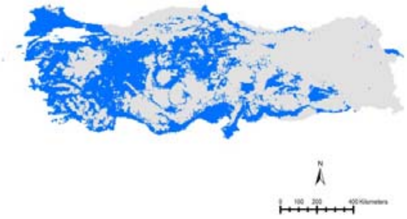
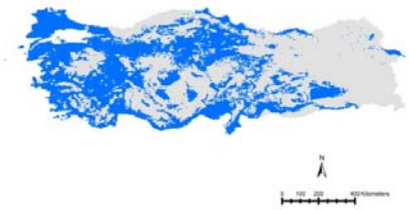
<tr><td>2020</td><td>
</td><td>
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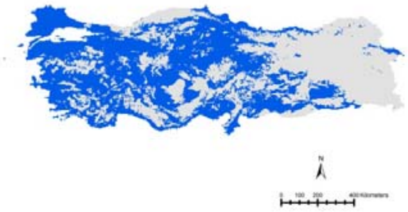
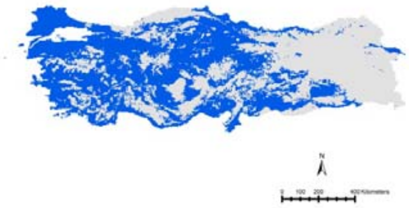
<tr><td>2050</td><td>
</td><td>
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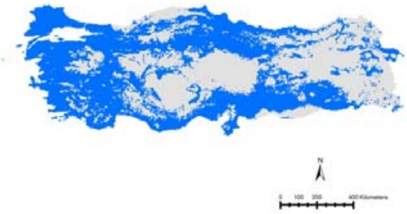
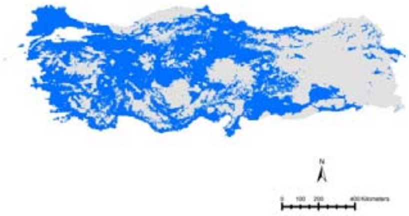
<tr><td>2080</td><td>
</td><td>
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Figure C6. Distribution patterns of *Galerida cristata*.

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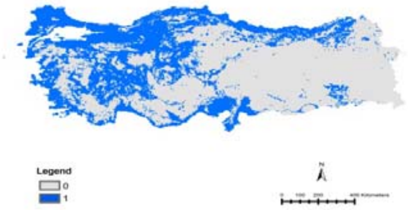
<tr><td>Current</td><td colspan="2">
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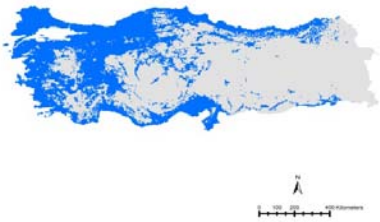
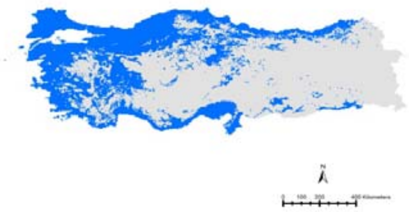
<tr><td>2020</td><td>
</td><td>
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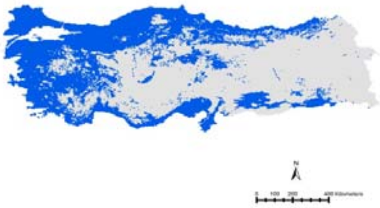
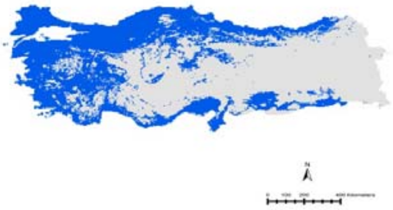
<tr><td>2050</td><td>
</td><td>
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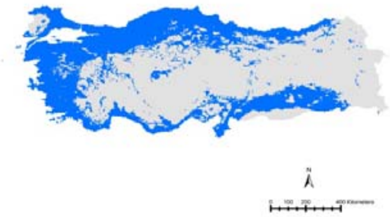
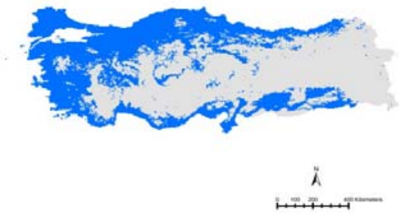
<tr><td>2080</td><td>
</td><td>
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Figure C7. Distribution patterns of *Garrulus glandarius.*

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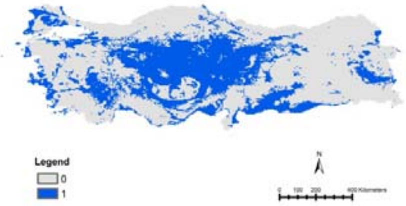
<tr><td>Current</td><td colspan="2">
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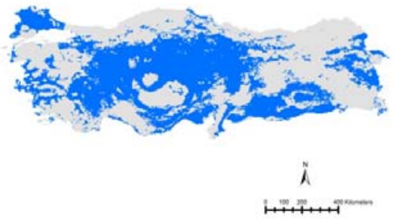
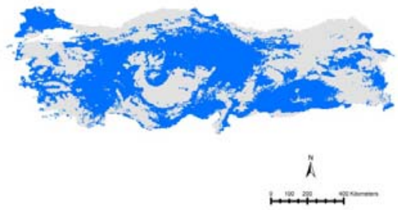
<tr><td>2020</td><td>
</td><td>
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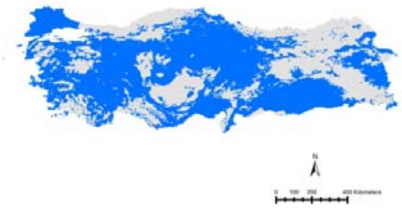
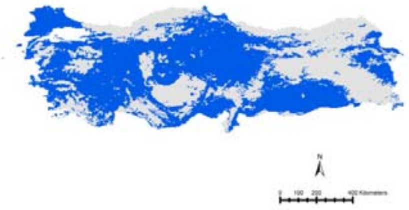
<tr><td>2050</td><td>
</td><td>
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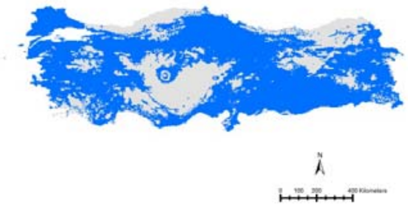
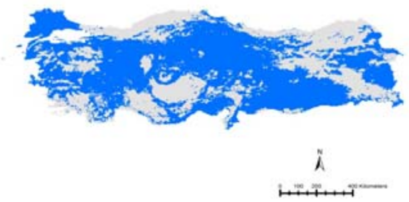
<tr><td>2080</td><td>
</td><td>
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Figure C8. Distribution patterns of *Melanocorypha calandra*.

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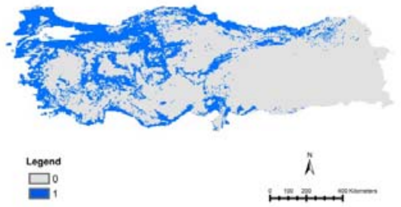
<tr><td>Current</td><td colspan="2"> </td></tr>
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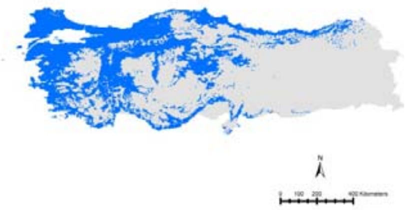
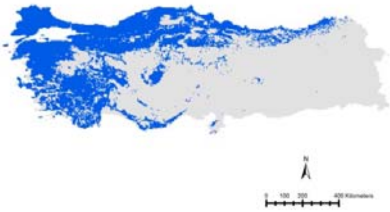
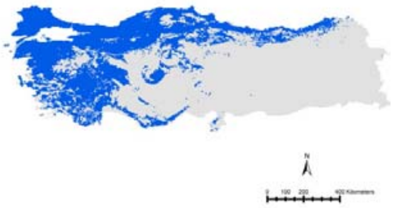
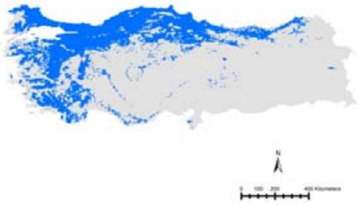
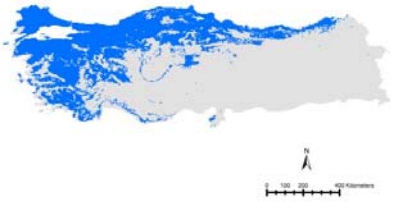
<tr><td>2020</td><td> </td><td> </td></tr>
<tr><td>2050</td><td> </td><td> </td></tr>
<tr><td>2080</td><td> </td><td> </td></tr>
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Figure C9. Distribution patterns of *Parus caeruleus.*

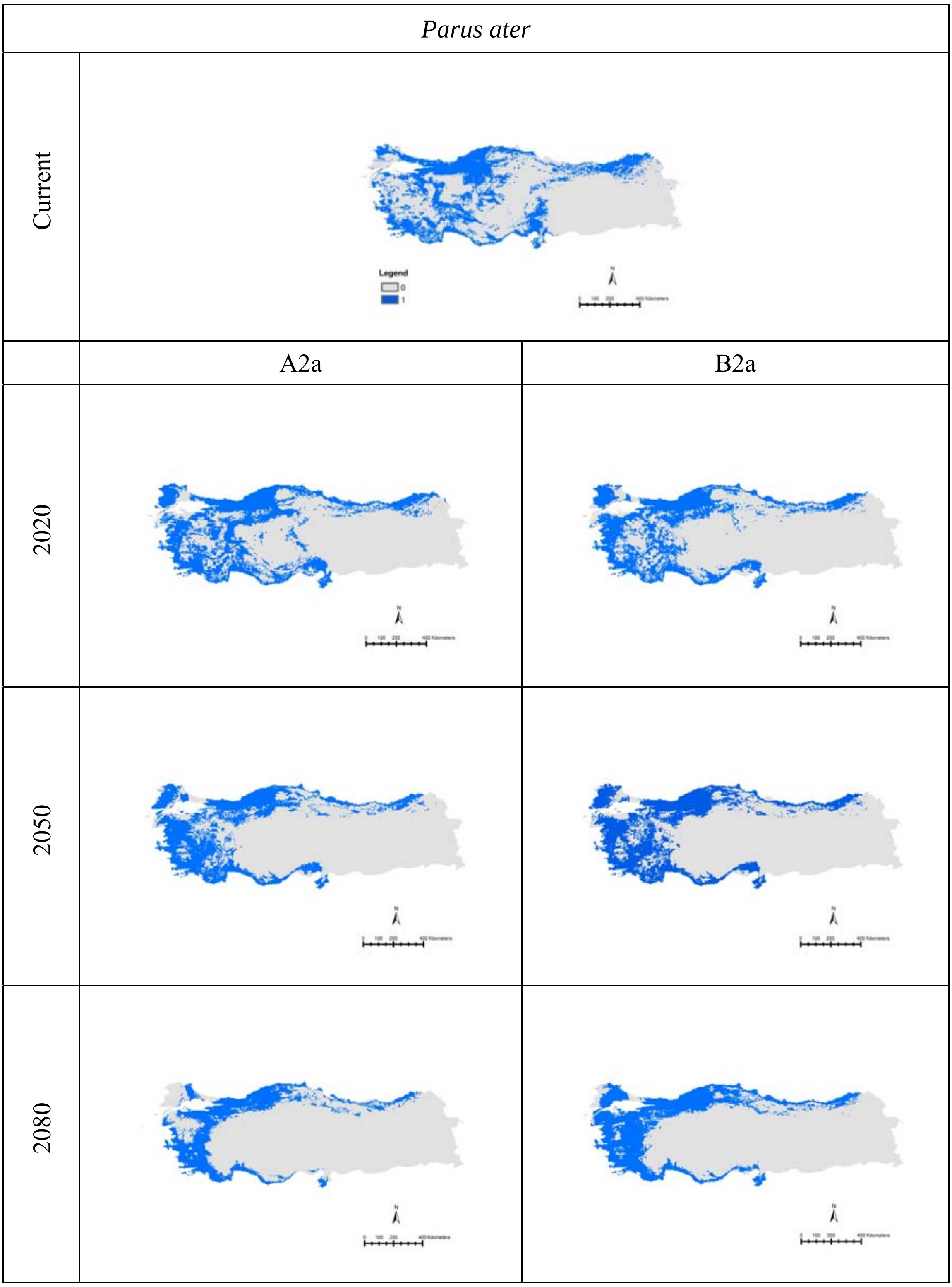

Figure C10. Distribution patterns of *Parus ater*.

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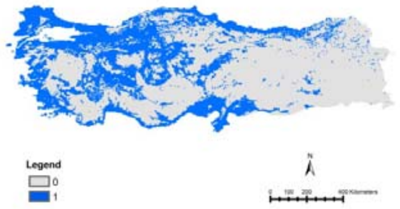
<tr><td>Current</td><td colspan="2">
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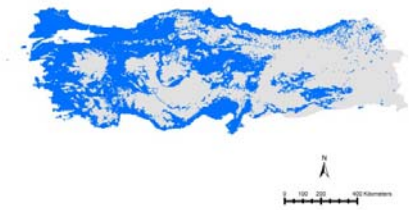
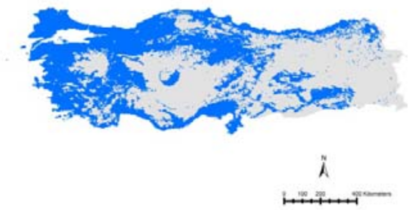
<tr><td>2020</td><td>
</td><td>
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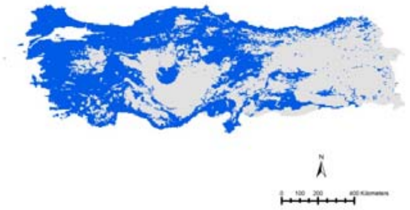
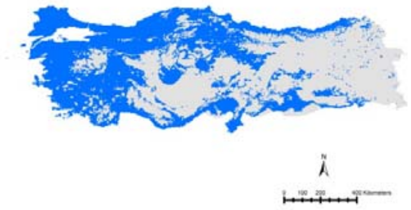
<tr><td>2050</td><td>
</td><td>
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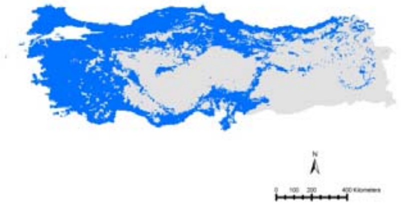
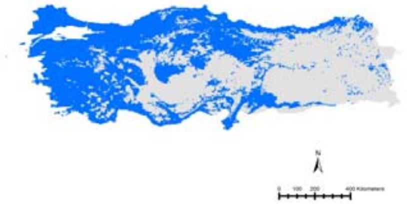
<tr><td>2080</td><td>
</td><td>
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Figure C11. Distribution patterns of *Parus major*.

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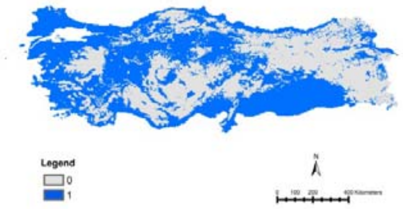
Current		
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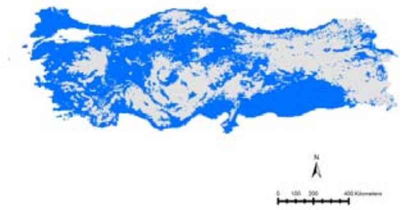
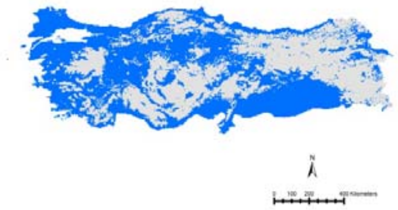
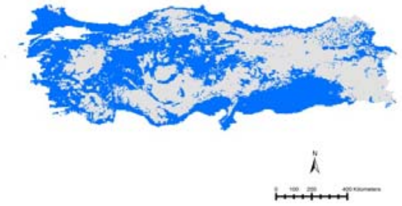
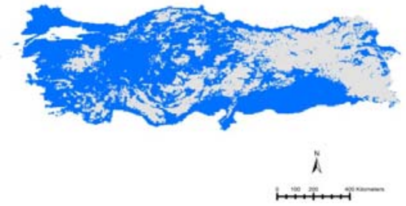
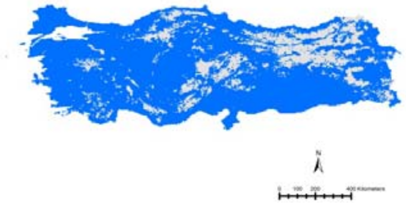
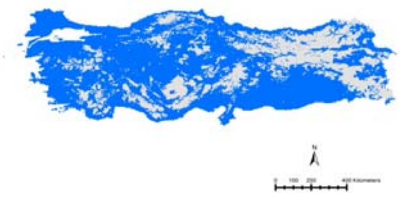
2020		
2050		
2080		

Figure C12. Distribution patterns of *Passer domesticus*.

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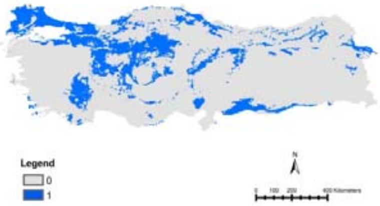
<tr><td>Current</td><td colspan="2">
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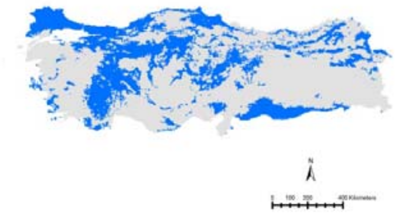
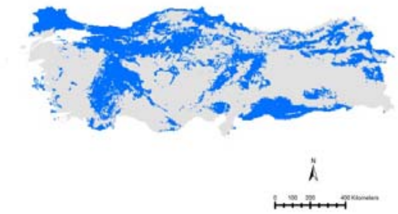
<tr><td>2020</td><td>
</td><td>
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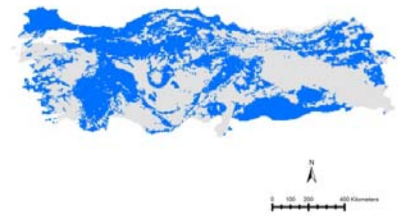
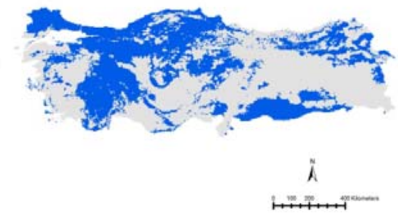
<tr><td>2050</td><td>
</td><td>
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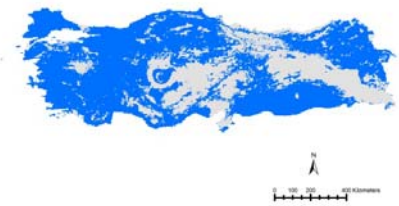
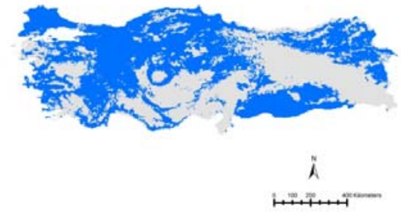
<tr><td>2080</td><td>
</td><td>
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Figure C13. Distribution patterns of *Passer montanus.*

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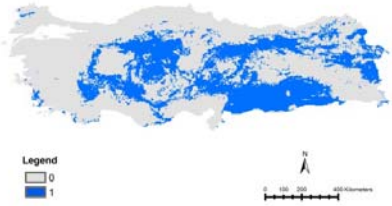
<tr><td>Current</td><td colspan="2"> </td></tr>
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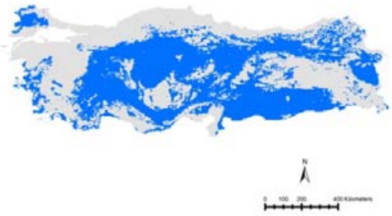
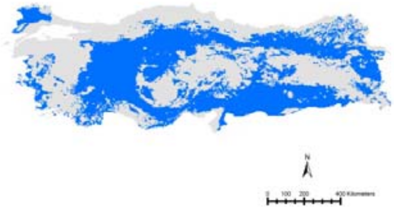
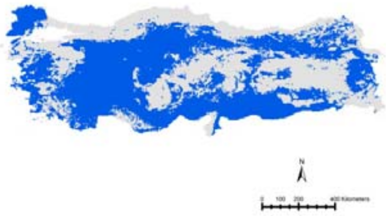
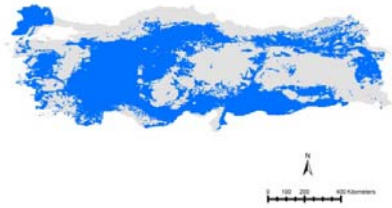
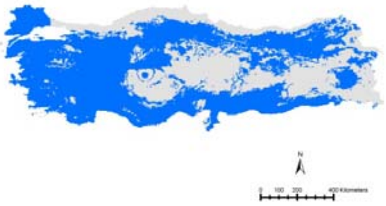
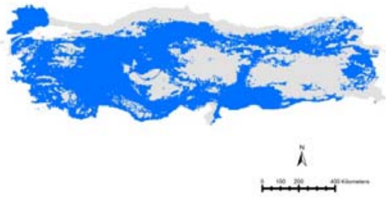
<tr><td>2020</td><td> </td><td> </td></tr>
<tr><td>2050</td><td> </td><td> </td></tr>
<tr><td>2080</td><td> </td><td> </td></tr>
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Figure C14. Distribution patterns of *Petronia petronia*.

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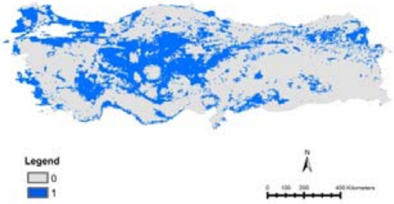
<tr><td>Current</td><td colspan="2">
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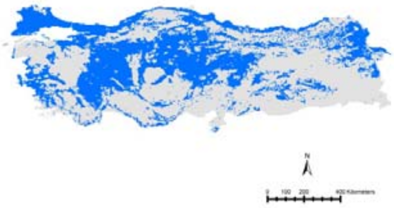
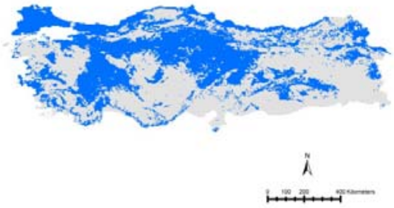
<tr><td>2020</td><td>
</td><td>
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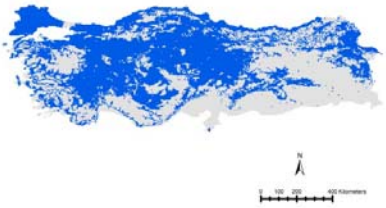
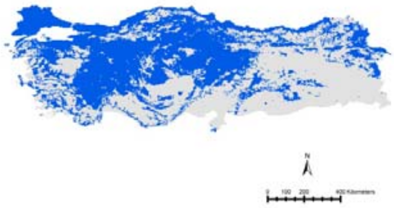
<tr><td>2050</td><td>
</td><td>
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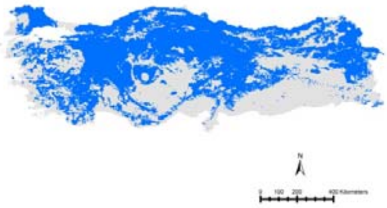
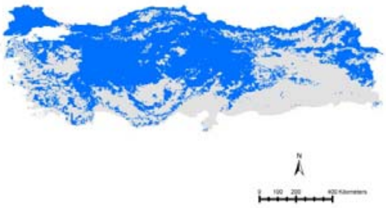
<tr><td>2080</td><td>
</td><td>
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Figure C15. Distribution patterns of *Pica pica*.

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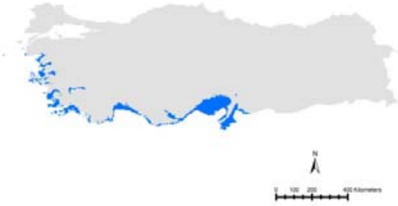
</td><td>
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Figure C16. Distribution patterns of *Pycnonotus xanthopygos*.

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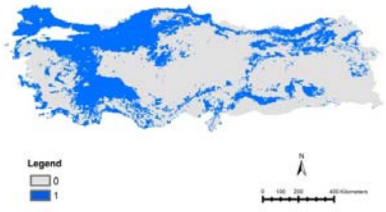
<tr><td>Current</td><td colspan="2">
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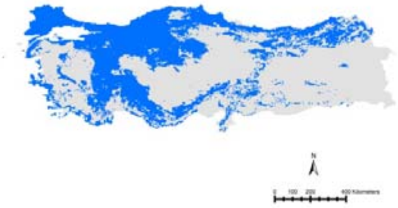
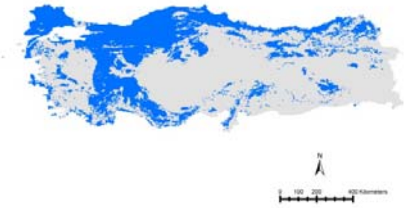
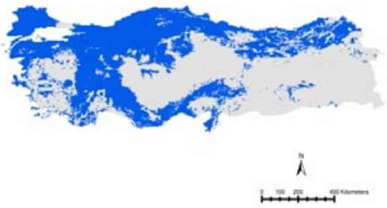
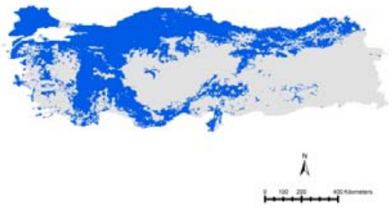
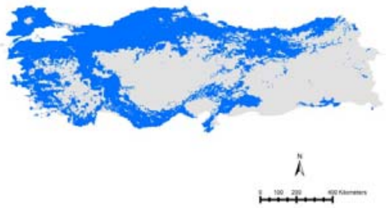
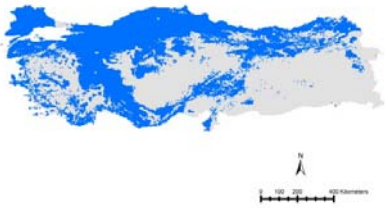
<tr><td>2020</td><td></td><td></td></tr>
<tr><td>2050</td><td></td><td></td></tr>
<tr><td>2080</td><td></td><td></td></tr>
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Figure C17. Distribution patterns of *Sitta europaea*.

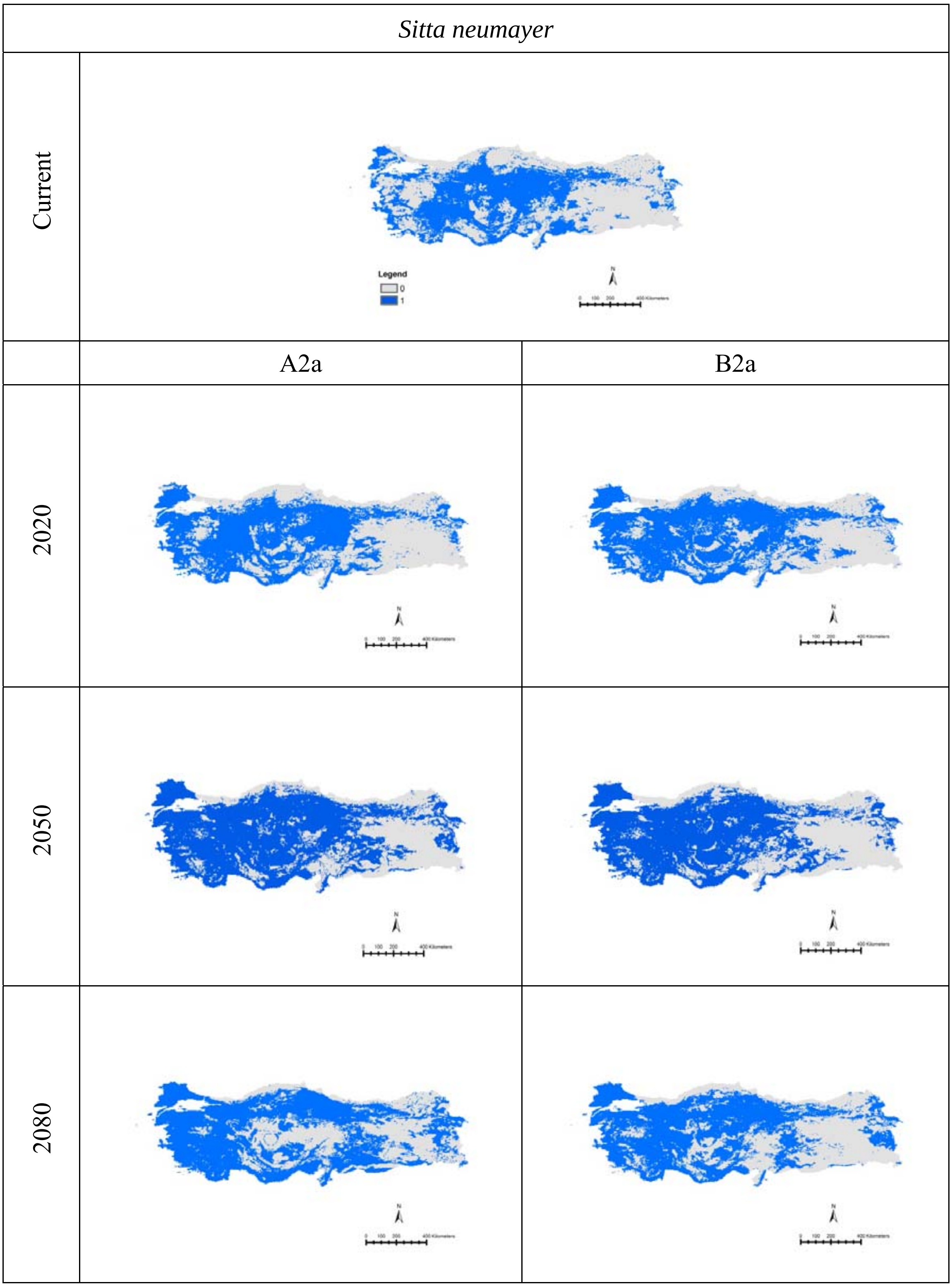

Figure C18. Distribution patterns of *Sitta neumayer*.

Sitta tephronota		
Current		
	A2a	B2a
2020		
2050		
2080		

Figure C19. Distribution patterns of *Sitta tephronota*.

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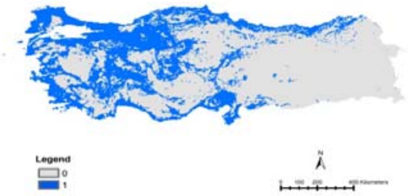
<tr><td>Current</td><td colspan="2">
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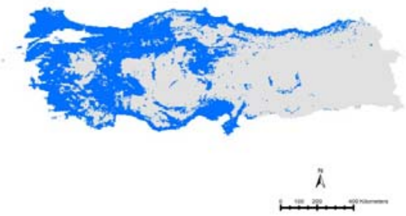
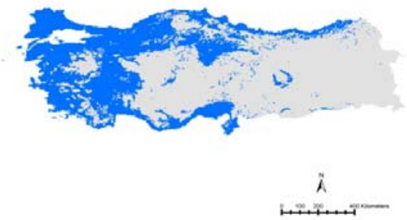
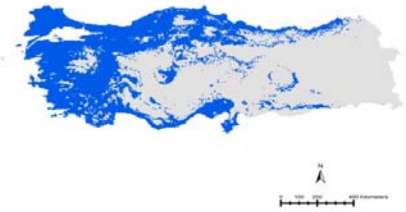
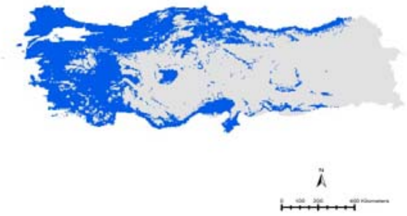
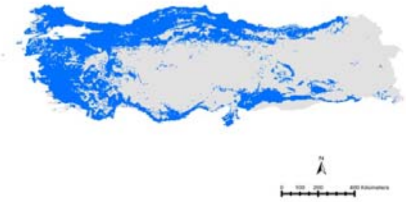
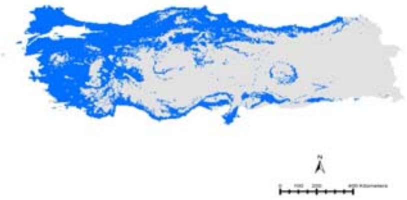
<tr><td>2020</td><td></td><td></td></tr>
<tr><td>2050</td><td></td><td></td></tr>
<tr><td>2080</td><td></td><td></td></tr>
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Figure C20. Distribution patterns of *Turdus merula*.

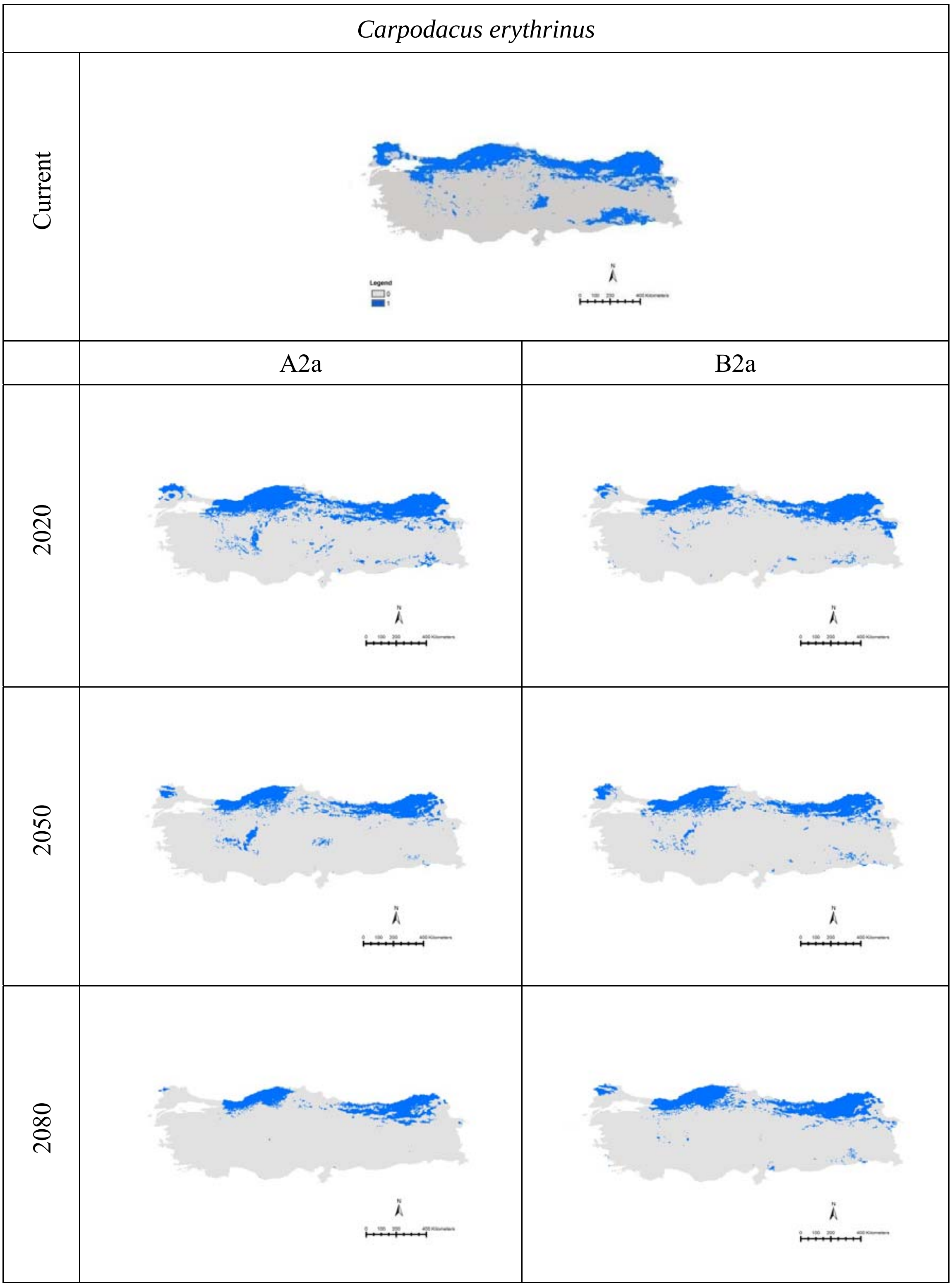

Figure C21. Distribution patterns of *Carpodacus erythrinus*.

Emberiza caesia		
Current		
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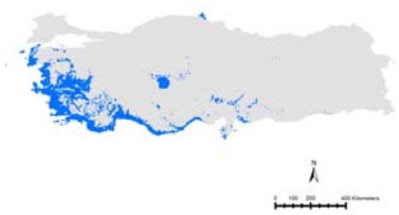
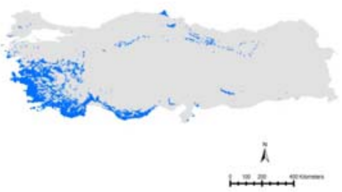
2020		
2050		
2080		

Figure C22. Distribution patterns of *Emberiza caesia.*

Erythropygia galactotes		
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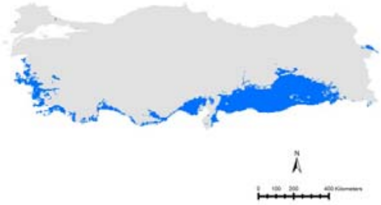
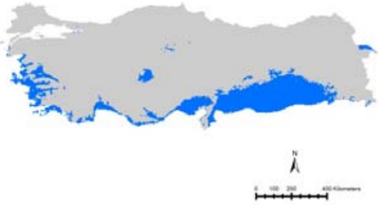
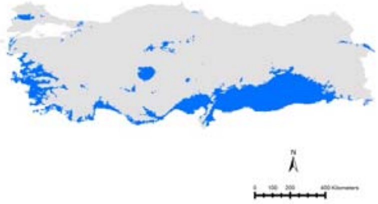
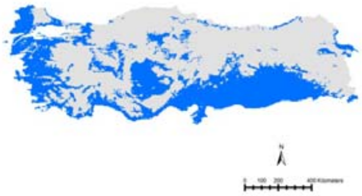
2020		
2050		
2080		

Figure C23. Distribution patterns of *Erythropygia galactotes*.

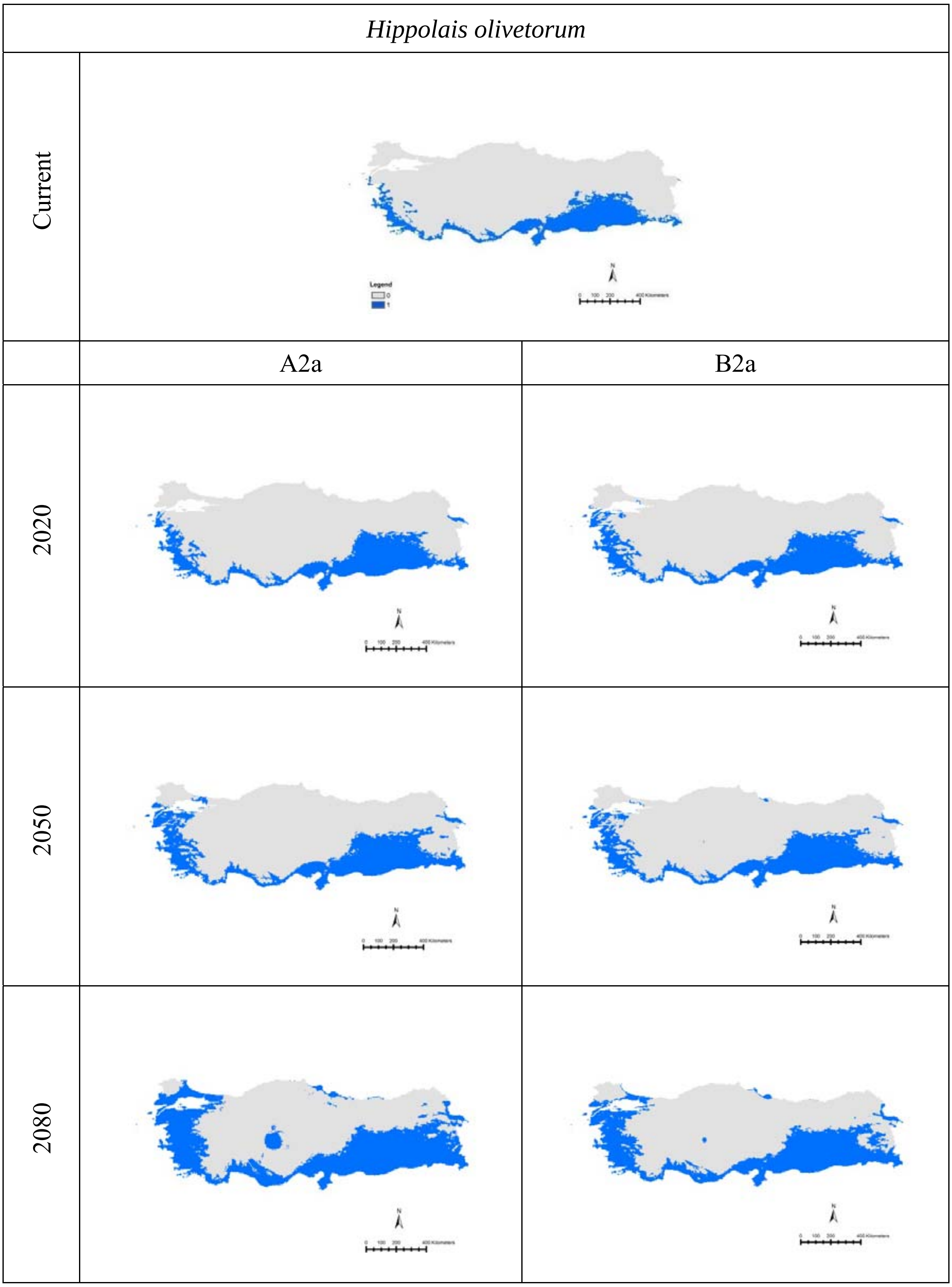


Figure C24. Distribution patterns of *Hippolais olivetorum.*

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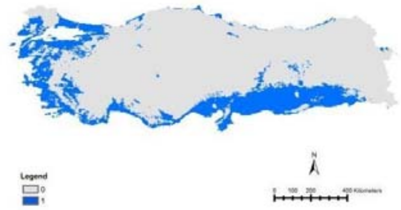
<tr><td>Current</td><td colspan="2"> </td></tr>
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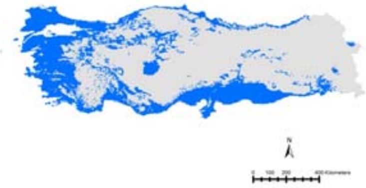
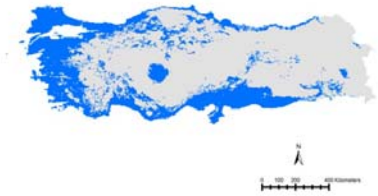
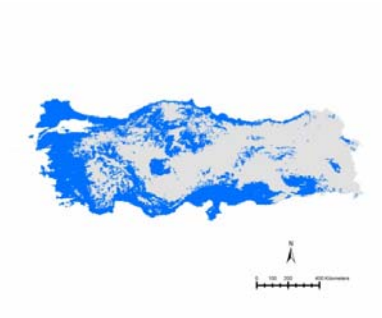
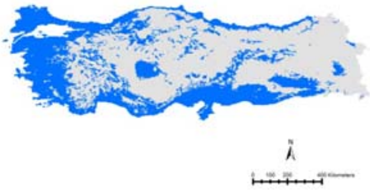
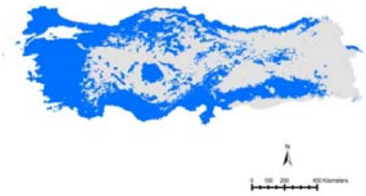
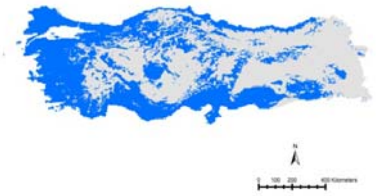
<tr><td>2020</td><td> </td><td> </td></tr>
<tr><td>2050</td><td> </td><td> </td></tr>
<tr><td>2080</td><td> </td><td> </td></tr>
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Figure C25. Distribution patterns of *Hirundo daurica*.

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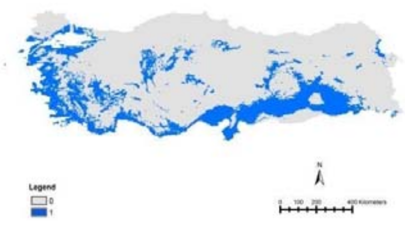
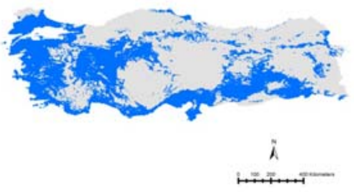
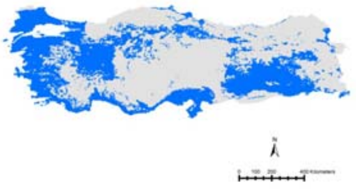
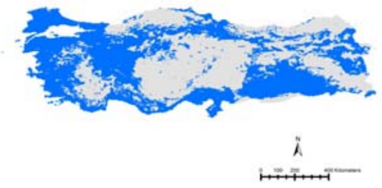
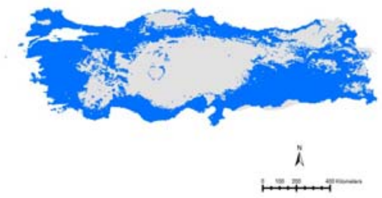
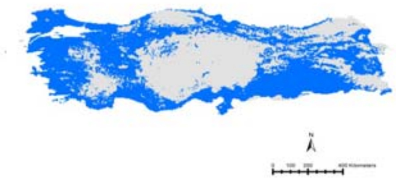
Current		
	A2a	B2a
2020		
2050		
2080		

Figure C26. Distribution patterns of *Lanius nubicus*.

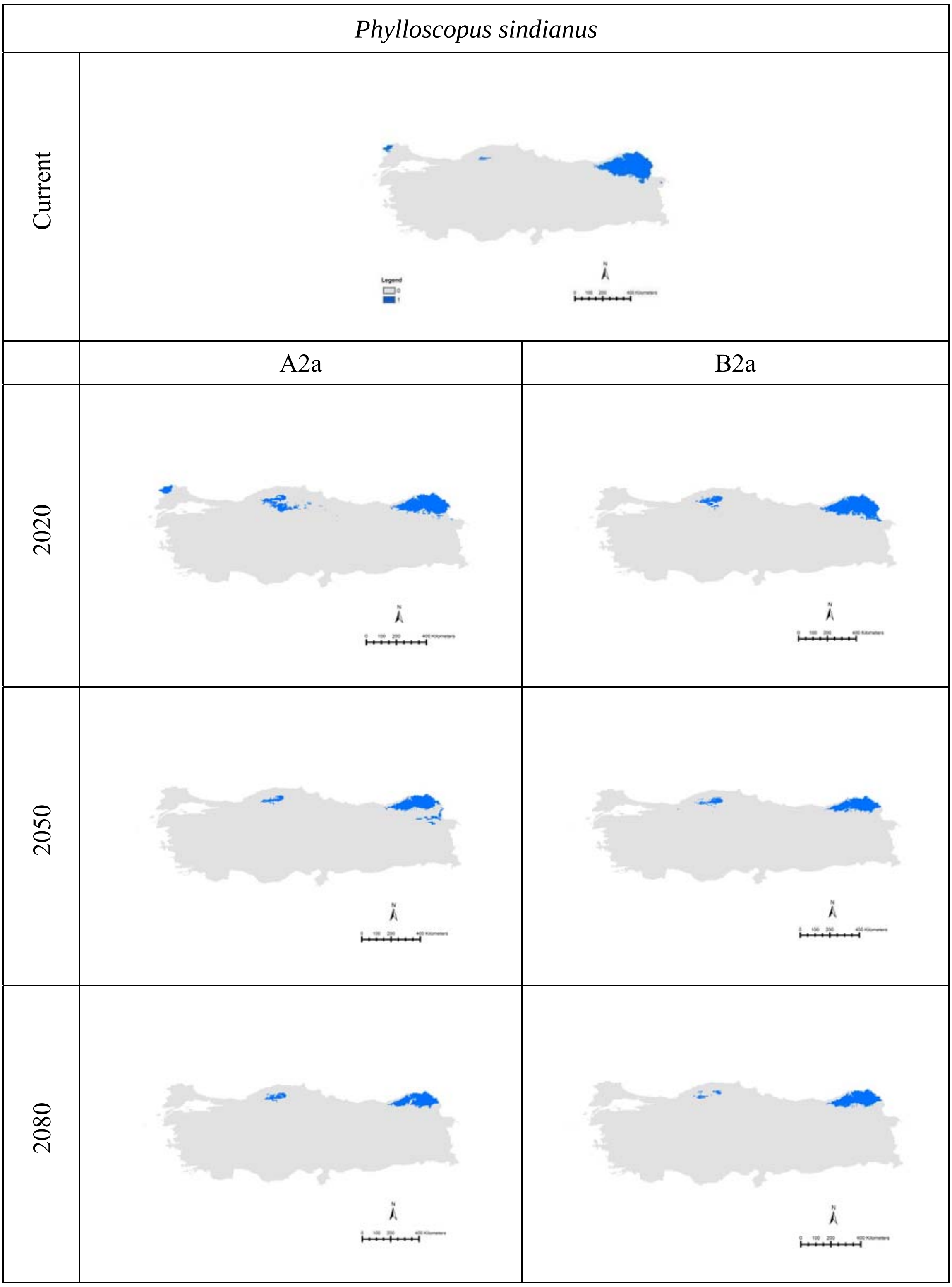


Figure C27. Distribution patterns of *Phylloscopus sindianus.*

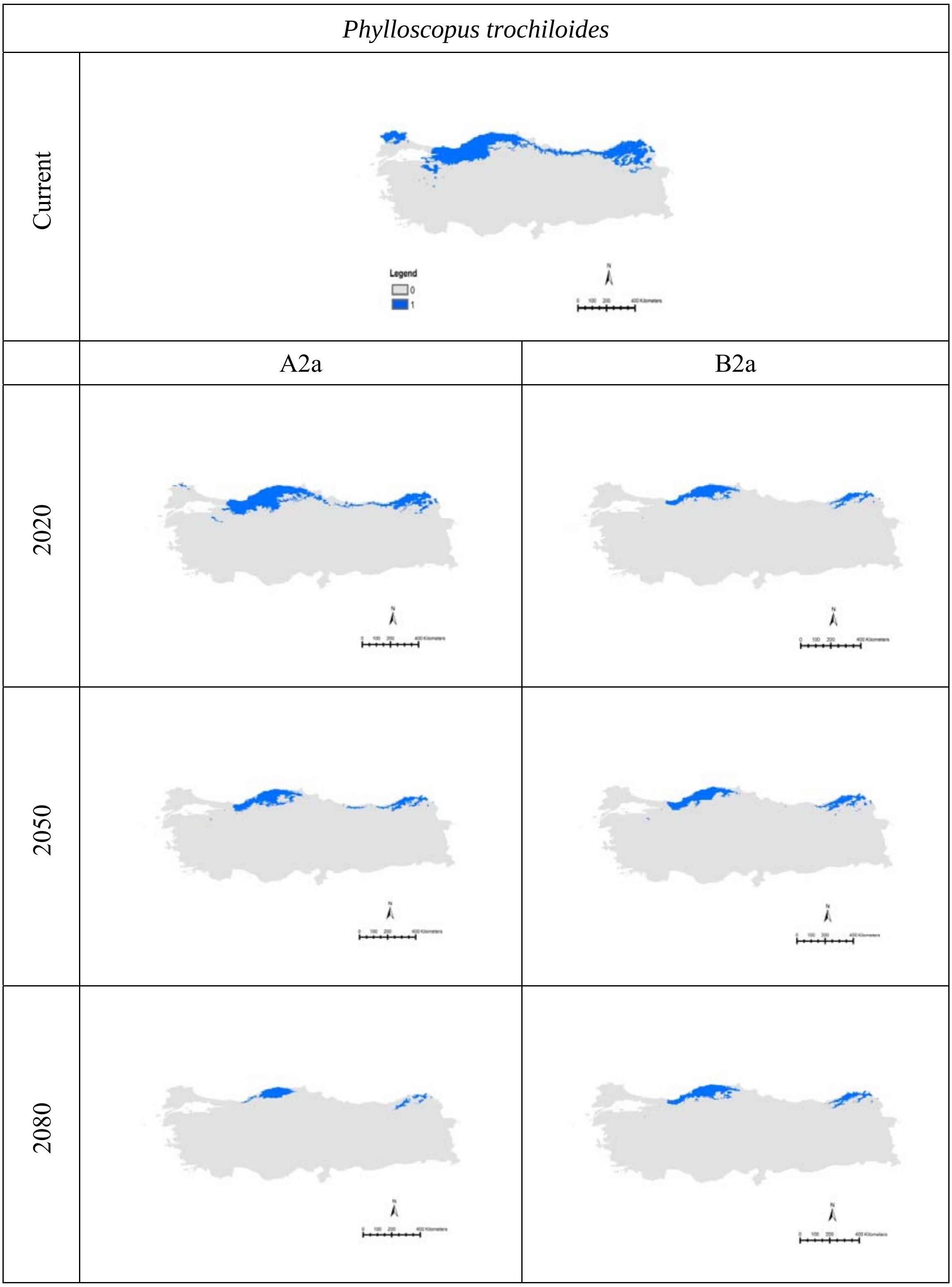


Figure C28. Distribution patterns of *Phylloscopus trochiloides.*

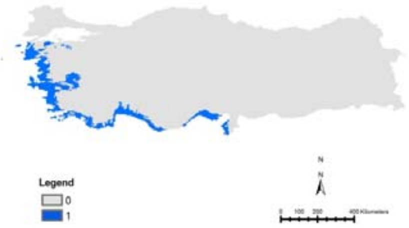
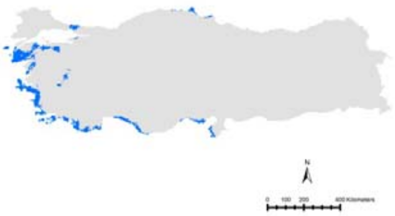
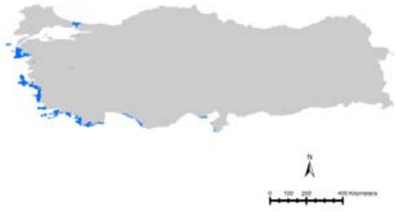
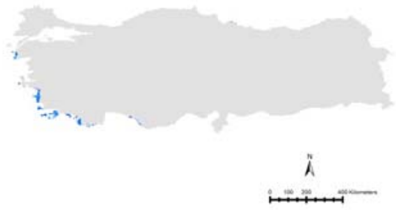
Sylvia cantillans		
Current		
	A2a	B2a
2020		
2050		
2080		

Figure C29. Distribution patterns of *Sylvia cantillans.*