Audubon

Audubon's Birds and Climate Change Report

Conservation Science, National Audubon Society

The National Audubon Society has spent the past century protecting birds. Now we are prepared to work on their behalf in the 21st century.

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Citation: National Audubon Society. 2014. Audubon's Birds and Climate Change Report: A Primer for Practitioners. National Audubon Society, New York. Contributors: Gary Langham, Justin Schuetz, Candan Soykan, Chad Wilsey, Tom Auer, Geoff LeBaron, Connie Sanchez, Trish Distler. Version 1.2.

Audubon's Climate Science

The National Audubon Society has completed a continental analysis of how North America's birds may respond to future climate change. Using extensive citizen science data and detailed climate layers, we developed models that characterize the relationship between the distribution of each species and climate. Then, we used our models to forecast species distributions to future time periods based on climate estimates described by the Intergovernmental Panel on Climate Change (IPCC). This core set of analyses will serve as the backbone for informing bird conservation in North America through planning tools for land managers, reports focused on species of conservation concern, and peer-reviewed publications addressing the impacts of climate change on birds. We addressed three topics of general interest for broad-scale bird conservation, which we summarize here and on Audubon's website: (1) the impact of climate change on bird diversity in the United States and Canada (Part I); (2) identification of areas that are expected to remain important to birds under the present and future climate (Part II); and (3) in-depth analyses of potential climate change impacts on 314 species (online at audubon.org/climate).

This document is a guide to Audubon's climate science analysis. In the following pages, you will find descriptions of the work, along with definitions of key terms, practical guides to using the data and maps, and examples of how Audubon's climate science can enrich your ongoing programs.

Audubon's Conservation Science team has generated three data products (Box 1). Each offers a distinct way to engage with the science. First, there are lists of climate-sensitive species, with potentially broad application to all users. Second, there are maps of modeled climatic suitability under a range of climate change scenarios across three future time periods. These are available as animated illustrations on Audubon's website (e.g. Fig. 1.1) and as data through ArcGIS desktop. Third, we have integrated the climate change projections into spatial prioritizations. These prioritizations highlight areas on the landscape that are likely to offer suitable climates for a single species or multiple species today and into the future. Prioritizations should have broad appeal throughout the bird conservation community. They can be used to strengthen the justification for projects already underway as well as to identify new areas in need of conservation attention.

Please take the time to review this document to better understand all the work that has been done. Then, begin to imagine how this science can support ongoing projects as well as create new opportunities to promote bird conservation. Contact climatescience@audubon.org for more information or for assistance in obtaining, interpreting and analyzing species maps and prioritizations.

CLIMATE SENSITIVITY LISTS

- Identify climate endangered, threatened, data deficient, and stable species
- Based on projected changes in climatic suitability for each species

INDIVIDUAL SPECIES MODELED CLIMATIC SUITABILITY

- Single-species climatic suitability maps
- Current and future ranges
- Three future emissions scenarios each informed by multiple general circulation models
- Three future time periods
- Visualizations available at Audubon.org/climate

CLIMATE PRIORITIZATIONS

- Spatial prioritizations providing the relative rank of locations on the landscape
- Available for summer, winter, or both seasons
- Single-species
- Multi-species
- Integrated assessments of current and future climatic suitability

Box 1. Audubon's Climate Science products.

About the cover:
This photo mosaic of a Baird's Sparrow was created by Charis Tsevis using fragments of John James Audubon's paintings of some of the bird species identified in the Audubon report as being under threat. Baird's Sparrow reference photo: Gerrit Vyn.

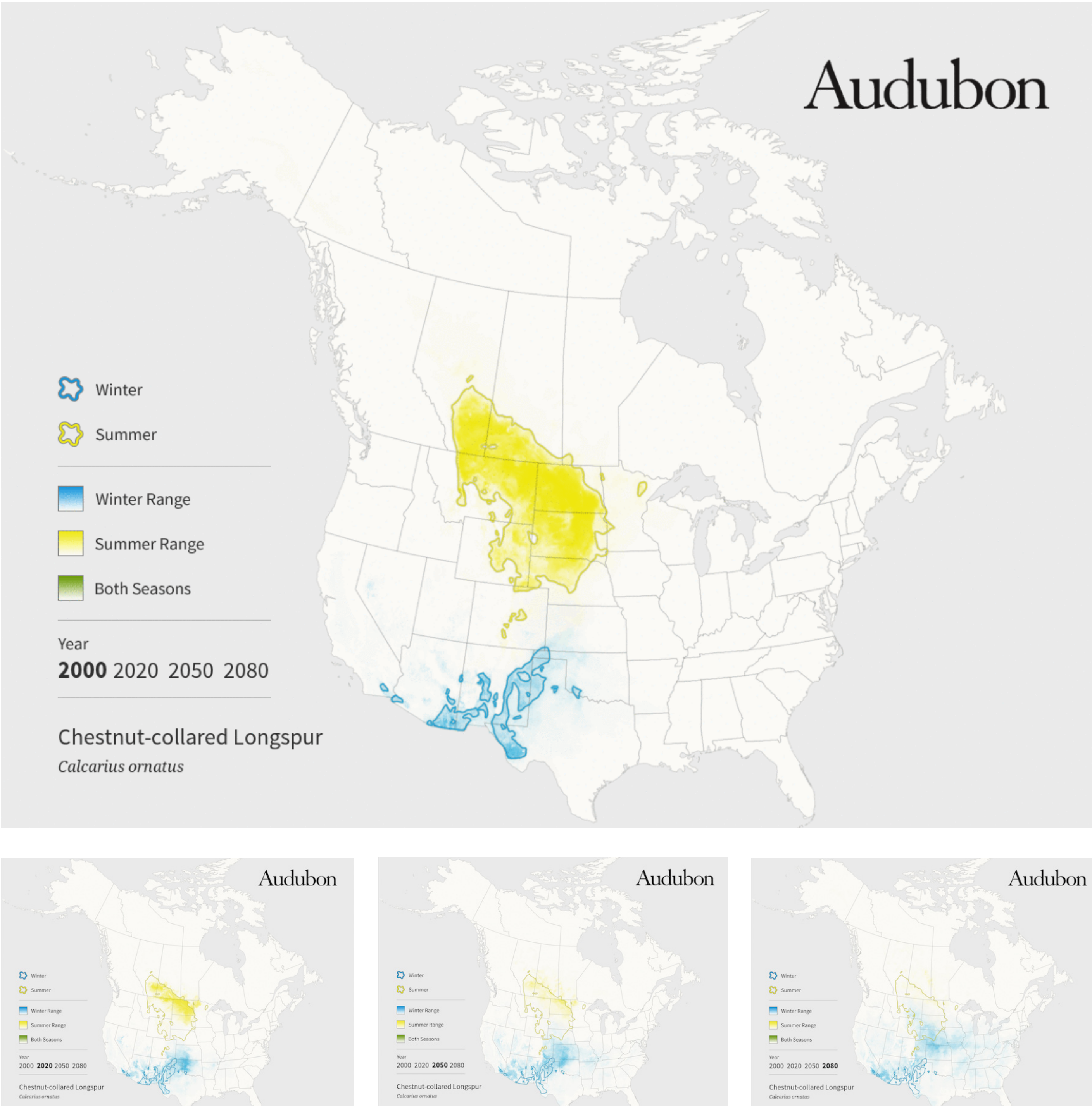

Figure 1.1. A sample climatic suitability map from Audubon.org/climate. This sequence of four maps reflects the four modeled time periods (2000s [top], 2020s, 2050s, and 2080s [left to right along bottom]) and are shown in sequence as an animated GIF online. Yellow and blue outlines are the current core climatically suitable range. Shaded yellow and blue areas are modeled climatically suitable range in summer and winter, respectively. The darker the color, the more climatically suitable the location. See Audubon.org/climate for climatic suitability projections of the 314 climate-threatened and endangered birds. See Appendix D for responses to frequently asked questions about climatic suitability maps.

PART I:

Conservation Status of North American Birds in the Face of Future Climate Change

SECTION CURRENTLY UNDER PEER-REVIEW.

For a detailed look at the methods, refer to PART V Expanded Methods, page 21.

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PART II:

Prioritizing Climate Strongholds for North American Birds

Summarizing the Science

Spatial prioritizations rank locations across a landscape according to their relative value for attaining a conservation goal, such as the protection of a priority species. This is useful for identifying areas of maximum return on conservation effort. Audubon seeks to identify areas that are likely to be suitable for a given species or suite of species today and under future climatic conditions. Therefore, we built spatial prioritizations based on shifts in climatic suitability for each of 588 species in North America as well as a multi-species spatial prioritization for the 314 climate-endangered and threatened species. We incorporated the inherent uncertainties of climate projections and species responses into our analysis. Both single- and multi-species prioritizations represent a useful way to synthesize Audubon's projections of climate impacts on birds. Areas within these spatial prioritizations with the highest relative ranking represent climatic strongholds.

Introduction

As described in Part I, Audubon has generated maps of projected climatic suitability under a range of future time periods and greenhouse gas emission scenarios. Here, we outline how these projections can be synthesized into landscape prioritization maps for individual or multiple species. Critical to this process is the treatment of uncertainty across climate-impacts projections. Sources of uncertainty include the emissions scenario considered (SRES B2, A1B, A2) and variation across future time periods (2020s, 2050s, 2080s). In addition, there are biological uncertainties, because we cannot be certain how species will respond to future climate change even though we have carefully modeled their historical responses.

We identified three views on biological uncertainty (Fig. 2.1) and explored the implications of adopting these views. First, a species might track and move with its shifting area of climatic suitability. Second, a species may be unable to move, staying in its current range and suffering in places that become climatically unsuitable. Finally, species may be more plastic than is currently understood and be able to adapt in place to a changing climate. Highly mobile and flexible species form a fourth group whose potential responses are very difficult to anticipate within a climate change framework.

We generate both single-species prioritizations for 588 North American bird species and a multi-species prioritization for 314 climate endangered and threatened species.

Methods

Single- and multi-species prioritizations were generated using Zonation spatial prioritization software. In a single-species prioritization, Zonation ranks each 10 x 10 km grid cell based on its contribution toward protecting a species' current and future climatically suitable range.

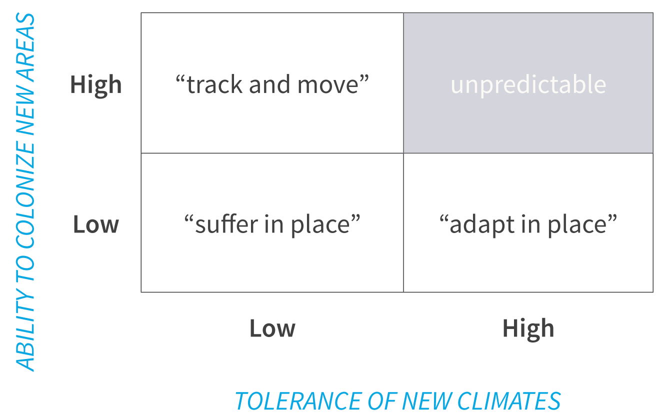


Figure 2.1. Conceptual diagram characterizing possible biological responses to climate change.

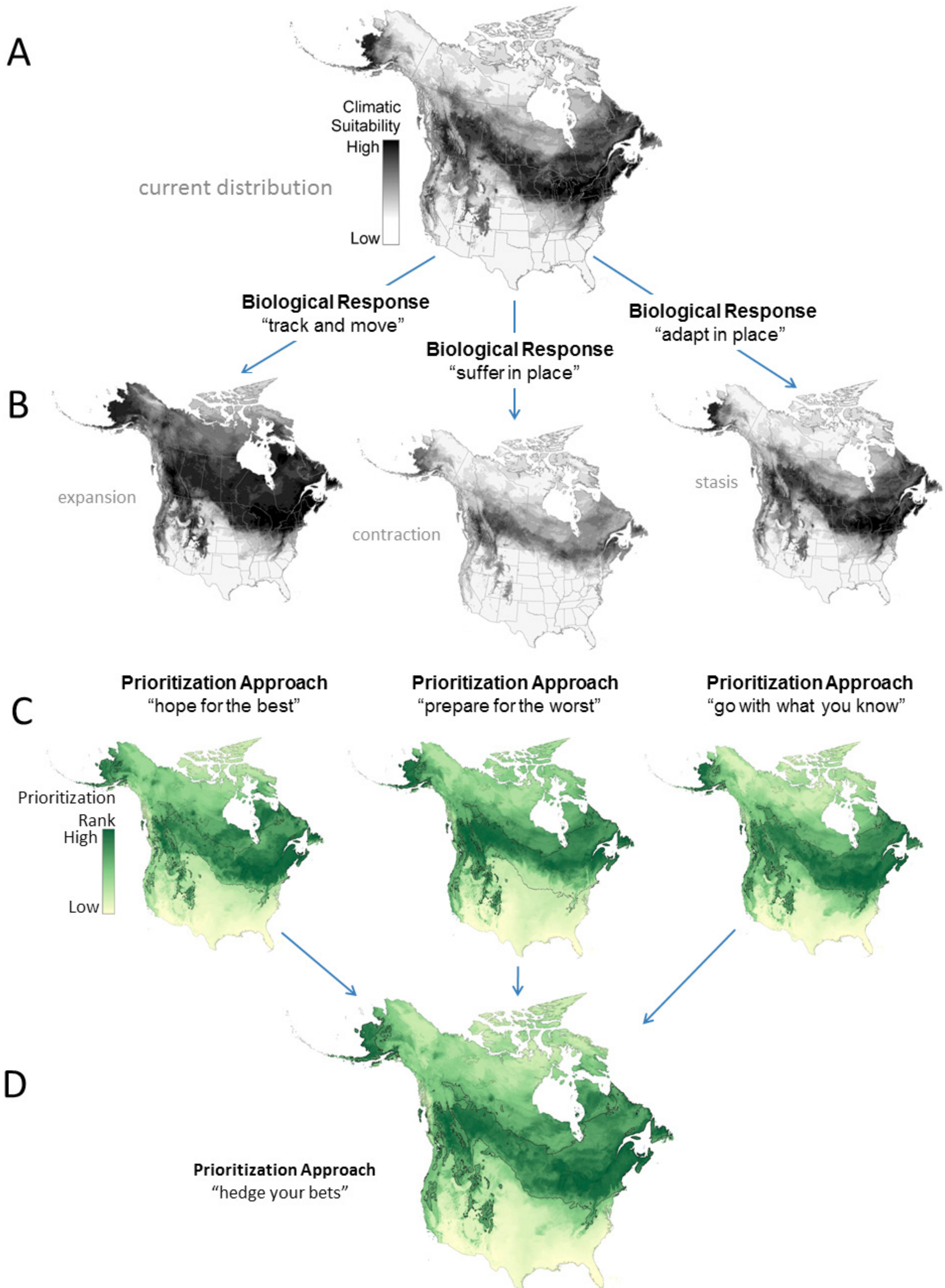


Figure 2.2. Spatial prioritization process for the Tree Swallow (*Tachycineta bicolor*). Start with the species' current modeled climatic suitability in summer (A) and future climatic suitability according to the three proposed biological responses (B). Then generate spatial prioritizations corresponding to each of the three biological responses (C) and ensemble them into a single "hedge your bets" prioritization (D).

Uncertainty due to emissions scenarios and variation across future time periods (2020s, 2050s, 2080s) are incorporated by ensembling projections. Biological uncertainty is captured in the prioritization by treating the future climatically suitable range as (1) opportunity, (2) risk, and (3) ignoring it. These correspond to the biological responses: "track and move", "suffer in place", and "adapt in place", respectively (Fig. 2.1). Three prioritizations are built for each season (summer and winter) and combined by taking the maximum score for any grid cell across all three prioritizations and rescaling the result between 0 and 1.

We also generated a multi-species prioritization for the 314 climate-endangered and -threatened species. With multiple species, Zonation highlights areas with climates that will allow for conservation of many species (especially rare ones) into the future. For this reason, when working with a group of species (e.g. grassland birds), it is critical to build a multi-species prioritization rather than summing or averaging across the single-species prioritizations for each group member (see Conclusions for more information).

Results

Projected range shifts across future emissions scenarios and time periods can be represented by range expansion, contraction, or stasis, depending on the assumed biological response (Fig. 2.2, row B). Prioritizations based on each of these assumptions differ, but those differences are minimized when the prioritizations are combined, or ensembled, into a final "hedge your bets" prioritization (Fig. 2.2, row D).

In each prioritization, grid cell on the landscape are ranked between 0 and 1, resulting in a high level of user flexibility (Fig. 2.3). For many applications, the top 5 or 10% of the landscape may be of greatest interest for targeting conservation actions. Prioritizations can be summarized at any spatial scale (Fig. 2.4). A climate stronghold (Box 2) is therefore user-defined, but represents some highest percentage of ranked grid cell on the landscape at a local, state, regional, or national scale (Box 2).

WHAT IS A SPATIAL PRIORITIZATION?

- NOT a species range map.
- A ranking of the landscape based on climate for the conservation value of one or more species.
- Incorporates information from multiple climate scenarios, time periods in the future, and hypotheses about how birds might respond to climate change into a single map for conservation planning.

WHAT IS A CLIMATE STRONGHOLD?

- An area that is relatively valuable for retaining one or more bird species while accounting for the potential effects of future climates on their distribution.
- The concept of a climate stronghold is useful for developing long-term conservation plans at a variety of spatial scales.
- Could be defined as some highest percentage (top 5 or 10%) of ranked pixels on the landscape (be it at a local, state, regional, or national scale).

Box 2. Climate prioritizations and strongholds.

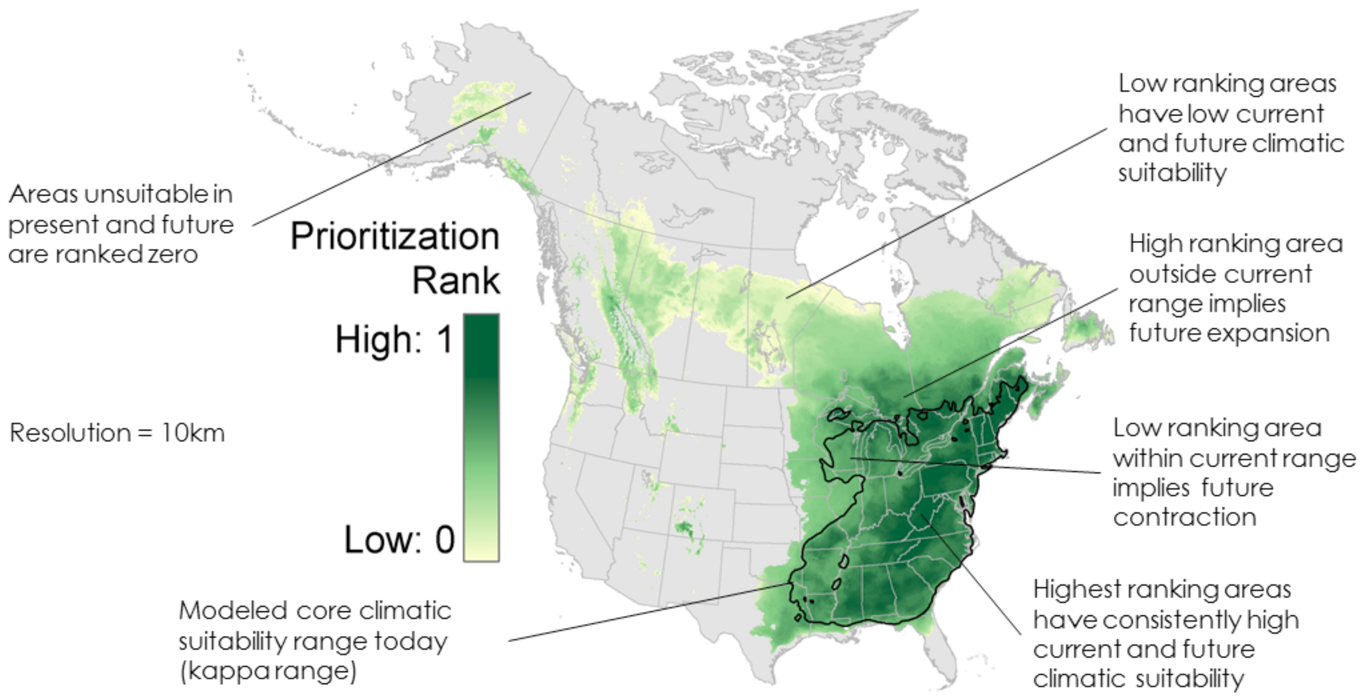


Figure 2.3. Anatomy of a spatial prioritization for Wood Thrush (*Hylocichla mustelina*) in summer.

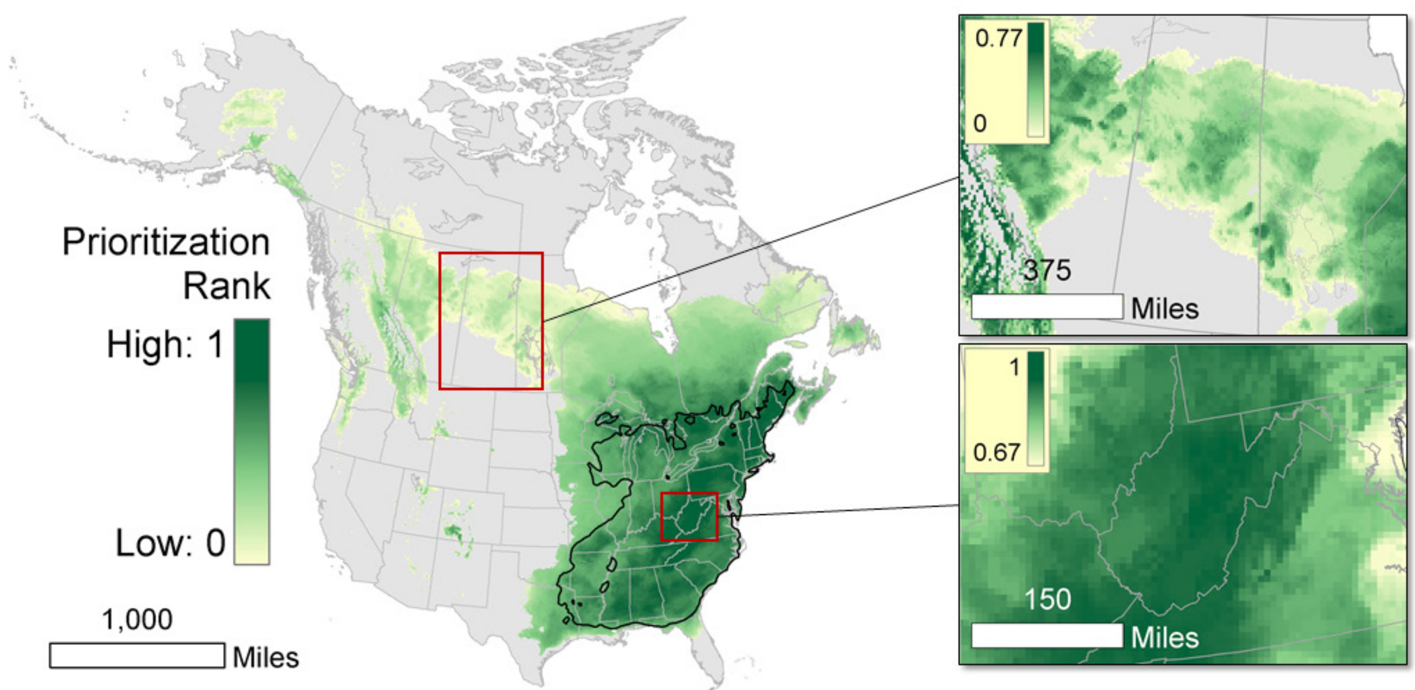


Figure 2.4. Visualizing prioritizations at different spatial scales (Wood Thrush in summer). Note the map scale and range of stronghold rankings respresented at the state and province scale (insets) differs from the national scale.

Conclusions

Spatial prioritizations are an effective means of synthesizing information across multiple future projections and species. A single-species prioritization identifies areas likely to be climatically suitable today and tomorrow. These can be combined with other spatial data inputs to develop a conservation plan for the species that is robust to a range of climate change futures and biological responses. See Appendix E for an example of how one could represent climate prioritizations in a map and responses to frequently asked questions.

Multi-species prioritizations are useful for state, regional, or national conservation planning. These are more than just averaging across the single-species prioritizations because multi-species prioritizations highlight areas with high species diversity as well as hosting narrowly distributed species. Contact climatescience@audubon.org for multi-species prioritizations tailored to a given species set.

Suggestions for Further Reading

Bateman, B. L., H. T. Murphy, A. E. Reside, K. Mokany, and J. VanDerWal. 2013. Appropriateness of full-, partial- and no-dispersal scenarios in climate change impact modelling. Diversity and Distributions 19:1224–1234.

Jezkova, T., V. Olah-Hemmings, and B. R. Riddle. 2011. Niche shifting in response to warming climate after the last glacial maximum: inference from genetic data and niche assessments in the chisel-toothed kangaroo rat *(Dipodomys microps)*. Global Change Biology 17:3486–3502.

Moilanen, A., H. Kujala, and J. Leathwick. 2009. The Zonation framework and software for conservation prioritization. Pages 196–210 in A. Moilanen, K. A. Wilson, and H. Possingham, editors. Spatial Conservation Prioritization: Quantitative Methods and Computational Tools. Oxford Univ. Press, Oxford; New York.

Thuiller, W., B. Lafourcade, R. Engler, and M. B. Araujo. 2009. BIOMOD - a platform for ensemble forecasting of species distributions. Ecography 32:369–373.

Contact climatescience@audubon.org for more information on Audubon’s Birds and Climate Change report or for assistance in obtaining, interpreting and analyzing species maps and strongholds rankings.

Applications of Audubon's Climate Science

Introduction

Audubon's climatic suitability maps and prioritizations were completed to inform conservation programs. Here, we present a set of examples demonstrating the application of Audubon's climate science.

Priority Species

Audubon's climate change sensitivity classifications suggest which species are most likely to be impacted by future climate. Lists of climate-threatened or endangered species can be compared or combined with existing priority species lists. Climate-endangered species need help where they are, whereas climate-threatened species need help where they are and with moving to new sites in the future. Either of these conditions can present a rationale for featuring a species as a priority species.

Figure 3.1. The Black Oystercatcher was selected as a climate priority species by Audubon California. Photo credit: Len Blumin.

Climate priority species can reinforce or complement existing programs as well as provide the basis for a new conservation campaign. When building a list of climate priority species, consider climate sensitivity along with other factors:

1. *Selecting species from diverse regional geographies/habitats,*

2. *Focusing on species featured in existing conservation programs,*

3. *Comparing species' climate sensitivity with their current conservation status,*

Once you have a list of climate-priority species, consider talking with other conservation groups and agencies in your geography to look for synergies or redundancies.

Important Bird Areas

Climate prioritizations are a useful conservation tool that can be combined with any spatial dataset to identify areas of high conservation value for birds today and into the future. The network of over 2,600 Important Bird Areas, identified across the United States for their significance to current bird populations, is one example. Important Bird Areas serve as the basis for many conservation efforts.

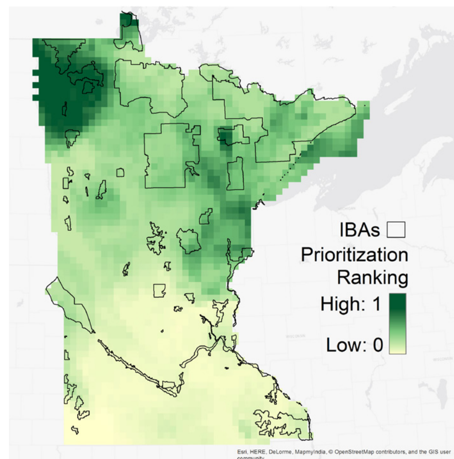


Figure 3.2. Important Bird Areas of Minnesota overlaid upon a climate prioritization of 314 climate-threatened and -endangered species.

By integrating climate prioritizations and Important Bird Areas, we can strengthen our understanding of this network. Climate prioritizations may contribute to the identification of new Important Bird Areas as well as the validation of existing sites. They can also be used to develop rankings of Important Bird Areas with respect to climate change for a particular state or geography of interest (Fig. 3.2). When considered along with information on opportunities, capacity, and conservation efforts underway, climate prioritizations may help further define where to work on conservation projects. Analyses integrating Important Bird Areas and climate prioritizations can inform efforts in policy, conservation planning, outreach, as well as volunteer engagement.

Climate Prioritizations and Land-Use

For most species, habitat loss to development has been the primary driver of population decline over the past century. Climate change presents an additional threat to many species, and it would be useful to identify areas where development threatens potential climate strongholds.

Projected future land-use change has been produced by the USGS EROS lab using the forecasting model FOR-SCE. For the example below, we use simulated future land-use under a high emissions scenario (A2) to estimate the development threat for each grid cell in the climate prioritization. We define threat as the simulated percent increase in developed land between 2005 and 2080.

For Texas, we then compare future development pressure against each grid cell's prioritization ranking to identify areas that may be suitable for conservation work. Texas has a broad range of climate prioritization rankings: highest along the Mexican border and Gulf Coast and lowest in the panhandle and northeast (Fig. 3.3).

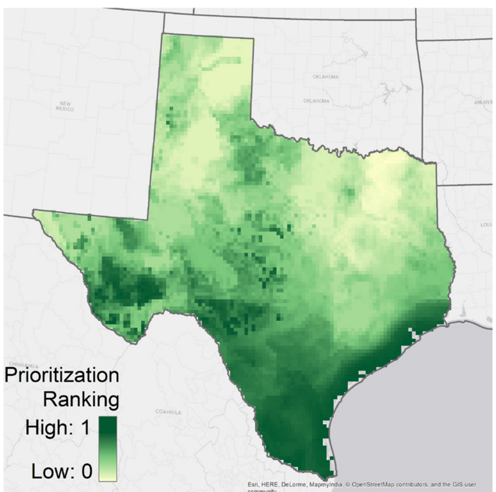
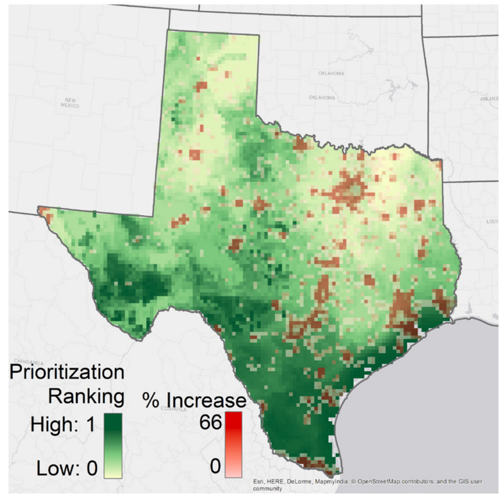


Figure 3.3. Climate prioritization rankings for Texas across all climate threatened and endangered species in the summer season.



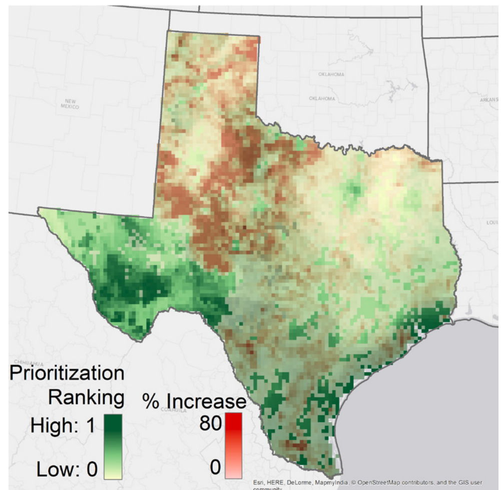


Figure 3.4. Percent increase in urban (top) and agricultural (bottom) development pressure overlaid on climate prioritization rankings.

Development pressure will be high (increases >50%) in some areas (Fig. 3.4), particularly around Dallas-Fort Worth and Houston (urban growth) and the Texas panhandle (agricultural expansion). High-ranking climate strongholds along the coast are most likely to be threatened by continued urbanization, whereas high-ranking sites in north-central Texas may be threatened by agriculture.

A conservation strategy based on this analysis might embrace one of two approaches (Fig. 3.5). First, conservation actions could focus on high-ranking climate strongholds with low development pressure, the so-called "low-hanging fruit". Second, conservation could focus on high-ranking areas with high likelihood for future development, the "biggest wins."

Conclusions

The previous three examples—priority species, working with Important Bird Areas, and evaluating climate strongholds against projected future land-use—are just a few of the possible applications of Audubon's climate science. One of the most exciting parts of the climate initiative is sharing this science across Audubon's network of state offices, chapters and centers as well as with external partners, all of whom will explore the data and devise unique solutions to conservation problems. If you have a novel idea, contact climatescience@audubon.org to talk it through and confirm that it represents an appropriate application of the science.

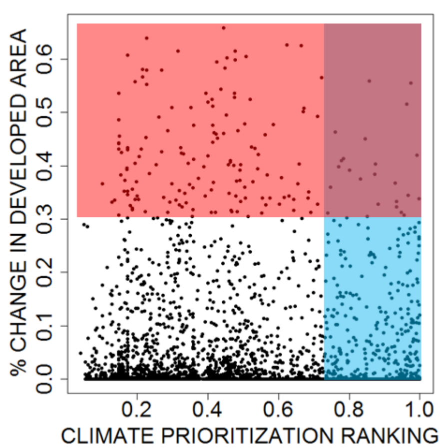


Figure 3.5. Alternative approaches toward setting conservation priorities incorporating both climate prioritization rankings and projected future development pressure. Areas in red have the greatest potential development pressure, whereas areas in blue are the highest-ranked climate strongholds. Purple areas are likely to be the hardest-fought conservation actions.

Contact climatescience@audubon.org for more information on Audubon's Birds and Climate Change report or for assistance in obtaining, interpreting and analyzing species maps and strongholds rankings.

PART IV:

Guidance on the Use and Interpretation of Audubon's Climate Maps

Introduction

Audubon recently released a series of maps showing the projected responses of birds in North America to future climate change. These maps look similar to range maps in a field guide, but they differ in important ways. Rather than showing the geographic limits of a species' distribution, these maps indicate climatic suitability for a species or group of species. Questions of interpretation are likely to arise for bird experts with detailed knowledge of bird distributions and conservation professionals interested in using the maps for decision-making. Here, we provide guidance on the use and interpretation of Audubon's climate science.

Creating the Maps

As described in Part I, Audubon scientists used computer modeling to relate historical bird observations from the Audubon Christmas Bird Count (CBC) and the North American Breeding Bird Survey (BBS) to a suite of climate variables. In essence, they built a climate profile of each species across a spectrum of temperature, precipitation, and seasonality variables. With sufficient geographic coverage and observations, models can describe the relationship between bird occurrences and the climate space that favors each species. This results in estimates of climatic suitability in summer and winter for each species for every 10 x 10 km grid cell across the continental United States and Canada (e.g. Fig. 4.1)

The key value of modeling the relationship between bird data and climate data is the ability to project that relationship onto a map of future climate. Collectively, this provides insight into of how each modeled species might respond to future climate with a sense of both the magnitude and location of these changes.

Interpretation of Maps

Within a climatic suitability map, the value of each grid cell is a probability of occurrence based on climatic suitability for the species. These can be converted into maps that look like traditional range maps in a number of ways. In a stretched color ramp, the strength of the color represents the probability values. In a binned color scheme, values are grouped and represented as solid colors or shades. Finally, a threshold can be chosen and the probability maps converted into binary presence/absence maps. The threshold is often chosen based on how accurately a model is able to discriminate between independent bird occurrence data not used in the modeling process (described below). Audubon scientists based this threshold on the kappa statistic.

Choosing whether to represent values as continuous (color ramp) or discrete (binned or presence/ absence) depends on the purpose of the map and aesthetics. Note that the maps can look quite different even though they are built from the same values (Fig. 4.2). If a map of current range looks off to an expert, some experimentation with binning values can often yield a map more consistent with expert opinion. All maps for that species should also be displayed in the same way, so that the whole set of maps for a season and species are comparable. This is important because we have no way to assess future maps for accuracy, and we must compare maps displaying the same thing.

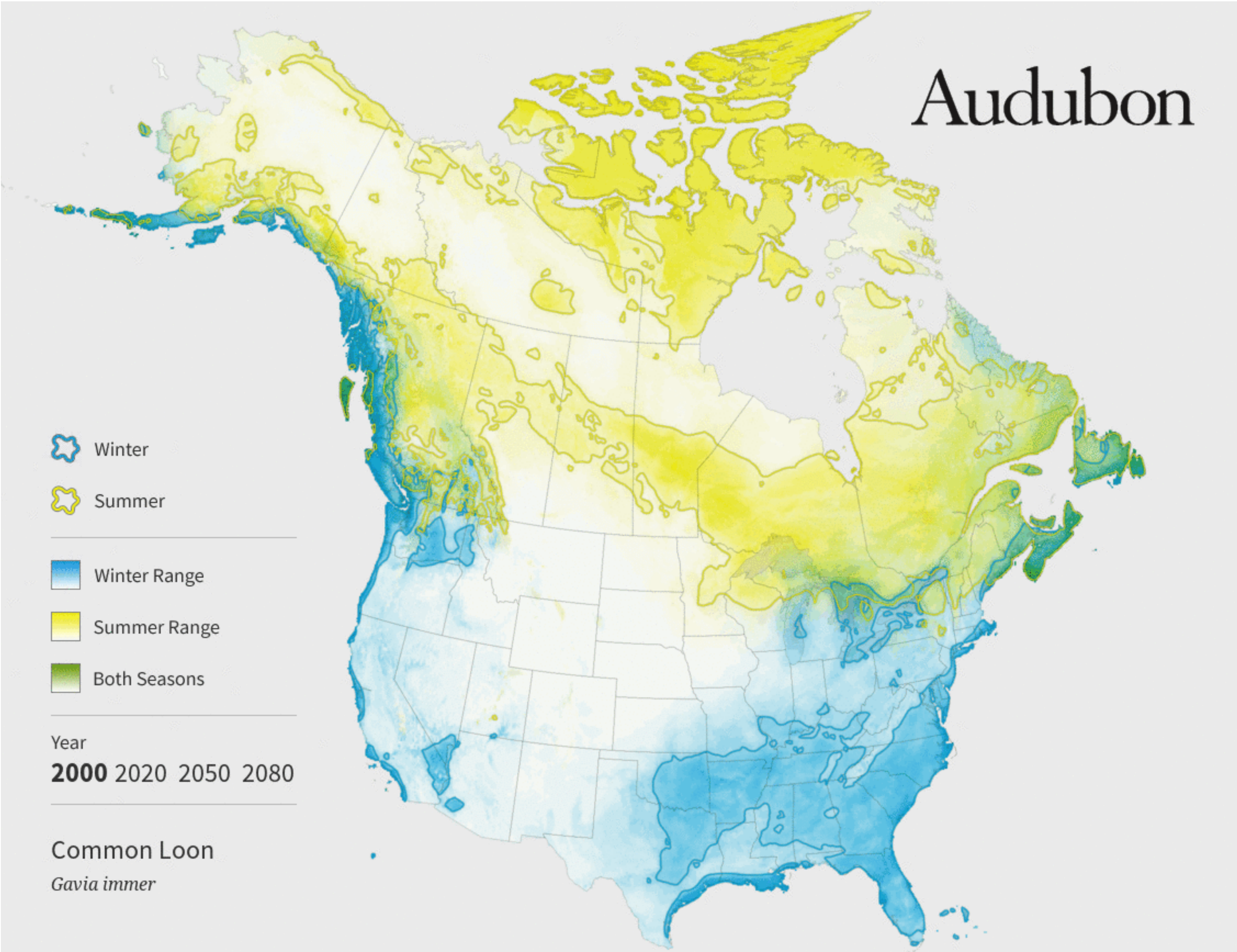


Figure 4.1. Modeled climatic suitability for Common Loon (year 2000).

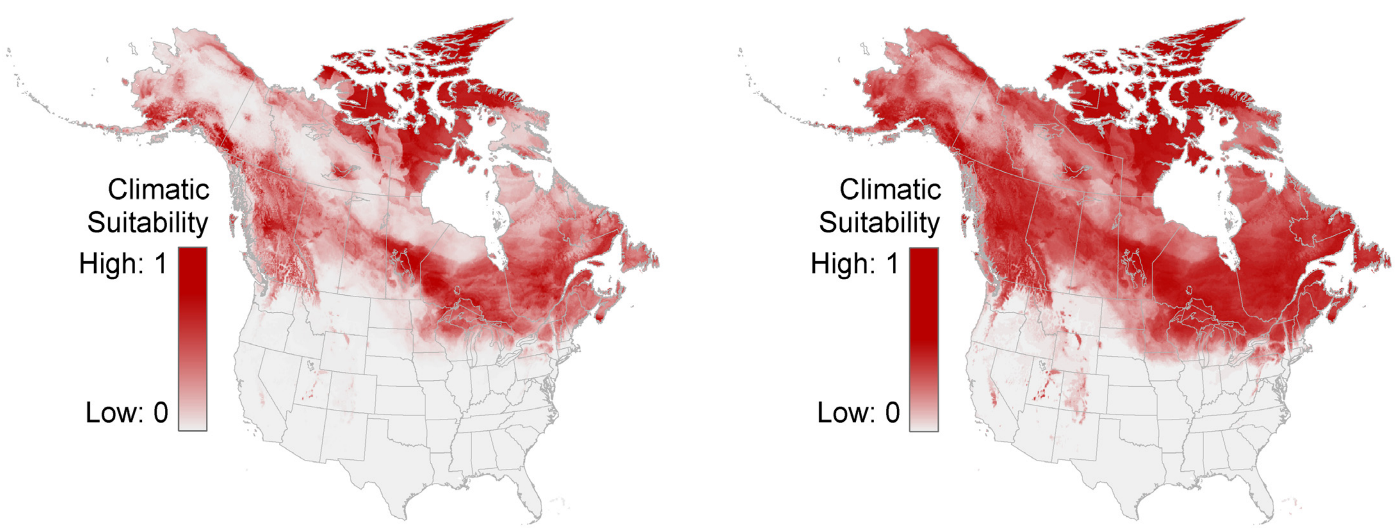


Figure 4.2. Two visualizations of Common Loon (*Gavia immer*) summer range using the same base data but varying color ramp scales: stretch by 2.5 standard deviations (left) and classified by geometric interval (right).

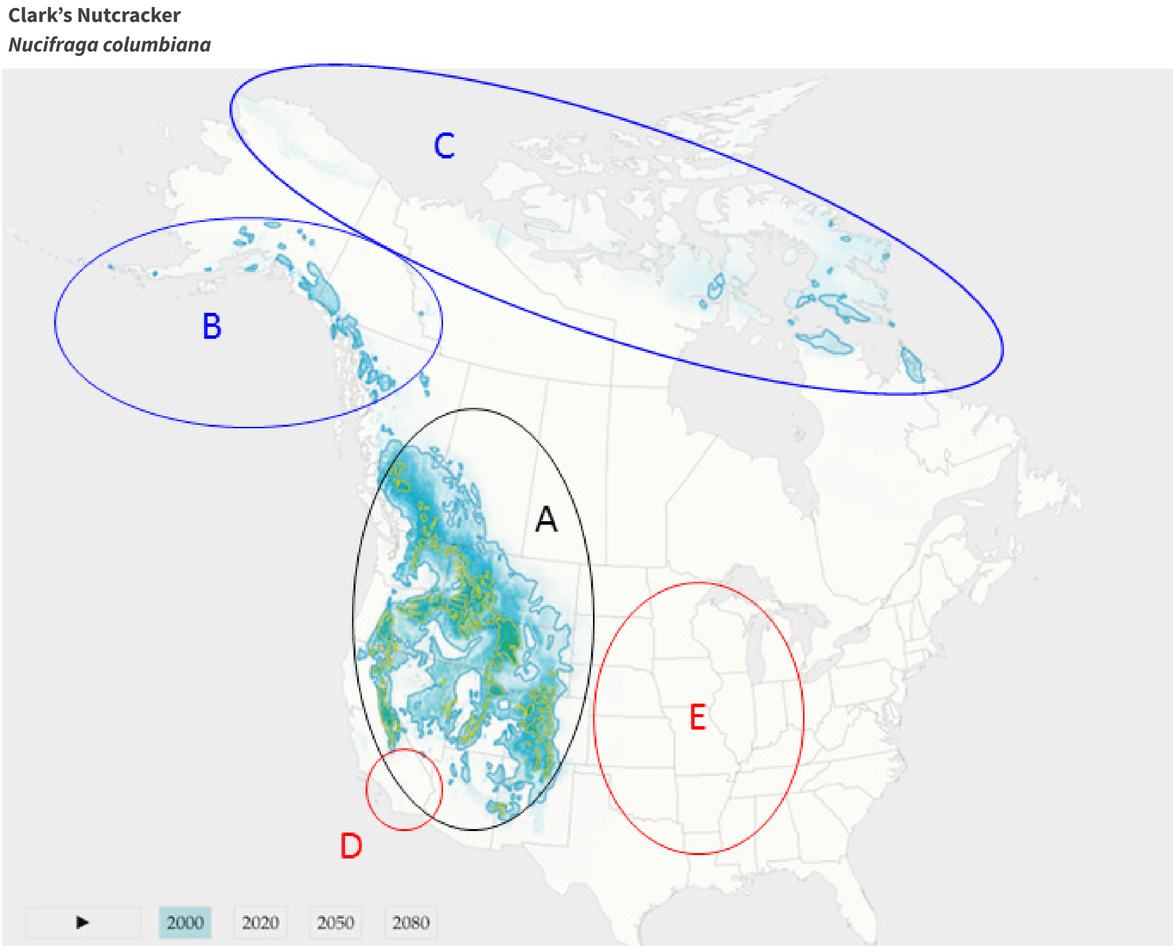


Figure 4.3. Example of climatic suitability map showing: (A) areas matching range maps, (B,C) areas that are climatically suitable but not part of the current range, and (D,E) areas that are part of the current range but not modeled as being climatically suitable.

Over- and Under-Prediction

All probabilistic maps have areas where they over-predict (errors of commission) and under-predict (errors of omission) the data. Over-prediction occurs where the projection shows a location is suitable, yet the species is not recorded there. These situations are challenging to interpret because the models only provide probabilities of occurrence based on climatic suitability. A species may not be present for biological reasons, such as interactions with other species (predation/competition), or limited dispersal. So, the result may be perfectly accurate and yet differ dramatically from a range map because the species cannot exploit certain parts of its climatic range (e.g., Fig. 4.3, B). Another common commission error comes from incomplete sampling of a species range. For example, the map below suggests that there are Clark's Nutcrackers in arctic Canada. This is likely untrue, but since there are no data points (CBC circles or BBS routes) in that area, the model building process was unable to properly characterize climatic suitability in the region (Fig. 4.3, C). This type of commission error occurs mostly in the Arctic. Under-predictions occurs where the projection shows a location as unsuitable, yet the species is known to occur there in large numbers. These errors are more serious than commission errors because they suggest that the models do not adequately sample climatic variables. Sampling problems are most likely the result of the data sources: the CBC and BBS. Although continental sampling for each survey is generally good, sampling is not uniform either spatially or temporally (Fig. 4.4).

For bioclimatic models, sampling a diversity of climates is more important than achieving uniform geographic sampling because large areas may have very similar climate and not require dense sampling. Therefore, low sampling density in northern Canada, for example, is likely to impact some species more than others. Extra care should be taken in interpreting results in areas of poor to no sampling and for species with large parts of range that are poorly sampled. Also, recall that species included in these analyses are limited to those observed in the CBC or BBS since 1950 and 1966, respectively, with sufficient

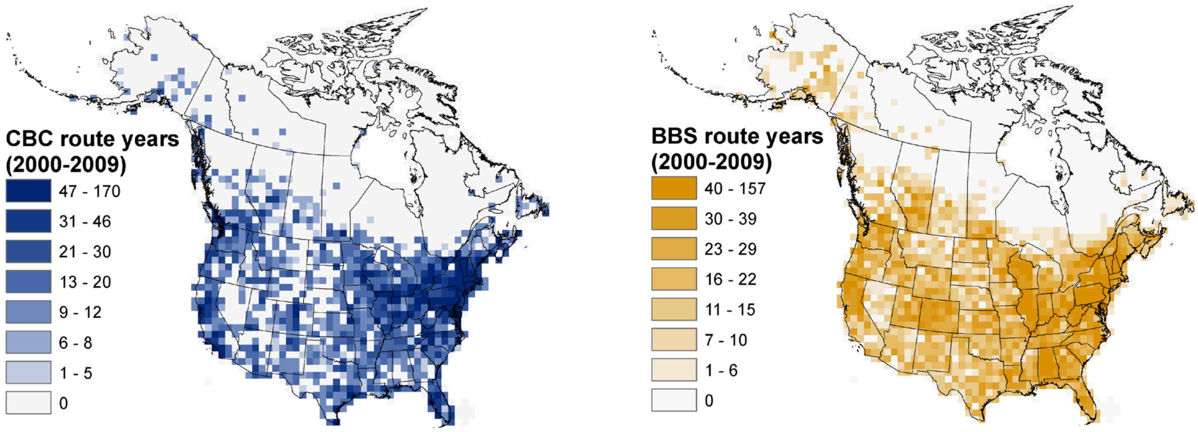


Figure 4.4. Sampling locations of the Audubon Christmas Bird Count (CBC) and North American Breeding Bird Survey (BBS) for years 2000-2009.

observations to construct a well-performing model (see Part I for further details).

Locations of sampling shown in the Fig. 4.4 are a reasonable proxy for the spatial limits of confidence in the data. In other words, there is reason to have lower confidence in areas with low sampling density.

What about Extinction?

Audubon's climate science does not specifically model the probability of species going extinct because the models do not estimate population size or persistence over time. Our classifications of climate-threatened and -endangered species refer to projected changes in the range of climatically suitable area across the United States and Canada. If the area of climatically suitable space is likely to shrink, this may contribute to population decline and eventual extinction, especially when combined with existing threats. For 10 species, projections suggest that their climatically suitable range disappears entirely under climate change. These are cases for which discussion of extinction risk is justified based on climate projections alone.

Extent

Due to limited data, modeled climatic suitability does not include Mexico. For species whose summer or winter ranges extend into northern Mexico, this is a deficiency because the statistical model is not based on the full breadth of the species' climatic range. The presence along the U.S.-Mexico border of climatic zones that extend into northern Mexico (e.g. Sonoran desert) minimizes this shortcoming for all but the most broadly distributed species. Furthermore, Audubon scientists incorporated this limitation into their climate prioritizations (Part II), which emphasize a species' current range and treat future projections as risks, opportunity, or as uninformative, depending on the biological response considered (See Part II for detailed methods). This approach generates prioritizations that identify areas suitable for a species today and in the future across a range of future time periods and scenarios for climate change.

Using Audubon Climate Maps for Conservation Decisions: Caveats and Limitations

Audubon climate maps can be a useful component of conservation planning. As with any conservation planning process, care should be taken to bring all relevant information together to inform the overall decision. As a standalone product, Audubon's climatic suitability maps are useful for identifying the climate sensitivity for each species and season modeled. They also provide predictions about the direction and magnitude of expected change across climate scenarios and timeframes. For on-the-ground conservation actions, this information is best summarized in climate prioritizations (Part II). And in decision-making, other sources of information should be included. For example, the maps do not explicitly include habitat or climate change impacts, such as sea level rise or land cover change.

Habitat

Audubon's climate science does not incorporate habitat directly in the model. The models link bird occurrences to climate variables to describe the climatic suitability of a given area. Projections of future suitability are for a given future time under a particular climate scenario. When we look at a range map in a field guide, we understand that areas within the range must have the right combination of factors on the ground, including habitat, for the bird to be present. Our climate maps should be interpreted similarly – the climatic conditions are favorable but all the other requirements must be in place too.

Note that while habitat is crucial for conservation, we should be mindful that every plant and animal is tuned to its climate. Biogeographers consider climate to be the biggest constraint on species distributions at broad (i.e. ecoregional) spatial scales. At sub-regional scales, habitat is most important, and a local scales species interactions dominate. Each of these aspects is important but they operate hierarchically. Therefore, climate remains a practical first filter for determining the suitability of a site.

Sea Level Rise

For coastal species, sea level rise caused by climate change will be crucial for conservation planning. Local impacts of sea level rise are challenging to calculate because tides, currents, land subsidence or uplifting, and other factors can dampen or amplify global averages. So, for a coastal conservation project, decision makers would want to consider focal bird species' response to climate change (e.g., Audubon climate prioritization maps) and sea level rise predictions in relation to existing and potential habitat. Lastly, considerations of land ownership and stewardship would help establish the potential for conservation efforts and provide estimates of returns on investment. Audubon climate maps are an important aspect of this process because they provide guidance on the likelihood of species colonization and persistence in the restored area.

Predation, Competition, and Dispersal

These factors are more difficult to assess, but will play a key role in shaping species responses to climate change. Just because an area is climatically suitable, has the appropriate habitat, and is free from sea level rise, does not mean that a species can successfully colonize it. Predators or competitors might prevent a species from getting established, or it might be unable to reach the area. Dispersal limitation is less likely to be important for birds than many other organisms, but is still a factor.

Migratory Species

Because the climate maps are derived from sources that do not sample during migratory periods (i.e., the CBC runs from Dec. 14 – Jan. 5 each year; the BBS from May – July), there is a reasonable chance that key stopover sites are not represented in the maps. For migratory species this should be taken into consideration during conservation planning. Species with distinct stopover sites, where large numbers of birds return to a small number of locations (e.g., shorebirds), can be accommodated by overlaying maps of these sites. For species with less distinct migration routes and places, conservation targets will be harder to identify.

The Audubon climate sensitivity categories (climate endangered, threatened, and stable) are based on the seasons modeled. So, for Neotropical migrants the winter season is missing from the assessment. Thus, these species could be facing larger threats from climate change than suggested by their classification. Neotropical migrants that are listed as climate stable — or any species with only one season modeled — should be interpreted with caution. Their climate sensitivity in the unmodeled season is unknown.

Suggestions for Further Reading

Araújo, M.B. and A.T. Peterson. 2012. Uses and misuses of bioclimatic envelope modeling. Ecology, 93(7): 1527–1539.

Elith, J., and J. R. Leathwick. 2009. Species distribution models: ecological explanation versus prediction across space and time. Annual Review of Ecology, Evolution, and Systematics 40:677–697.

Pearson, R. and T.P. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology & Biogeography 12: 361-371.

Contact climatescience@audubon.org for more information on Audubon's Birds and Climate Change report or for assistance in obtaining, interpreting and analyzing species maps and strongholds rankings.

PART V:

Expanded Methods for Audubon's Climate Science[1]

The Importance of Scale

It is widely recognized that species distributions are influenced by a variety of biotic and abiotic factors, including habitat availability, resource availability, species interactions, and physiology. However, the respective influences of these factors are highly dependent on the spatial and temporal scales of analysis. One of the major challenges for understanding the effects of climate change on species distributions lies in identifying the appropriate spatiotemporal scales at which species distributions can and cannot be reliably predicted from a mechanistic knowledge of climate dependence. As a first approximation, species distributions considered at small scales tend to be mostly influenced by biotic interactions, mid scales by habitat and resource availability, and large scales by climate, putatively through interactions with the physiological limits of the organism.

Here, we use correlative models to predict the geographic responses of the North American avifauna to changes in climate. We intentionally focus on a large geographic extent to approximate the spatial scale at which many bird distributions are proximately shaped by climate, and a 10 x 10 km resolution to approximate the resolution of our survey data. However, non-modeled factors such as habitat dependencies, biotic interactions, and dispersal limitations may in some cases prove highly important even at this coarse scale. Because it is impossible to incorporate all of these "non-climatic" variables into an analysis, the correlative distribution models presented here are best described as capturing the bioclimatic envelope of each species.

Use of bioclimatic envelope models to forecast a future distribution has been criticized for making overly simplified assumptions about dispersal and biotic interactions. However, these issues become more of a concern if we are intending to predict actual species distributions, rather than the distribution potential of species. In this sense, these climate models should be seen as delineating areas where a species could occur in the future if other variables necessary for the survival of the species such as suitable habitats and biotic interactions are present, and dispersal is non-limiting. Recent studies testing the performance of mechanistic models that explicitly incorporate hypothetical biological processes against correlative bioclimatic models, conclude that bioclimatic models performed as well as mechanistic models for estimating current distributions, but showed varying results when predicted to future climate spaces.

Given the challenges of collecting the species-specific physiological data necessary for mechanistic niche modeling, it is not primarily intended for use in forecasting, but rather provides a framework for understanding how species respond to particular climatic gradients. Bioclimatic models remain the most widely used method to project impacts of climate change on species distributions; and when applied at the macro scale, are suitable for making broad predictions to inform conservation planning. Hence, the models in this study are not intended to provide a passive answer to the question of how bird species will respond to future climate change. They are instead meant to identify conservation opportunities that can only be realized if we proactively plan for changes in climate and biological responses.

Climate Change Models and Uncertainty

Predictions about the future require the development of models, and all models entail uncertainty. In the case of climate change, our best hope for making sound conservation decisions is to account for uncertainty to the degree possible. There are three major sources of uncertainty to consider when forecasting species responses to climate change: future climate uncertainty, modeling uncertainty, and biological uncertainty. In this analysis, we have gone to great lengths to understand all three sources of uncertainty. We base our methods on recent work showing that with a thorough treatment of algorithmic uncertainties and ensemble forecasting, correlative distribution modeling is a valuable tool for forecasting continental scale impacts of climate change for a large number of species.

Future climate uncertainty is obvious: we don't yet know how much climate will change in the future and at what rate, because human behaviors that influence emissions are difficult to anticipate, as are the influence of emissions on climate. To deal with this uncertainty, we base our analyses on a suite of possible emissions scenarios and General Circulation Models (GCMs) for which we had reasonable access to climate data layers for North America (Appendix B). We ensemble predictions using consensus

[1] *Excerpted from National Audubon Society. 2013. Developing a Management Model of the Effects of Future Climate Change on Species: A Tool for the Landscape Conservation Cooperatives. Unpublished report prepared for the U.S. Fish and Wildlife Service.*

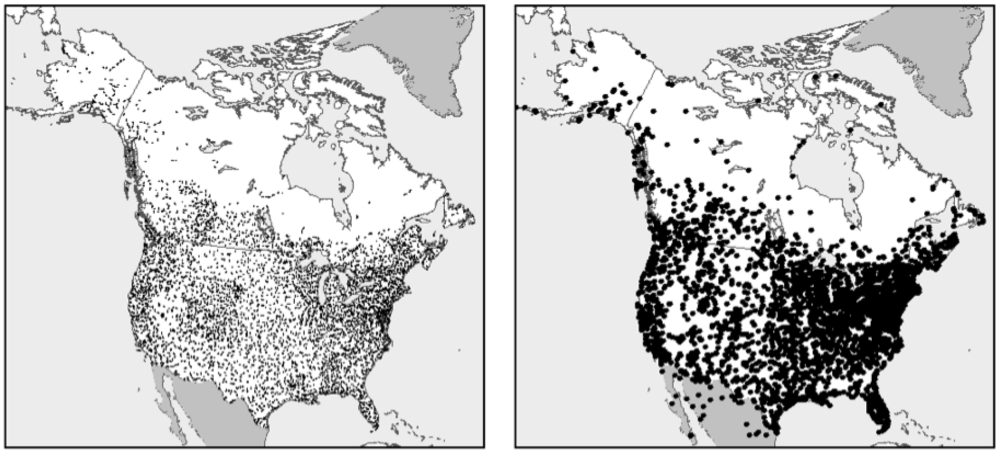


Figure 5.1. Distribution of Audubon Christmas Bird Count circles and North American Breeding Bird Survey routes (2000–2009).

forecasting to explore how biological outcomes might be affected by human action to reduce climate change impacts through reduced emissions. Consensus forecasting is one form of ensemble modeling that uses the central tendency (e.g. mean or median value) from a set of possible models. The rationale behind consensus forecasting is that the 'signal' one is interested in emerges from the 'noise' associated with individual model errors and uncertainties. Some conservation leaders will be uncomfortable making decisions based on models. It is worth noting, however, that assuming species will not shift their distributions in response to climate change is also a model of the future. This status quo model has all the same uncertainties associated with change models, except that there is no formal attempt to bracket or measure the uncertainty. A status quo model may, in fact, be the riskiest approach of all.

Modeling uncertainty stems from the quality of the data used to develop the model as well as the limits of the modeling technique. Data quality is tied to both the validity and spatial scale of the geographic coordinate data used to formulate the model. Ideally, models constructed from the relationship between current climate and species occurrence should be validated using independent data from other time periods to assess their predictive ability. Such validation provides users with a sense of how well the models can correctly predict known presences within different times and climate spaces. Previous studies that have tested for past changes in species distributions using bioclimatic envelope models provide a valuable validation of their use in studies of the potential impacts of future climatic changes. Modeling uncertainty is further propagated by the fact that different modeling techniques often yield different predictions. To deal with this, we used three different modeling methods that fit complex non-linear relationships between species occurrence data and environmental data. We then validated each of the models with independent data from historical time periods, compared their predictive ability, and chose the one that performed the best overall.

Biological uncertainty means that we are not sure if a species can persist, or colonize newly suitable areas, under future climate change. Much of the last 100 years of ecology has dealt with understanding how populations and species persist: birth rates, death rates, immigration, emigration, competition, foraging, lifespan, et cetera. These key biological factors are challenging to measure and each estimate has sources of uncertainty, too. Our models do not incorporate any of these measures directly, but we can still consider them post hoc when issuing conservation recommendations. Here, biological uncertainty is minimized through a spatial prioritization process bases on multiple biological responses and subsequent identification of climate strongholds—areas climatically suitable today and in the future accounting for both future climate uncertainty, modeling uncertainty, and biological uncertainty.

Bird data

Bird distribution data were obtained from two sources: the Audubon Christmas Bird Count (CBC) and the North American Breeding Bird Survey (BBS). Audubon Christmas Bird Counts began in 1900 as an alternative to the Christmas "side hunt" and have been used to document early winter bird assemblages across North America, and beyond. CBC surveys are conducted by citizen scientists within 24.1 km diameter circles for one 24 h period during a two-week interval, centered on December 25. For this study, all circles located in Canada and the United States were included (Fig. 5.1). We elected not to include data from other areas due to relatively incomplete geographic sampling and poor spatio-temporal resolution of climate data.

For every circle and count year, we translated raw count data into presence/absence information for each species to reflect whether or not it was detected.

The Breeding Bird Survey was initiated in 1966 for the purpose of monitoring bird populations in the summer months (USGS Patuxent Wildlife Research Center). Most BBS routes in the United States and Canada are surveyed in June but some are run as early as May and others extend as late as mid-July. Survey routes are 24.5 miles long with stops at 0.5-mile intervals. At each stop, participants conduct a 3-minute point count and record birds seen or heard. We used data for the first 30 stops (~24 km) for our analyses in an effort to balance the geographic scales at which CBC and BBS sample the landscape and maintain a reasonable match to the resolution of our climate data (10 x 10 CBC circles BBS routes 5 km). Again, we only used data for the United States and Canada and, for every route and year; we translated raw count data into presence/absence information for each species.

Climate data

We obtained contemporary climate data from the Canadian Forest Service (CFS) website for the mid-point of each CBC circle and to the start-point of each BBS route. The CFS has produced a set of high resolution (10 km), yearly contemporary (1950 – 2010) climate datasets for Canada and the United States based on thin plate smoothing algorithms. We matched bird data and climate data on an annual basis (i.e., for CBC count year x and BBS survey year x, we used climate data from year x-1), assuming that climate variables from the year leading up to each survey would best inform our understanding of occurrence data. For instance, climate data for the year prior to a CBC survey event would actually include monthly climate data from that winter's survey because each CBC survey date is considered as of the 1st of January following the December counts (i.e., survey data from 2000 spans December 1999–January 2000). This is important since our climate parameters include indices of minimum and maximum monthly temperatures and precipitation (Appendix A), as well as mean variables. Similarly, climate data from the prior year matched to BBS survey events would encompass the winter climate preceding the summer (breeding) season.

Spatially downscaled (5-min resolution) climate grids for 2010-2039, 2040-2069, and 2070-2099 were obtained from the International Center for Tropical Agriculture (CIAT) for 13 combinations of emissions scenarios and General Circulation Models (GCMs, Appendix B). These grids used historical climate data from WorldClim, which differs from our CFS historical dataset. Therefore, we calculated projected future climate anomalies for each model and scenario by subtracting contemporary WorldClim grids for monthly minimum temperature, maximum temperature, and precipitation from the CIAT future grids and added these monthly anomaly grids to CFS mean climate grids for the base period (1971–2000). Emissions scenarios are described in the IPCC Special Report on Emissions Scenarios and are grouped into families (e.g., A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces on greenhouse gas emissions (Fig. 5.2). As described by the IPCC (2007), the B2 scenario is a relatively "low" emissions trajectory that emphasizes clean and sustainable technology. In contrast, the A1B scenario is a relatively "middle-of-the-road" emissions scenario where technological change is balanced across fossil and non-fossil energy sources. Finally, the A2 scenario represents a relatively "high" emissions pathway characterized by fragmented technological and economic growth. General Circulation Models (GCMs) are numerical models that represent physical processes in the atmosphere, ocean, cryosphere and land surface used to simulate the response of the global climate system to increasing greenhouse gas concentrations. Future climate predictions can be derived by combining emissions scenarios and GCMs (Fig. 5.3).

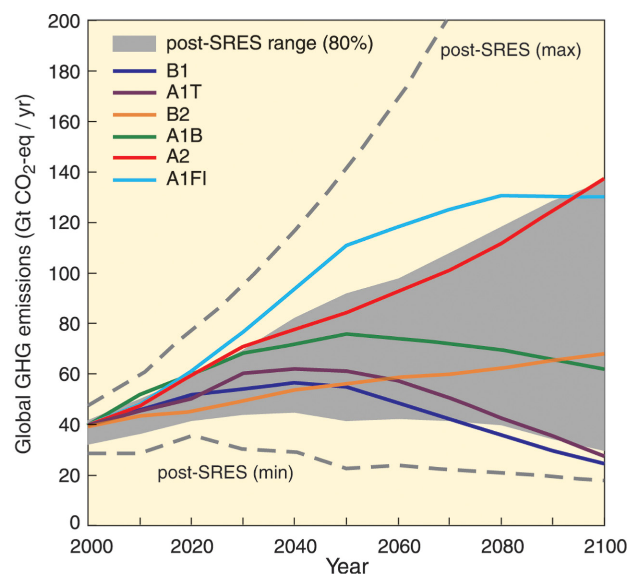


Figure 5.2. Global emissions scenarios for the 21st Century. The present study considers three scenarios: B2, A1B, and A2. Source: Figure SPM.5 IPCC WG1 2007.

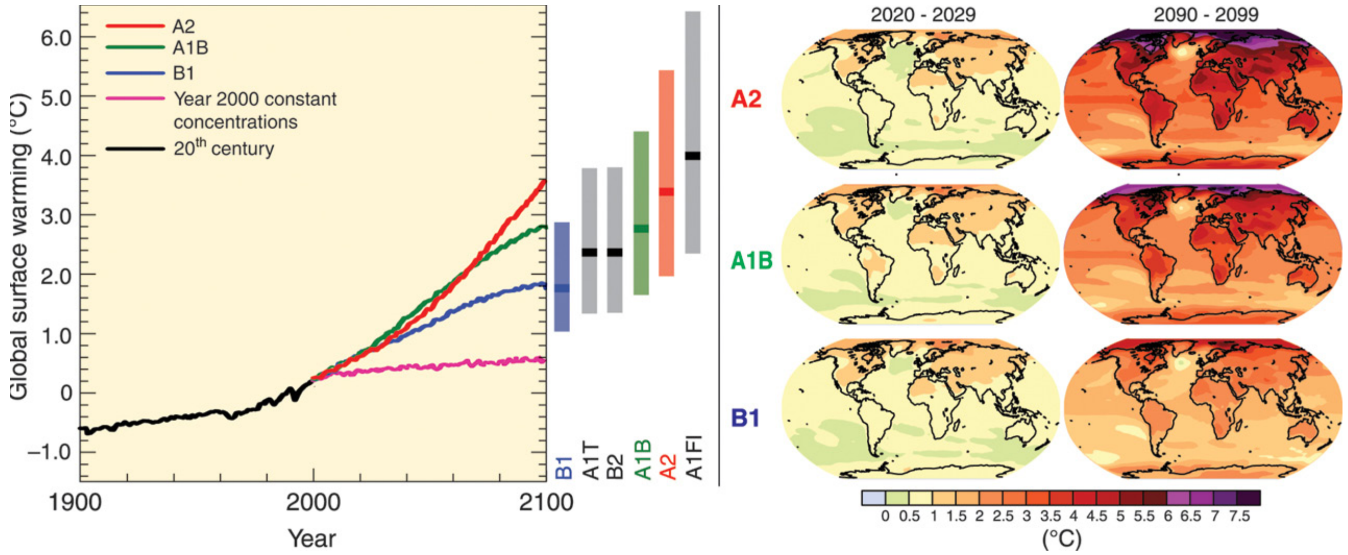


Fig. 5.3. Predicted global surface warming by year and emissions scenario. Source: Figure SPM.5 IPCC WG1 2007.

After creating our future climate grids, we transformed raw temperature and precipitation data into a series of bioclimatic variables (Appendix A). Bioclimatic variables are thought to represent more biologically meaningful combinations of the original monthly climate variables because they aggregate climate information in ways known to drive biological processes.

Bioclimatic Models

Bioclimatic models are formulated by using a modeling algorithm to describe relationships between geographically coincident environmental variables and bird occurrence data (Figure 5.4a). While the models are simply a mathematical description of climate-bird relationships (Figure 5.4b), they can be projected into spatially organized, gridded climate data. The resulting predictive distribution maps describe geographic areas that are expected to be climatically suitable for a species (Figure 5.4c). Climatic suitability maps can be made for the same time and place from which the data were collected, or, alternatively, they can be projected to different times or places so long as information is available to generate bioclimatic variables used in the model.

We built separate bioclimatic models for winter and summer seasons using CBC and BBS data, respectively. For CBC analyses, we included as predictor variables the 17 bioclimatic variables in addition to the number of survey hours invested in each CBC circle to account for uneven observer effort across circles. Survey hours accounts for variation in both the number of participants and the duration of counts. We used 19272 records collected at 2278 circles from 2000–2009 to train our models and 30630 records collected from 1980–1999 to assess the predictive ability of our models. This approach allowed us to take advantage of increasing numbers of CBC circles and BBS routes in recent years to build models as well as availability of abundant historical data to assess the predictive ability of our models with a temporally independent dataset. We had sufficient data to construct models for 543 species of wintering birds, representing 90% of the species with at least one count in a CBC circle for the period 1950–2010. In an effort to assess the predictive ability of our models to earlier time periods we also validated models using CBC data from 1956–1965. This reduced our sample size from 543 species to 440 species.

Our analysis of BBS data was similar in approach with small adjustments to account for differences in data sets and survey protocols. Instead of survey effort, which varied in the CBC, but was constant in the BBS, we used Julian date to account for when the survey was completed in the summer months. We felt this was important because species occurrences and detection probabilities may have been associated with the timing of BBS surveys. For example, surveys that take place later in the summer season may miss bird species that have completed their breeding season and become less conspicuous or departed for their wintering grounds. We used 25081 records collected along 3718 routes from 2000–2009 to train our models and 41959 records collected from 1980–1999 to test the predictive performance of our models. We had sufficient data to construct models for 508 species that occur in the United States and Canada during the summer representing 73% of the species identified at any time in a BBS survey since its inception in 1966. Again we assessed the predictive ability of our models using earlier survey time periods (1966–1975), but this reduced our sample size considerably from 508 species to 403 species.

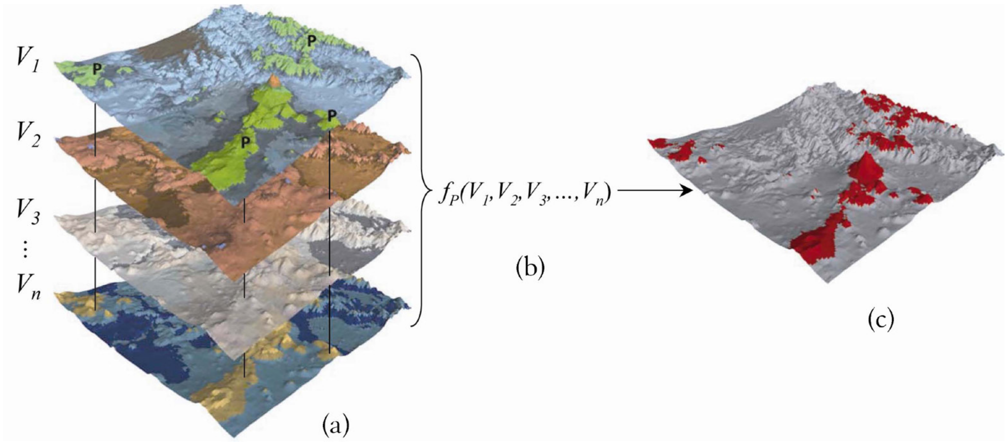


Figure Fig. 5.4a, Fig. 5.4b, and Fig. 5.4c. Correlative distribution modeling. Models combine species data (P) and bioclimatic variables (V1, V2, V3, …, Vn) (a) to formulate a mathematical model (f) (b). The model may then be projected back into geographic space to generate a predictive distribution map (c).

Results were comparable between the two historical time periods for both the CBC and BBS datasets, so we restrict our presentation of validation results, graphs and figures within the body of this report to those from the 1980-1999 time period.

Modeling algorithms

To explicitly address aspects of modeling uncertainty, we used three different modeling algorithms to describe relationships between bioclimatic variables and winter bird occurrence data: boosted regression trees (BRT), maximum entropy (MAX), and generalized additive modeling (GAM). We evaluated model performance by backcasting models to historical climates and assessing how well predictions matched historical observations using Receiver Operating Characteristic (ROC) curves. Area Under the Curve (AUC) scores were used as a metric of performance that characterizes each model's ability to discriminate between presence points and absence points in the historical data (Fig. 5.5). High AUC scores indicate that a model very efficiently differentiates true presences from false presences as the discrimination threshold is varied. Low AUC scores indicate that the model does a poor job of distinguishing true presences from false presences across a wide range of discrimination thresholds. We then compared the predictive performance of all pairwise combinations of species' models to test for statistical significance. The predictive performance of BRT models proved as good as, or better than, GAM or MAX models for 512 of 543 wintering species. GAM or MAX models performed significantly better than BRT models for only 31 species (Fig. 5.5). Given these results, we decided to use BRTs alone to model summer distributions.

BRT models combine two modeling algorithms to fit relationships between predictors and a response variable: regression trees and boosting. Regression trees define relationships between predictors and response through recursive binary splits that act to serially reduce unexplained deviance. Boosting algorithms aim to improve predictive performance of any single model by incorporating information from a multitude of simple models. Resulting models are able to fit complex non-linear relationships in large datasets, are relatively insensitive to outliers, and handle interactions between predictors automatically. By partitioning data into subsets, or folds, and training models on those subsets, BRTs are also able to reduce the risks associated with overfitting data.

We built BRT models based on techniques outlined in Elith et al. (2008) using the following parameters: 1) learning rate = 0.01, 2) tree complexity = 5, 3) family = Bernoulli. These settings resulted in models built with an average of 3100 and 2800 trees for winter and summer species, respectively, well above the suggested 1000 trees. Although BRT models are complex, their predictive performance is superior to most traditional modeling methods and their results can be summarized to give valuable ecological insight into the relationships between independent variables and the response.

Predicting distributions and characterizing ranges

To predict the current distribution of species, we projected species bioclimatic models built with BRTs into a climate surface composed of bioclimatic variables averaged from 1999–2008, the same period used to construct the models.

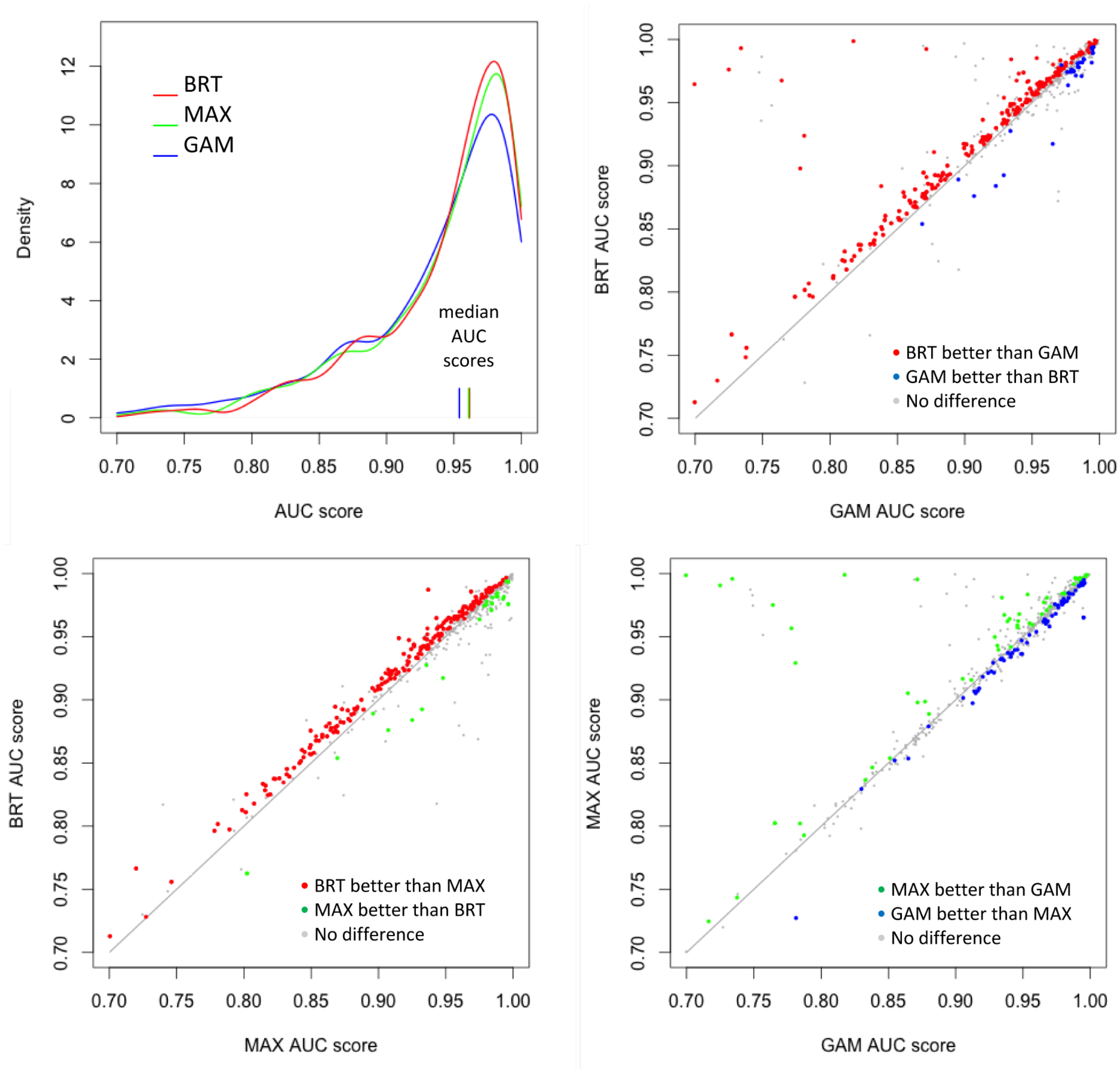


Figure 5.5. Density distribution of AUC scores for three modeling algorithms and pairwise evaluation of performance. Each point represents a species. Red points = BRT performance significantly better than alternative algorithm; blue points = GAM performance significantly better than alternative algorithm; green points = MAX performance significantly better than alternative algorithm; gray points = models do not differ significantly in predictive performance. The solid line has intercept = 0, slope = 1.

We also projected using our models into each of 39 future climate surfaces (i.e., 13 combinations of emissions scenarios and GCMs in each of 3 future time periods) and then averaged across GCMs within each combination of emissions scenario and time period (e.g. consensus forecasting). This process resulted in 9 future prediction grids for each species, one for each emissions scenario (B2, A1B, A2) in each time period (2020, 2050, 2080).

For each species, our prediction grids describe climatic suitability of the United States and Canada on a continuous scale from 0 (unsuitable) to 1 (highly suitable). In order to characterize species ranges as defined areas of presence or absence, we converted our continuous prediction grids to binary grids using a threshold value based on the maximum Kappa statistic. The Kappa statistic measures the proportion of correctly predicted sites after the probability of chance agreement has been removed. Suitability values below the threshold were considered climatically unsuitable while values above the threshold indicated that an area was suitable. The Kappa statistic provided a conservative estimate of ranges compared to alternative thresholds. Since many of our analyses required estimates of range size or refugia size, we applied a North American Albers Equal-Area Conic projection to each prediction grid before estimating areas.

Glossary of Terms

Breeding Bird Survey (BBS)
The BBS is a long-term, large-scale, international avian monitoring program initiated in 1966 to track the status and trends of North American bird populations. The USGS Patuxent Wildlife Research Center and the Canadian Wildlife Service, National Wildlife Research Center jointly coordinate the BBS program.

bioclimatic model (Also referred to as climate envelope model and species distribution model, this is a statistical)
Statistical model that characterizes relationships between climate data and a species presence or absence. We built models using measures of climate as the predictor variables and presence/absence based on CBC or BBS data as the response.

biological response
How a species may respond to a changing climate depends upon its ability to colonize new areas and the overall flexibility of its climatic niche (Fig. 3.1). We identify three possible responses: "suffer in place," "track and move," and "adapt in place."

Christmas Bird Count (CBC)
The CBC is a long-standing program of the National Audubon Society, with over 100 years of citizen science involvement. It is an early-winter bird census in which thousands of volunteers across the U.S., Canada, and many other countries in the Western Hemisphere, go out over 24-hour periods to count birds.

climate change mitigation
Reductions in greenhouse gas emissions through clean energy policies and carbon sequestration.

climate change adaptation
Efforts to lower the risks associated with climate change, such as preparing species and ecosystems for disruptions that accompany a changing climate.

climate sensitivity
A classification of species based on the projected impacts of climate change on their current and future range. Audubon classified species as climate endangered, climate threatened, data deficient, or climate stable (Table 1.1).

climatic suitability
Output of a bioclimatic model reflecting the probability that a species is found in a location based on its associated climate. Areas of higher climatic suitability are more likely to be occupied by a species.

climate stronghold
An area that is relatively valuable for retaining one or more bird species while accounting for the potential effects of future climates on their distribution. The concept of a climate stronghold is useful for developing long-term conservation plans at a variety of spatial scales. Because Audubon's spatial prioritizations describe the relative value of every grid cell on the landscape, users can compare the value of grid cell across any geography of interest to them. For example, users can identify the top 10% of ranked grid cell within a state and use that information to guide decision-making within their state, even though there may be relatively more valuable areas in different parts of the continent.

emissions scenario
A possible future trajectory for greenhouse gas emissions in the 21st century. Scenarios reflect assumptions about the pace and distribution of global economic development. Audubon has used emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4).

ensemble prioritization
A combination of spatial prioritizations in which the maximum rank for each grid cell is taken across prioritizations and then the grid cell are re-ranked between 0 and 1. The "hedge your bets" spatial prioritization is an ensemble prioritization as are those combining summer and winter seasons.

general circulation models (GCMs)
Complex models that simulate the physical processes of climate. Models used here are coupled atmosphere-ocean general circulation models. The complexity of the models derives from the physical equations used to calculate the movement of mass, momentum, and energy through the climate system. The greenhouse effect is an emergent property of this system. GCMs are run assuming different greenhouse gas emissions scenarios.

Glossary of Terms

grid cell
Finest unit of spatial analysis. In this case, the U.S. and Canada were divided into a regular grid of approximately 10 x 10 km grid cell.

kappa range
Representation of a species range based on a bioclimatic model. Application of a kappa threshold allows conversion of a continuous climatic suitability map into a binary presence/absence range map by balancing the omission and commission errors.

over-projection (commission error)
Areas predicted to be suitable by a model, but where the species is not actually found (false positive).

spatial prioritization
An assignment of value to different parts of the landscape according to a conservation goal. The primary goal of Audubon's spatial prioritization work is to highlight locations across the United States and Canada that are best able to retain birds while accounting for future uncertainties associated with climate change. Audubon's single-species spatial prioritizations rank areas highly if they are likely to be climatically suitable today and in the future for an individual species. Multi-species prioritizations rank areas highly if they are likely to preserve the diversity of a species assemblage today and in the future.

under-projection (omission error)
Areas predicted to be unsuitable by a model, but where the species is found (false negative).

APPENDIX A

Bioclimatic variables used to model bird distributions

BIOCLIMATIC VARIABLES

Annual Mean Temperature (°C)
Mean Diurnal Range (Mean of monthly [maximum temperature - minimum temperature]) (°C)
Isothermality (Mean Diurnal Temperature Range/Temperature Annual Range)
Maximum Temperature of Warmest Month (°C)
Minimum Temperature of Coldest Month (°C)
Temperature Annual Range (°C)
Mean Temperature of Wettest Quarter (°C)
Mean Temperature of Driest Quarter (°C)
Mean Temperature of Warmest Quarter (°C)
Mean Temperature of Coldest Quarter (°C)
Annual Precipitation (mm)
Precipitation of Wettest Month (mm)
Precipitation of Driest Month (mm)
Precipitation of Wettest Quarter (mm)
Precipitation of Driest Quarter (mm)
Precipitation of Warmest Quarter (mm)
Precipitation of Coldest Quarter (mm)

APPENDIX B

Sources of future climate data

CLIMATE CENTER	GCM	B2 SCENARIO	A1B SCENARIO	A2 SCENARIO
Canadian Center for Climate Modeling and Analysis	CCCMA-CGCM3.1		X	
Canadian Center for Climate Modeling and Analysis	CCCMA-CGCM3.0			X
Commonwealth Scientific and Industrial Research Organisation	CSIRO-Mk3.0		X	X
Institut Pierre-Simon Laplace	IPSL-CM4		X	
Max Planck Institute for Meteorology	MPI-ECHAM5		X	
National Center for Atmospheric Research	NCAR-CCSM3.0		X	
Hadley Center for Climate Prediction and Research	HCCPR-HADCM3	X	X	X
Hadley Center for Climate Prediction and Research	HCCPR-HADGEM1		X	
National Institute for Environmental Studies	NIES	X		X

APPENDIX C

Flowchart for working with climate science data products

STEP 1: IS CLIMATE SCIENCE RELEVANT TO MY CONSERVATION PROBLEM?

- *Do you work in an area with sufficient BBS or CBC survey coverage?*
- *Is your problem forward-thinking?*
- *Is the scale such that 10-km resolution projections would be meaningful?*
- *Is climate likely a driver in your system?*

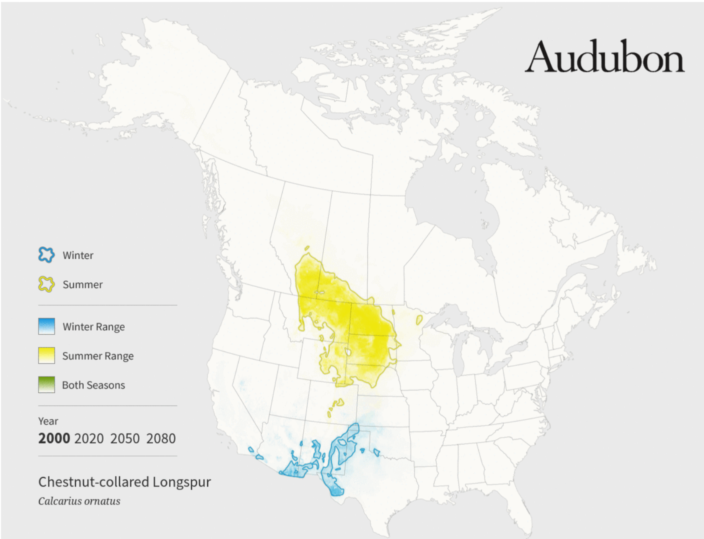
CONTINUE IF YOU ANSWER YES TO ALL OF THE ABOVE

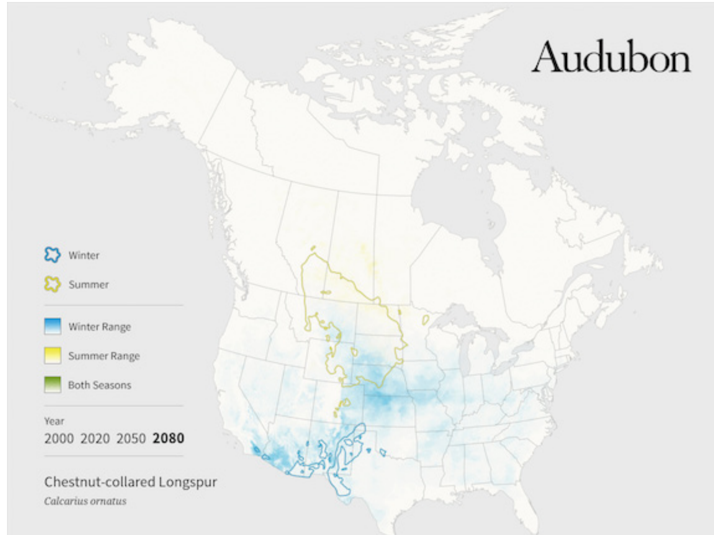
STEP 2: WHICH PRODUCT SHOULD I USE?

STEP 3: WHAT PRODUCT-SPECIFIC DECISIONS ARE REQUIRED?

STEP 2: Which product should I use?	STEP 3: What product-specific decisions are required?
Climate Sensitivity Lists suitable for identifying climate priority bird species.	*What is your priority?* Identifies climate endangered, threatened, data deficient, or stable species
Individual Species Projections suitable for public outreach and detailed single-species analyses. Available on the web and with ArcGIS desktop.	Website visualizations available for viewing/sharing. Further analyses requires the user to select relevant species, emissions scenarios, and future time periods of interest
Climate Prioritizations suitable if you already have a target species or list of species. Ranks landscape's climate suitability for present and future.	**Single-species Prioritizations** for priority species projects **Multi-species Prioritizations** preferred when working with three or more species. Contact climatescience@audubon.org to generate one unique to your needs

APPENDIX D
FAQ for Audubon's climatic suitability maps





What do the maps show?
These maps show modeled climatic suitability for the Chestnut-collared Longspur in the summer and winter seasons. These are range maps based only on climate.

What are the solid lines?
The solid lines delineate the core climatically suitable range for the species based on current climate.

What is the difference between light and dark areas?
Darker colored areas are more climatically suitable, meaning there is a higher probability that the species is found there.

Is the model wrong because it leaves out an area in west Texas where longspurs winter?
The model may omit a region (or add a region) because the species may be responding to some factor other than climate (e.g. vegetation, habitat, management) that is not included in the model. Or, the model may not have sufficient data for the area in question.

How is this species impacted by climate change?
By late in the century, the longspur's climatically suitable range in summer is greatly reduced and shifts to the northeast. Its climatically suitable range in the winter is shifted and potentially expanded.

Do these maps suggest the longspur go extinct due to climate change?
The diminished future summer range suggests the longspur may run out of suitable places to live in the future. This could lead to severe population decline and eventual extinction if the species cannot adapt to new climatic conditions.

APPENDIX E

FAQ for Audubon's climate prioritizations

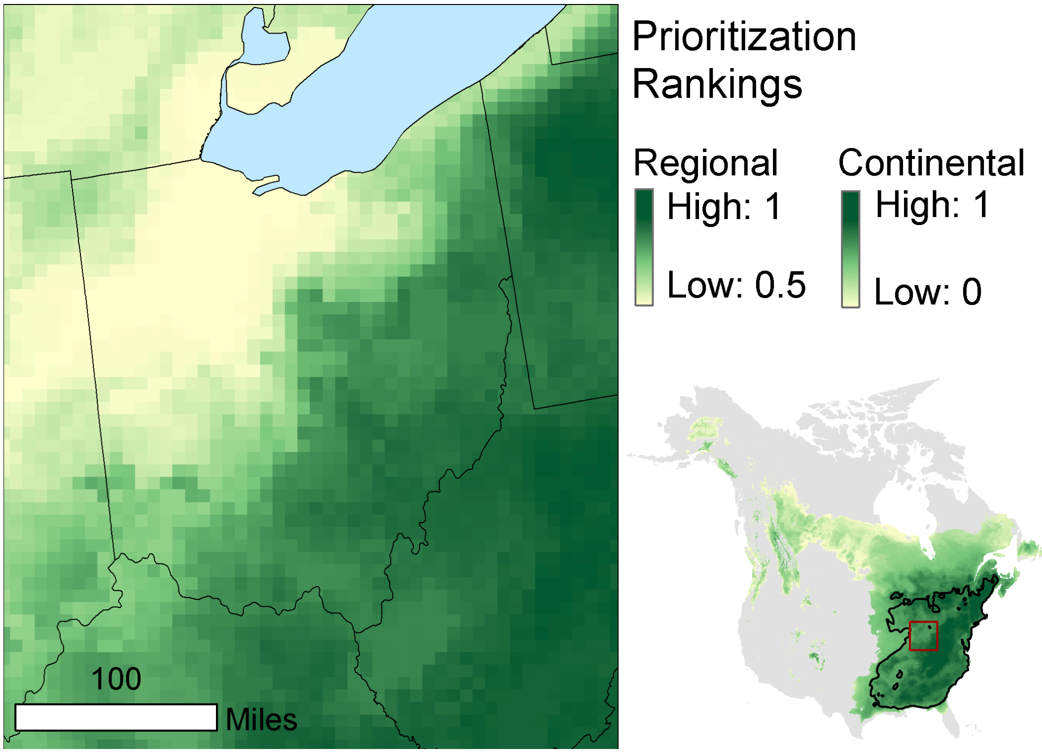


Figure E1. A single-species prioritization for the Wood Thrush.

How do I describe this map (Fig. E1)*?*

This climate prioritization ranks every location on the landscape based on its climatic suitability today and in the future. Darker green ranks highest.

Why is this useful? Can't I just use the climatic suitability maps?

These rankings take into account uncertainty relating to the magnitude and rate of climate change as well as how the species may respond. It synthesizes the information into one map and can be combined with other datasets (e.g. vegetation and land-use) to inform conservation decisions.

Is this the same as a species range map?

No. This is a tool for conservation planning. It identifies places where a species is likely to persist based on climate alone both within and outside its current range.

What are best practices for mapping prioritizations?

- Display a local map of a prioritization with a regional map for perspective.
- Use the core climatic range (kappa range) polygon layer as an overlay.
- Use the provided yellow-to-green color ramp.
- Always display the range of prioritization rankings represented in your view.

Can I overlay many single species prioritizations to find the best areas in my state?

It is less effective to overlay single-species prioritizations. If you are interested in conservation planning for multiple species, contact climatescience@audubon.org to request a multi-species prioritization.

What does this tell me about future changes in the species' range?

Prioritizations are not designed to show range shifts like climate suitability maps. However, areas ranked high outside a species core suitability are likely areas of colonization with climate change. Conversely, areas ranked low within the current core suitability may experience range contraction. Highest ranking areas are likely to remain suitable over time.

APPENDIX E

FAQ for Audubon's climate prioritizations

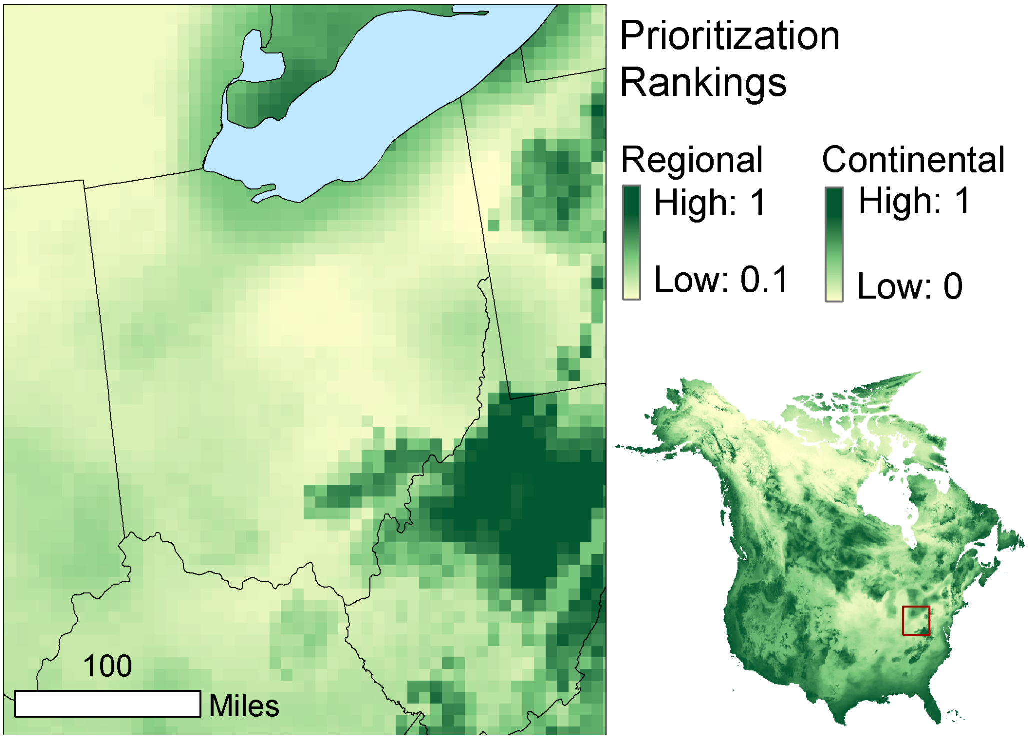


Figure E2. A multi-species prioritization based on 314 climate-threatened and – endangered species.

What are the gray areas on the continental map?

Areas that fall outside of both the current and projected future climatically suitable range are ranked zero.

Is Ohio important for this species?

Yes. Ohio is located within the species' core climatically suitable range (see continental map) and is uniformly ranked above 0.5. Within the state of Ohio (regional map), areas in the southeast are relatively higher ranked than the rest of the state.

Do prioritizations differ by season?

Yes. We can build prioritizations for summer and winter. We can also build an ensemble for both summer and winter. It depends on your conservation goal.

What does a multi-species prioritization (Fig. E2) say that is different from a single-species prioritization?

A multi-species prioritization is ranking the landscape for its ability to support a diversity of species today and the future. High ranking areas have the greatest species diversity among the species included.

Much of Ohio is yellow. Is Ohio important under climate change?

Most of Ohio likely has relatively low diversity for the species represented in this multi-species prioritization. The southeastern corner is certainly the most important for this set of species. Ohio may be more uniformly important for a different set of species.

What if my whole region is yellow?

You can always zoom into your state and identify areas that are relatively more valuable. Or, you may want to identify and group of species for which your state is important and focus your climate change work on those species.

APPENDIX F

Accessing the Data

Audubon's climate science can be accessed and used in a number of ways, allowing for static exploration, basic overlays and processing, and direct manipulation of the imagery using geoprocessing tools. Currently, access to spatial datasets beyond what is available on Audubon's website (Audubon.org/climate) is restricted to Audubon staff. If you are external to Audubon and interested in working with the data, contact climatescience@audubon.org to discuss your interest in the data and to explore options for gaining access.

Static Exploration

Maps and visualizations of projected ranges will be hosted on Audubon.org/climate for exploration and public consumption.

Basic Overlays

Individual species and multi-species climate prioritizations will be hosted on Audubon's ESRI platform. Audubon users can access this imagery to perform overlays and basic analyses on arcgis.com. Upon completion of relevant training, Audubon staff will be given access to these data within the climate change group. This user group will allow for discussion and sharing among users across the Audubon network and will include metadata and reports. Contact GIS_help@audubon.org to create an ArcGIS online account or to gain access to the climate change user group.

Geoprocessing on the Desktop

ArcGIS desktop users can access the data directly by connecting to the Audubon server. Contact GIS_help@audubon.org for assistance in configuring your connection. This connection also includes geoprocessing tools for localizing the data.

GIS Support & Training

For assistance in accessing and working with existing climate science imagery contact GIS_help@audubon.org. Training for data access will be delivered through AudubonWorks and custom trainings can be provided upon request. For new data requests (e.g. new multi-species prioritizations) or to discuss appropriate uses of climate science, contact climatescience@audubon.org.