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General Technical Report NE-318

Atlas of Climate Change Effects in 150 Bird Species of the Eastern United States

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Abstract

This atlas documents the current and potential future distribution of 150 common bird species in the Eastern United States in relation to climate and vegetation distributions. Distribution data for individual species were derived from the Breeding Bird Survey (BBS) from 1981 to 1990. Regression tree analysis was used to model the BBS data as functions of contemporary environmental variables. These predictor variables included the abundance of 68 tree species as determined by USDA Forest Service's Forest Inventory and Analysis data, as well as 8 climate variables and 4 elevation variables. The model for each bird species is described. These models were then projected onto two scenarios of global climate change for which future distributions of the climate variables and tree species had previously been calculated. This allowed comparison of the future habitat for each bird species against its current modeled distribution. Summary statistics of the current and projected range and abundance within the Eastern United States are included. Depending on the global climate model used, as many as 78 bird species are projected to decrease by at least 25 percent, while as many as 33 species are projected to increase in abundance by at least 25 percent.

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Photo Credits

Kevin T. Karlson provided the majority of the species photographs. R. G. Potts supplied the Gray Partridge photo; Michael Danzenbaker, the Chimney Swift; and Brian E. Small provided the Common Loon, Acadian Flycatcher, Mississippi Kite, Evening Grosbeak, Purple Finch, Bank Swallow, Warbling Vireo, Yellow-throated Vireo, Golden-winged Warbler, Cerulean Warbler, Blackburnian Warbler, Mourning Warbler, Yellow-breasted Chat, Brown-headed Nuthatch, and Bachman's Sparrow. Front cover landscape photos were provided by Louis Iverson.

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Atlas of Climate Change Effects in 150 Bird Species of the Eastern United States

Contents

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Part I: Atlas Explanation

Introduction

Present-day bird communities occupy a variety of habitats across North America. Changes in these habitats, including those induced by climate change, could dramatically alter the composition and distribution of these communities. There is mounting evidence that increases in greenhouse gases during the last 50 years have contributed greatly to the warming of the Earth's climate (IPCC 2001), and to changes in the behavior of numerous organisms (Parmesan et al. 1999; Thomas and Lennon 1999; Moss et al. 2001; Walther et al. 2002). More importantly, rapid and dramatic changes in the Earth's climate over the next century are anticipated following continued increases of greenhouse gases (IPCC 2001).

Several studies provide evidence of strong correlations between climate and the distribution patterns of birds (Ashmole 1963; Currie 1991; Root 1988). Using associations between climate variables and birds, Price and Glick (2002) and Price and Root (2001) assessed the potential for large shifts in range of numerous bird species in the conterminous United States. Price and Root (2001) predicted significant losses of neotropical species throughout the Nation due to shifts in their range. Investigating the effect of drought sensitivity on populations of waterfowl, Sorenson et al. (1998) predicted significant reductions in the populations of 14 migratory bird species throughout the Prairie Pothole Region that extends from north-central Iowa to southeastern Alberta, Canada. In South Africa, Erasmus et al. (2002) projected reductions in range for nearly 80 percent of the 179 species studied -- including 38 species of birds.

Bird distributions are influenced not only by the surrounding climate but also by the availability of suitable habitat, which, in turn, is influenced by climate change. Thus, it is possible that climate and habitat envelopes of a species disassociate under climate change such that the availability of suitable habitat may be more limiting than fluctuations in climate. This possibility has not been considered in previous studies of distribution shifts. In this atlas we have incorporated both climate variables and tree-species distributions (to quantify habitat availability) to model the current distribution patterns of 150 common bird species in the Eastern United States. These environmental relationships can help researchers gain a more complete understanding of the factors underlying current distribution patterns and aid in determining the potential effect of climate change on future patterns.

To the extent that a shift in distribution enables a species to remain within the bounds of identified environmental constraints (as climate change progresses), our predictions should be valid. This would not be true should that species adapt to climate change through changes in environmental requirements. Our model assumes that changes in the future distribution of trees under climate changes have essentially equilibrated by the end of the present century. However, lag times associated with tree migration (Iverson et al. 1999b; Schwartz et al. 2001) and tree longevity, particularly of those in refugia, could result in distributions that differ significantly from those projected on the basis of our assumptions.

This atlas follows a similar one developed for 80 common tree species in the Eastern United States (Iverson et al. 1999a). (An updated version of the tree atlas is available at http://www.fs.fed.us/ne/delaware/atlas/). Here we use available data on the current distribution of the 150 bird species to generate a predictive model of the species abundance. The models of the species abundance allowed us to identify the environmental variables that show associations with the species distribution. Then we use these relationships to predict the species models onto two scenarios of global climate change: the Canadian Climate Center model (CCC) (Boer et al., 2000; Kittel et al., 2000) and the Hadley (U.K.) Center for Climate Prediction and Research model (Hadley) (Mitchell et al. 1995). We chose these 2xCO_2 models because they span the spectrum of potential climate change. For each bird species we predicted the change in distribution that would occur should a species continue to track current climate and habitat envelopes.

Data Sources and Methods

This atlas covers the United States east of the 100th meridian. Bird data were obtained from the national Breeding Bird Survey (BBS), a population monitoring program conducted annually since 1966 in the United States and Canada. Currently, the BBS is administered jointly by the U.S. Geological Survey's Patuxent Wildlife Research Center, Laurel, Maryland, and the Canadian Wildlife Service. The BBS generates data from nearly 4,000 routes across North America (Robbins et al. 1989; Sauer et al. 1997).

In a review of the BBS, O'Connor et al. (2000) concluded that the survey met its goals with only minor biases. After extracting 1,223 representative routes that had been surveyed frequently from 1981 to 1990, O'Connor et al. (1996) determined the incidence value (proportion of surveys along a route in which a bird was recorded) for each of the 150 species. For our purposes, incidence values are interpreted as absolute abundance given the typical relationship between incidence and abundance for most organisms (e.g., Hanski 1992; Maurer 1990). Yang et al. (1995) interpolated the incidence value to obtain an abundance surface over the conterminous United States for each species, using White et al.'s (1992) 640 km^2 hexagonal grid with 12,600 points.

For the present analysis, we identified the hexagons east of the 100th meridian, then cross-walked the bird data for each hexagon to a U.S. county map using an area-weighting technique (Matthews et al. 2002). This enabled us to match the environmental data from the county-based tree atlas (Iverson and Prasad 1998; Iverson et al. 1999a). Incidence values for birds ranged from 0.0 to 1.0. Species with a value less than 0.05 were considered absent from a county.

The environmental data included eight climate and four elevation variables, and Importance Values (IV) for 80 tree species (of which 68 tree variables occurred in the bird models) (Table 1). As a measure of abundance, IV's incorporate the number of stems and basal area of a species relative to those variables for all species in a county (Iverson and Prasad 1998). For the climate data, potential future conditions for the years 2070 to 2099 were projected onto the CCC and Hadley scenarios as mapped to the counties of the Eastern United States. We also obtained data for the projected future habitat (under CCC and Hadley) of the 68 tree species listed in this atlas. The use of individual tree-species abundances allowed us to track the projected movement of habitat for each bird species for each climate scenario. Because it is anticipated that tree species will migrate independently to form new vegetation communities following climate change (Davis 1989; Webb III 1992), it would have been inappropriate to use current vegetation communities as predictors of bird species abundance. In practice, most bird species were mapped successfully with respect to the distributions of a small number of individual tree species; that is, either individual tree species were effective surrogates of forest-community properties or the birds were not sensitive to community properties.

The entire set of potential predictors provide a wide array of environmental variables (Table 1) that a priori evidence indicated might be associated with the abundance patterns of bird species. By building contemporary models in terms of climate and vegetation variables that were available spatially both for contemporary conditions and future conditions (see examples, Fig. 1), we could predict future bird distributions assuming only that the contemporary relationships between birds and climate and vegetation did not change in the future and that climate change follows the CCC or Hadley scenarios.

To generate representative statistical models of the bird species abundance based on available data, we used regression tree analysis (Breiman et al. 1984; Clark and Pregibon 1992). Traditional methods require normality and rely on strict linear relationships between the bird data and the environmental data. Regression tree procedures do not require normality, are less sensitive to outliers, and can handle interactions between variables by subsetting the data in the tree-building process without the need to identify all possible interactions a priori (Verbyla 1987; Clark and Pregibon 1992; Iverson and Prasad 1998). A regression tree proceeds by recursively partitioning the sample into groups defined by the predictor variables. The resulting regression tree was then pruned back using ten-fold cross-validation (Breiman et al. 1984; Clark and Pregibon 1992) to protect against overfitting of the model. These groups

Table 1. --Environmental data and importance values (iv) for 68 tree species that occurred in the models for 150 bird species. The frequency and percent columns indicate, respectively, the number and percentage of the 150 bird species for which that variable appeared in the regression tree model

Abbreviation	Variable	Frequency	Percent
	Climate Variables		
JANT	Mean January temperature (°C)	85	56.7
PET	Potential evapotranspiration (mm/month)	46	30.7
JULT	Mean July temperature (°C)	54	36.0
PPT	Annual precipitation (mm)	62	41.3
AVGT	Mean annual temperature (°C)	52	34.7
MAYSEPT	Mean May-September temperature (°C)	42	28.0
JUL.JANT	Seasonality: difference between JULT and JANT (°C)	71	47.3
JARPPET	July-August ratio of precipitation to PET	28	18.7
	Elevation		
MAX.ELV	Maximum elevation (m)	49	32.7
MIN.ELV	Minimum elevation (m)	37	24.7
avg.ELV	Average elevation (m)	35	23.3
ELV.CV	Elevation coefficient of variation	24	16.0
	Trees Species Importance Values		
iv12	Balsam fir (*Abies balsamea*)	39	26.0
iv68	Eastern redcedar (*Juniperus virginiana*)	4	2.7
iv110	Shortleaf pine (*Pinus echinata*)	5	3.3
iv111	Slash pine (*Pinus elliottii*)	7	4.7
iv121	Longleaf pine (*Pinus palustris*)	2	1.3
iv125	Red pine (*Pinus resinosa*)	1	0.7
iv129	Eastern white pine (*Pinus strobus*)	10	6.7
iv131	Loblolly pine (*Pinus taeda*)	13	8.7
iv222	Pond cypress (*Taxodium distichum* var. *nutans*)	3	2.0
iv241	Northern white-cedar (*Thuja occidentalis*)	7	4.7
iv261	Eastern hemlock (*Tsuga canadensis*)	16	10.7
iv313	Boxelder (*Acer negundo*)	1	0.7
iv315	Striped maple (*Acer pensylvanicum*)	10	6.7
iv316	Red maple (*Acer rubrum*)	21	14.0
iv317	Silver maple (*Acer saccharinum*)	1	0.7
iv318	Sugar maple (*Acer saccharum*)	7	4.7
iv371	Yellow birch (*Betula alleghaniensis*)	14	9.3
iv372	Sweet birch (*Betula lenta*)	12	8.0
iv375	Paper birch (*Betula papyrifera*)	13	8.7
iv391	American hornbeam (*Carpinus caroliniana*)	2	1.3
iv400	Hickory (*Carya* spp.)	11	7.3
iv402	Bitternut hickory (*Carya cordiformis*)	4	2.7
iv403	Pignut hickory (*Carya glabra*)	3	2.0
iv407	Shagbark hickory (*Carya ovata*)	2	1.3
iv409	Mockernut hickory (*Carya tomentosa*)	2	1.3
iv461	Sugarberry (*Celtis laevigata*)	2	1.3
iv462	Hackberry (*Celtis occidentalis*)	2	1.3
iv471	Eastern redbud (*Cercis canadensis*)	2	1.3
iv491	Flowering dogwood (*Cornus florida*)	4	2.7

continued

Table 1. --cont.

Abbreviation	Variable	Frequency	Percent
iv500	Hawthorn (*Crataegus* spp.)	2	1.3
iv521	Common persimmon (*Diospyros virginiana*)	3	2.0
iv531	American beech (*Fagus grandifolia*)	9	6.0
iv540	Ash (*Fraxinus* spp.)	2	1.3
iv541	White ash (*Fraxinus americana*)	16	10.7
iv543	Black ash (*Fraxinus nigra*)	8	5.3
iv544	Green ash (*Fraxinus pennsylvanica*)	5	3.3
iv591	American holly (*Ilex opaca*)	7	4.7
iv602	Black walnut (*Juglans nigra*)	1	0.7
iv611	Sweetgum (*Liquidambar styraciflua*)	3	2.0
iv621	Yellow-poplar (*Liriodendron tulipifera*)	18	12.0
iv641	Osage-orange (*Maclura pomifera*)	1	0.7
iv653	Sweetbay (*Magnolia virginiana*)	1	0.7
iv691	Water tupelo (*Nyssa aquatica*)	5	3.3
iv693	Blackgum (*Nyssa sylvatica*)	11	7.3
iv694	Swamp tupelo (*Nyssa biflora*)	4	2.7
iv711	Sourwood (*Oxydendrum arboreum*)	8	5.3
iv743	Bigtooth aspen (*Populus grandidentata*)	3	2.0
iv746	Quaking aspen (*Populus tremuloides)*	12	8.0
iv762	Black cherry (*Prunus serotina*)	8	5.3
iv802	White oak (*Quercus alba*)	10	6.7
iv812	Southern red oak (*Quercus falcata* var. *falcata*)	4	2.7
iv813	Cherrybark oak (*Quercus falcata* var. *pagodaefolia*)	2	1.3
iv820	Laurel oak (*Quercus laurifolia*)	4	2.7
iv823	Bur oak (*Quercus macrocarpa*)	2	1.3
iv826	Chinkapin oak (*Quercus muehlenbergii*)	4	2.7
iv827	Water oak (*Quercus nigra*)	2	1.3
iv830	Pin oak (*Quercus palustris*)	1	0.7
iv832	Chestnut oak (*Quercus prinus*)	9	6.0
iv833	Northern red oak (*Quercus rubra*)	9	6.0
iv835	Post oak (*Quercus stellata*)	6	4.0
iv837	Black oak (*Quercus velutina*)	6	4.0
iv901	Black locust (*Robinia psuedoacacia*)	1	0.7
iv931	Sassafras (*Sassafras albidum*)	6	4.0
iv951	American basswood (*Tilia americana*)	1	0.7
iv970	Elm (*Ulmus* spp.)	4	2.7
iv971	Winged elm (*Ulmus alata*)	8	5.3
iv972	American elm (*Ulmus americana*)	9	6.0
iv975	Slippery elm (*Ulmus rubra*)	1	0.7

are increasingly homogenous with respect to the response variable. The resulting model contains a series of decision rules that define each of these groups relative to thresholds of environmental predictors. The predictors, in turn, lead to predictions of the bird-species incidence as the average of the species abundance (incidence) in the counties contained in the terminal nodes.

We use the white-eyed vireo (Fig. 2) to illustrate the modeling procedure and the types of results obtained from this analysis. For this species, the first split occurred at the average January temperature of -2.4°C. The 873 counties (43 + 250 + 580) with temperatures below the threshold are segregated into the left branch where they are split again by the occurrence of yellow-poplar. The right split resulted in a terminal node (the bird data could not be split further by the predictors) of 43 counties with high abundance of

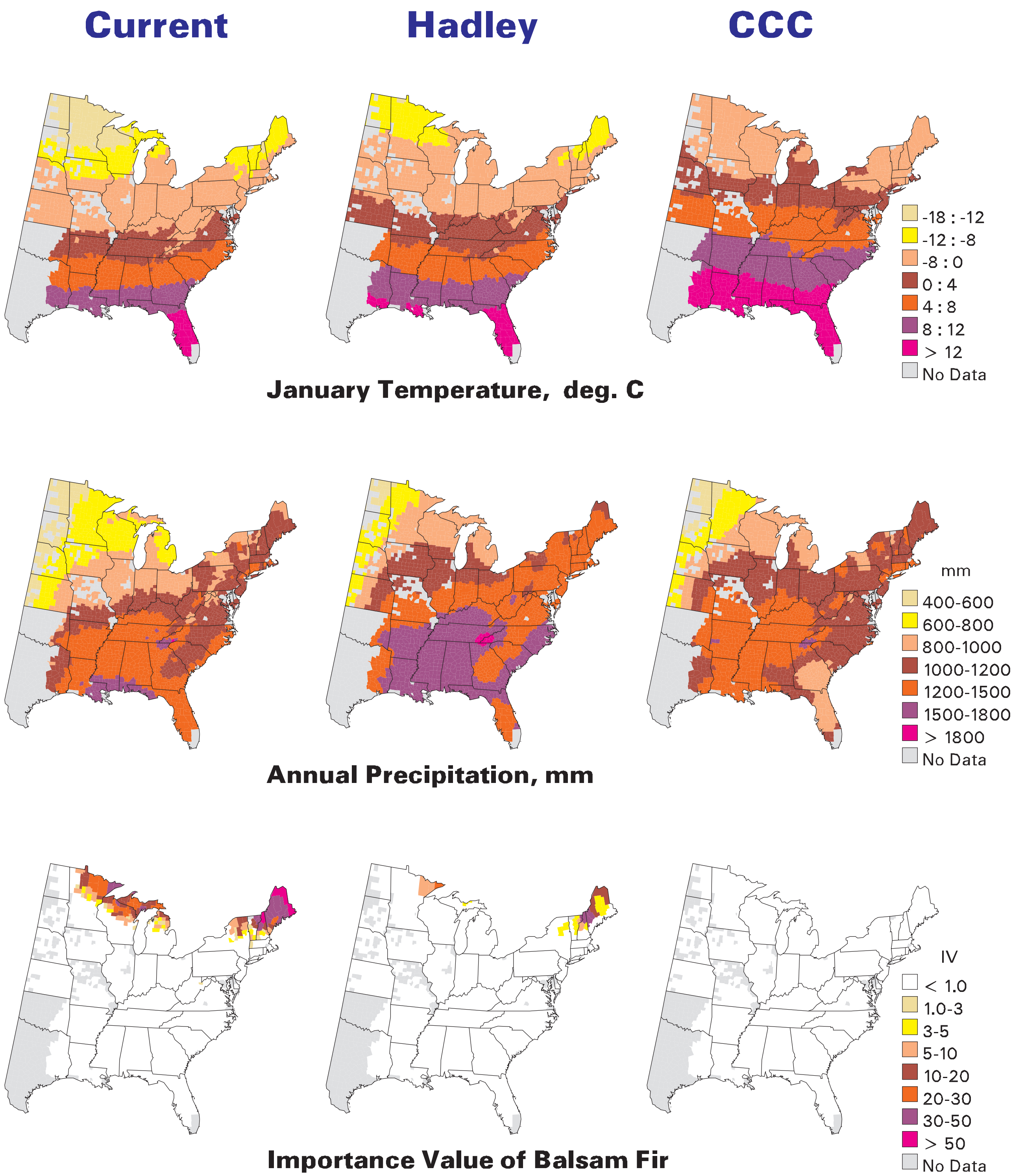

Figure 1. --Maps of three predictor variables plotted under current conditions and as modified by the CCC and Hadley scenarios. Variables in this example include average January temperature (°C), average precipitation (mm), and importance value (abundance) of balsam fir.

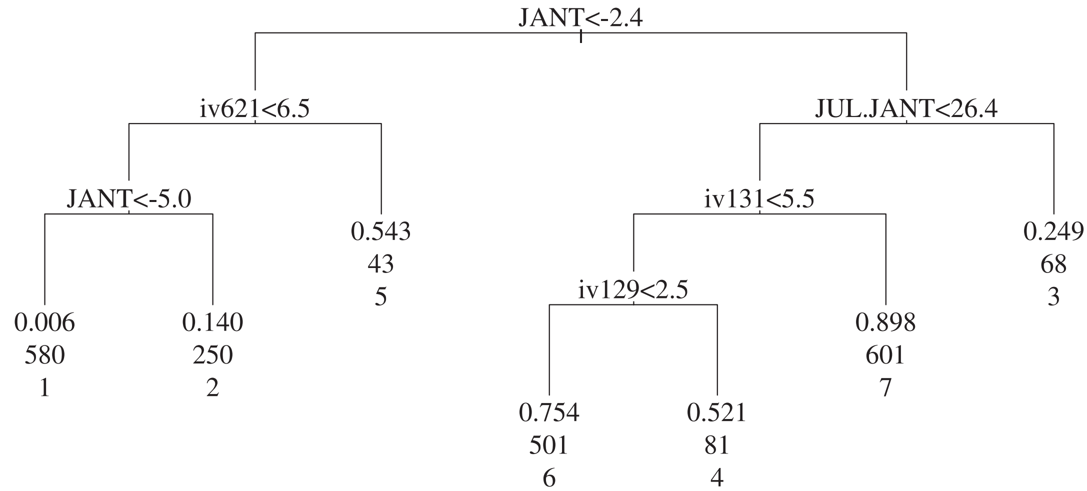

Figure 2. --Regression tree structure of the model for white-eyed vireo. Values at each branch end refer, respectively, to predicted species incidence and number of counties in that branch, and a key for locating those counties on the geographic predictors map. JANT is average January temperature (°C), JUL.JANT is average seasonality (difference between July and January average temperatures °C), iv621 is abundance of yellow-poplar, iv131 is abundance of loblolly pine, and iv129 is abundance of eastern white pine.

yellow-poplar and a predicted incidence of 0.543, i.e., the vireo was typically recorded 54 percent of the time on the BBS routes in this region. Moving back to the right side of the root split, that is, the counties with January temperatures exceeding the -2.4°C threshold, the same logic applies on following the branch down to the four rightmost terminal nodes.

Atlas Format and Explanations

This Atlas provides information on the current and potential future distribution of 150 common bird species in the Eastern United States. Two pages are devoted to each species and include tables and maps related to the current status of the bird in the Eastern United States, and to the model developed to project the bird's future distribution under climate change. Also included are a map of current abundance based on BBS data, the regression tree model relating species abundance to environmental variables, a map of modeled current distribution, a map of the bird's geographic dependence on environmental variables, and statistics for the model goodness of fit. Two additional maps show species distributions projected under the two future climate scenarios and a third map shows the distribution of changes in abundance projected from the current distribution.

Distribution Statistics

Each species account includes distribution statistics that were interpreted as follows:

Area-weighted incidence

Average species incidence within each county was weighted by the county area and summed across all counties with at least one occurrence. Incidence is the proportion of surveys at a location at which a species was recorded and typically is highly correlated with abundance (Hanski 1992; Maurer 1990).

Species incidence is based on the probability of a bird species being encountered along a BBS route during the breeding season. Observers would stop every half mile along a 25-mile roaded route and look and listen for 3 minutes. Compiled over 10 years (1981-1990), the resulting average incidence value gives a respresentive picture of each species' abundance. Therefore, we assume that the area-weighted incidence can be interpreted as a measure of the absolute abundance of that species in the Eastern United States.

Ranked area-weighted incidence
Used to rank each species in descending order of average incidence within its eastern range. For species with the same abundance value, the mean rank of the tied values was assigned and rounded to the nearest integer (values thus range from 1 to 150).

Range
The total area of the species' range in the Eastern United States (km^2 x 1,000) as determined by the BBS data at the county resolution. Range was determined by summing the areas of counties in which a species was present (incidence greater than 0.05).

Ranked Range
The rank in descending order of the range size of the species (values ranged from 1 to 150).

Breeding Status
As described by Gough et al. (1998) and included here as background information, species are classified as a resident, short-distance migrant, or neotropical migrant. Patterns of migration and residency vary widely among species and influence species response to changes in climate. The breeding status of the first 20 species in this atlas (all waterfowl) was not classified by Gough et al. For these we followed Ehrlich et al. (1988) and Alsop (2001) in classifying them as resident, migrant, or partial migrant.

Primary Breeding Diet
Using the classification described in Ehrlich et al. (1988), the species' primary breeding diet is represented as insects, aquatic invertebrates, small mammals, fish, carrion, omnivorous, seeds, greens, fruits, or nectar. Birds often rely on a variety of food throughout the year and the classification here represents their primary source only during the breeding season.

Deviance Explained by Predictors
Percent deviance of species incidence explained by each variable in the model was calculated to quantify the relative importance of each of the environmental variables. These were then summed to obtain the overall goodness of fit of the model.

Predicted Response for CCC and Hadley Scenarios
The decision rules obtained from the regression tree models were used to project the species abundance onto the CCC and Hadley climate scenarios. This projection was accomplished by changing the values of the predictor variables from contemporary values to those of CCC and Hadley and then reapplying the decision rules of the species models to calculate the new potential distributions.

Abundance Change
The percentage change between the current and projected future abundance. This was obtained as

$$P = \left[\frac{\sum_i \left(w_i (b_i - a_i) \right)}{\sum_i w_i a_i} \right] \times 100$$

where P is the percentage change in species incidence; *i* is the county identifier; w_i is the weighted area of the county in the study area; a_i is the current species incidence ranging from 0.0 to 1.0, and b_i is the predicted species incidence under the future climate scenario.

Total Range Change
Expresses the area of the projected future range of a species as a percentage of its current range within the Eastern United States. Note that this total is the combination of range lost and range gained and might conceal information on potential shifts in range. For example, a low value might

indicate that the species is little affected by climate change, or that large areas of its current range are abandoned but offset by corresponding gains elsewhere. We provide separate estimates for range lost and range gained to allow one to distinguish between these two cases.

Range lost
The percentage of the current range of the species that no longer will be occupied under climate change despite potential gains elsewhere in the Eastern United States.

Range gained
The potential gain in area as a percentage of its current range despite potential losses elsewhere.

Differences in CCC and Hadley Scenarios

The CCC and Hadley scenarios represent two separate projections following a doubling of carbon dioxide, and, therefore, differ in predictions of the response of bird species to climate change. The histogram presented for each species identifies the frequency distribution of the within county differences between the projected species incidences under CCC and Hadley. Where outcomes are similar for both scenarios (CCC minus Hadley approximate zero), there is greater agreement and certainty as to the pattern of change anticipated.

Regression Trees and Modeled Current Distribution

Regression tree analysis was used to generate a predictive model for each species. The regression tree algorithm selects the predictor variables that best delineate the species incidence at each point in the regression tree. The location of the counties in the models can be identified in the geographic predictor maps by matching the id number in the regression tree diagram with the map legend. For 77 bird species, the model was too complex to present in full on a single page. Thus, these models omit the least important nodes. The geographic predictors maps were similarly simplified, though the calculation of range and of abundance changes were computed with the complete model.

Maps

The atlas includes three maps that depict species current distribution and three that show the spatial distribution of the species' predicted response to climate change. All maps are produced at the county resolution using ARC/INFO (ESRI 1993).

Current BBS
Shows the current distribution of species east of the 100th meridian, by county, according to the BBS data for 1981-90. Values for species incidence range from 0.0 to 1.0. Values below 0.05 are included on the map but were excluded from subsequent quantitative analyses due to potential rounding errors.

Thus if you went to a county shaded in the 0.2-0.4 incidence range (during the breeding season), you might expect a 20 to 40% chance of seeing or hearing the bird if you stopped for 3 minutes every half mile along the 25-mile BBS routes within the county.

Modeled current
Shows current distribution as reconstructed by the regression tree model. Spatial distribution was reconstructed by applying the decision rules in the species model to the mapped predictor data. This was accomplished for each county by following the tree diagram to a terminal node and assigning to the county the predicted incidence of that node.

Geographic predictors
This map is linked directly to the regression tree diagram for each species. Its legend keys the map to the end-node id numbers that identify a terminal branch of the tree. By following the decision rules that determine the terminal node, one can identify the counties that meet the specified criteria,

thus providing an understanding of how the environmental variables in the model divide the study area, and how different environmental conditions are associated with the abundance of the species across its distribution.

Predicted CCC

Shows the predicted distribution for the CCC climate scenario. As with the modeled current map, decision rules from the regression tree model were applied to a dataset that contained environmental data, in this case, information characterizing projected future conditions of counties under the CCC scenario.

Predicted Hadley

Prepared in the same way as CCC map but using the conditions predicted under the Hadley scenario. Because there is considerable uncertainty as to the actual extent of climate change, using the Hadley and CCC scenarios provides a range of possible outcomes as well as a more complete understanding of the uncertainty surrounding the response of bird species to global climate change.

Potential shifts

Summarizes the potential response of bird species to CCC and Hadley. The first column indicates the direction and magnitude of change between the modeled current and predicted incidence under CCC, the second column shows the corresponding differences under Hadley. The corresponding map color indicates the location at which that particular combination of CCC and Hadley projections occur. A plus sign indicates a projected increase in species incidence in that county of at least 10 percent, a minus sign indicates a decrease of at least 10 percent. A zero indicates no projected shift (did not change by more than 10 percent). This scheme allows one to quickly visualize where CCC and Hadley show agreement and disagreement with respect to potential changes in the distributions of bird species.

Summary

This atlas contains detailed information on traits and biogeographic factors contributing to current and potential future range and abundance for 150 individual bird species common in the Eastern United States. In this section we consider the broader response of all the species collectively in their possible response to projected climate change. These models predict major shifts in many bird species ranges and abundance in the Eastern Unites States under both the CCC and Hadley GCM scenarios (Table 2).

As shown in Table 2, about half of the species show a potential decrease of at least 25% of their abundance (species incidence) with either GCM model, while about a fifth of the species show a potential increase of at least 25% in their abundance. With respect to potential area changes in range, roughly 40% of the species will likely decrease while about 20% would likely increase in area by at least 25% following climate change (Table 2). Because the CCC scenario is more severe relative

Table 2. --Number (and percentage) of bird species potentially increasing or decreasing in abundance and area by at least 25% according to our models driven by the CCC and Hadley GCM scenarios

	Increase by >25%		Decrease by > 25%	
Scenario	Abundance	Area	Abundance	Area
CCC	33 (22%)	31 (21%)	78 (52%)	60 (40%)
Hadley	28 (19%)	24 (16%)	75 (50%)	56 (37%)

to the Hadley scenario (hotter and drier), the models also show slightly greater effects on species outcomes from the CCC scenario. By subtraction, we see that 26-31% of the species evaluated would have small (<25%) changes in abundance and 39-47% of the species would have small range changes after climate change.

For those species modeled to decrease by at least 25%, there were 18-19 more species modeled to be reduced in abundance than in area. These species are likely to continue to occupy large portions of their current ranges while undergoing substantial changes in their abundance. It is important to emphasize that Canada was not part of this model exercise so that many of the species projected to decrease in area and abundance will be compensated for by new territory potentially occupied in Canada.

These summaries provide a broader perspective on the potential changes of bird species distributions due to climate change. From our models, we see many of the species that currently occupy the northern portion of the Eastern United States moving north out of our study area and into Canada, and many species currently restricted to the south expanding their range or shifting their abundance core northward. While each species has its own unique model and the potential to move independently in response to climate change, their responses can be viewed as patterns of change. By assessing the collective response of climate changes across a broad array of bird species, we have the ability to gain further insight into potential future distribution of birds, in general, within the Eastern United States.

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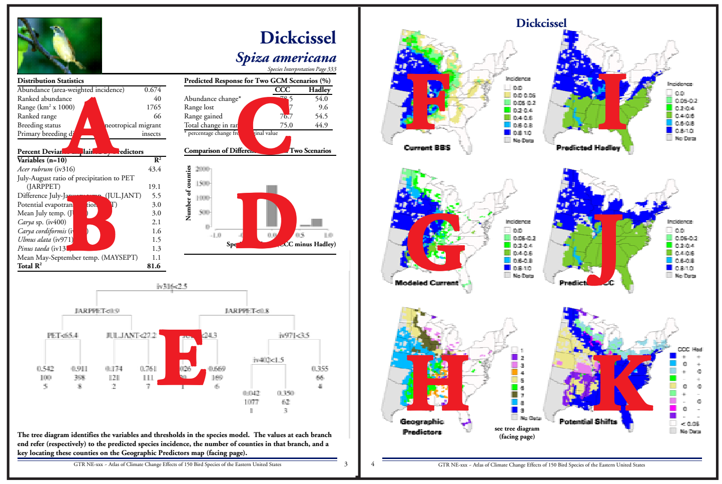
Key to Species Pages



This atlas provides information on the current and potential future distribution of 150 common bird species in the Eastern United States. Two pages are devoted to each species and include tables and maps related to the current status of the bird in the Eastern United States, and to the model developed to project the bird's future distribution under climate change. The following brief descriptions provide information on these two pages; further details can be found in the preceding pages.

Summary Data Page

A. Area-weighted Incidence --(0-1 scale) is the average incidence (proportion of BBS surveys which recorded the species) weighted by county area from those counties with at least 1 occurrence. It is highly correlated with abundance of the species throughout the study area. Ranked abundance refers to the species rank relative to all other species, ranging from 1 being the most abundant to 150. Range and ranked range refer to the total area occupied by the species, as calculated from summing the areas of counties where the species was present with an incidence above 0.05. Breeding status refers to patterns of migration and residency of the species, and can be resident, short-distance migrant, neotropical migrant, or partial migrant (for 20 waterfowl species). Primary breeding diet represents the species' primary source of food during the breeding season, and can be insects, aquatic invertebrates, small mammals, fish, carrion, omnivorous, seeds, greens, fruits, or nectar.

B. Deviance Explained by Predictors -- Percent deviance of species incidence explained by each variable in the model was calculated to quantify the relative importance of each of the environmental variables. These were then summed to obtain the overall goodness of fit of the model.

C. Predicted Response for Future Scenarios -- After building the regression tree models for current distribution for each species, the current climate variables were swapped with CCC and Hadley future (year 2100) climate variables to model potential future bird species abundance and range. The future projections assume equilibrium with climate and vegetation and would represent a time far beyond the year 2100. Abundance change is the percentage change between the current and projected future abundance. Total range change is the area of the projected future range of a species as a percentage of its current range. Note that this total is the combination of range lost and range gained which accounts for the situation where changes in one part of the range may be offset by opposite changes in another part of its range.

D. Differences in CCC and Hadley Scenarios -- This graph shows the agreement between the two scenarios in future abundance projections. For these histograms the minimum number of counties necessary for a bar is 25. If most of the >2000 counties have a value near 0 (CCC minus Hadley approximate zero), both scenarios indicate similar future distribution changes. If not, the disagreement is larger between scenarios and the uncertainty with future climate also leads to uncertainty with bird distributions.

E. Regression Trees and Modeled Current Distribution -- Regression tree analysis was used to generate the predictive models. It selects the predictor variables that best delineate the species incidence at each end point in the regression tree. The location of the counties in the models can be identified in the geographic predictor map (Map H) by matching the id number in the regression tree diagram with the map legend. For 77 of the 150 species, the model contained too many branches to present in full on a single page, so the tree was "pruned" for publication.

Map Page

F. Current BBS -- Shows the current distribution, by county, according to the BBS data for 1981-90. Values for species incidence range from 0.0 to 1.0 (present in 100% of the surveys). Values below 0.05 are included on the map but were excluded from subsequent quantitative analyses due to potential rounding errors.

G. Modeled Current -- Shows current distribution as reconstructed for each county by the regression tree model.

H. Geographic Predictors -- Linked directly to the regression tree diagram ("E"), this map's legend keys to the end-node id numbers that identify a terminal branch of the tree. By following the decision rules that determine the terminal node, you can identify the counties that meet the specified criteria, how the environmental variables in the model divide the study area, and how different environmental conditions are associated with the abundance of the species across its distribution.

I. Predicted Hadley -- Shows the predicted distribution for the Hadley climate scenario, derived using the regression tree model, but with projected future climate and vegetation variables. Although the projected time for the Hadley climate is year 2100, because of lag times with trees, equilibrium with the new climate would not be expected for many years beyond 2100. Because of uncertainty as to the extent of future climate change, using both Hadley and CCC scenarios provides a range of possible outcomes as well as a more complete understanding of the uncertainty surrounding the response of bird species to global climate change.

J. Predicted CCC -- Prepared in the same way as Hadley map but using the conditions predicted under the CCC scenario.

K. Potential Shifts -- Summarizes the potential response of bird species to CCC and Hadley. The first column indicates a positive (+), a negative (-), or no (0) difference of at least 10 percent between the modeled current and predicted incidence under CCC. The second column shows the corresponding differences under Hadley. Thus, you can quickly visualize where CCC and Hadley show agreement and disagreement with respect to potential changes in the distributions of bird species.

Part II: Bird Species

Species listed in the standard taxonomic order followed by the American Ornithologists Union (AOU)

Common Loon, *Gavia immer*
Ring-billed Gull, *Larus delawarensis*
Laughing Gull, *Larus atricilla*
Black Tern, *Chlidonias niger*
Mallard, *Anas platyrhynchos*
Blue-winged Teal, *Anas discors*
Canada Goose, *Branta canadensis*
White Ibis, *Eudocimus albus*
American Bittern, *Botaurus lentiginosus*
Great Blue Heron, *Ardea herodias*
Great Egret, *Ardea alba*
Snowy Egret, *Egretta thula*
Little Blue Heron, *Egretta caerulea*
Cattle Egret , *Bubulcus ibis*
Green Heron , *Butorides virescens*
Yellow-crowned Night-Heron, *Nyctanassa violacea*
Sora, *Porzana carolina*
American Coot, *Fulica americana*
Common Snipe, *Gallinago gallinago*
Spotted Sandpiper, *Actitis macularia*
Killdeer , *Charadrius vociferus*
Gray Partridge, *Perdix perdix*
Northern Bobwhite, *Colinus virginianus*
Ruffed Grouse, *Bonasa umbellus*
Ring-necked Pheasant, *Phasianus colchicus*
Rock Dove, *Columba livia*
Mourning Dove, *Zenaida macroura*
Common Ground-Dove, *Columbina passerina*
Turkey Vulture, *Cathartes aura*
Black Vulture, *Coragyps atratus*
Mississippi Kite, *Ictinia mississippiensis*
Northern Harrier, *Circus cyaneus*
Red-tailed Hawk, *Buteo jamaicensis*
Red-shouldered Hawk, *Buteo lineatus*
Broad-winged Hawk, *Buteo platypterus*
American Kestrel, *Falco sparverius*
Great Horned Owl, *Bubo virginianus*
Yellow-billed Cuckoo, *Coccyzus americanus*
Black-billed Cuckoo, *Coccyzus erythropthalmus*
Downy Woodpecker, *Picoides pubescens*
Yellow-bellied Sapsucker, *Sphyrapicus varius*
Pileated Woodpecker, *Dryocopuc pileatus*
Red-headed Woodpecker, *Melanerpes erythrocephalus*
Red-bellied Woodpecker, *Melanerpes carolinus*
Chuck-Will's Widow, *Caprimulgus carolinenis*
Whip-poor-will, *Caprimulgus vociferus*
Common Nighthawk, *Chordeiles minor*
Chimney Swift, *Chaetura pelagica*
Ruby-throated Hummingbird, *Archilochus colubris*
Scissor-tailed Flycatcher, *Tyrannus forficatus*
Eastern Kingbird, *Tyrannus tyrannus*
Eastern Phoebe, *Sayornis phoebe*
Eastern Wood-Pewee, *Contopus virens*
Acadian Flycatcher, *Empidonax virescens*
Willow Flycatcher, *Empidonax traillii*
Least Flycatcher, *Empidonax minimus*
Horned Lark, *Eremophila alpestris*
Blue Jay, *Cyanocitta cristata*
American Crow, *Corvus brachyrhynchos*
Fish Crow, *Corvus ossifragus*
European Starling, *Sturnus vulgaris*
Bobolink, *Dolichonyx oryzivorus*
Brown-headed Cowbird, *Molothrus ater*
Yellow-headed Blackbird, *Xanthocephalus xanthocephalus*
Eastern Meadowlark, *Sturnella magna*
Orchard Oriole, *Icterus spurius*
Baltimore Oriole, *Icterus galbula*
Brewer's Blackbird, *Euphagus cyanocephalus*
Evening Grosbeak, *Coccothraustes vespertinus*
Purple Finch, *Carpodacus purpureus*
House Finch, *Carpodacus mexicanus*
American Goldfinch, *Carduelis tristis*
Vesper Sparrow, *Pooecetes gramineus*
Savannah Sparrow, *Passerculus sandwichensis*
Grasshopper Sparrow, *Ammodramus savannarum*
White-throated Sparrow, *Zonotrichia albicollis*
Chipping Sparrow, *Spizella passerina*
Clay-colored Sparrow, *Spizella pallida*
Field Sparrow, *Spizella pusilla*
Darkeyed junco, *Junco hyemalis*
Bachman's Sparrow, *Aimophila aestivalis*
Song Sparrow, *Melospiza melodia*
Lincoln's Sparrow, *Melospiza lincolnii*
Swamp Sparrow, *Melospiza georgiana*
Eastern Towhee, *Pipilo erythrophthalmus*
Northern Cardinal, *Cardinalis cardinalis*
Rose-breasted Grosbeak, *Pheucticus ludovicianus*
Blue Grosbeak, *Guiraca caerulea*
Indigo Bunting, *Passerina cyanea*
Painted Bunting, *Passerina ciris*
Dickcissel, *Spiza americana*
Summer Tanager, *Piranga rubra*
Purple Martin, *Progne subis*
Cliff Swallow, *Petrochelidon pyrrhonota*
Barn Swallow, *Hirundo rustica*
Tree Swallow, *Tachycineta bicolor*
Bank Swallow, *Riparia riparia*
Cedar Waxwing, *Bombycilla cedrorum*
Loggerhead Shrike, *Lanius ludovicianus*
Red-eyed Vireo, *Vireo olivaceus*
Warbling Vireo, *Vireo gilvus*
Yellow-throated Vireo, *Vireo flavifrons*
Blue-headed Vireo, *Vireo solitarius*
White-eyed Vireo, *Vireo griseus*
Black-and-white Warbler, *Mniotilta varia*
Prothonotary Warbler, *Protonotaria citrea*
Worm-eating Warbler, *Helmitheros vermivorus*
Blue-winged Warbler, *Vermivora pinus*
Golden-winged Warbler, *Vermivora chrysoptera*
Nashville Warbler, *Vermivora ruficapilla*
Northern Parula, *Parula americana*
Yellow Warbler, *Dendroica petechia*
Black-throated Blue Warbler, *Dendroica caerulescens*
Yellow-rumped Warbler, *Dendroica coronata*
Magnolia Warbler, *Dendroica magnolia*
Cerulean Warbler, *Dendroica cerulea*
Blackburnian Warbler, *Dendroica fusca*
Yellow-throated Warbler, *Dendroica dominica*
Black-throated Green Warbler, *Dendroica virens*
Pine Warbler, *Dendroica pinus*
Prairie Warbler, *Dendroica discolor*
Ovenbird, *Seiurus aurocapillus*
Northern Waterthrush, *Seiurus noveboracensis*
Kentucky Warbler, *Oporornis formosus*
Mourning Warbler, *Oporornis philadelphia*
Common Yellowthroat, *Geothlypis trichas*
Yellow-breasted Chat, *Icteria virens*
Hooded Warbler, *Wilsonia citrina*
Canada Warbler, *Wilsonia canadensis*
American Redstart, *Setophaga ruticilla*
House Sparrow, *Passer domesticus*
Northern Mockingbird, *Mimus polyglottos*
Gray Catbird, *Dumetella carolinensis*
Brown Thrasher, *Toxostoma rufum*
Carolina Wren, *Thryothorus ludovicianus*
House Wren, *Troglodytes aedon*
Winter Wren, *Troglodytes troglodytes*
Sedge Wren, *Cistothorus platensis*
Brown Creeper, *Certhia americana*
White-breasted Nuthatch, *Sitta carolinensis*
Red-breasted Nuthatch, *Sitta canadensis*
Brown-headed Nuthatch, *Sitta pusilla*
Tufted Titmouse, *Baeolophus bicolor*
Black-capped Chickadee, *Poecile atricapillus*
Blue-gray Gnatcatcher, *Polioptila caerulea*
Wood Thrush, *Hylocichla mustelina*
Veery, *Catharus fuscescens*
Swainson's Thrush, *Catharus ustulatus*
Hermit Thrush, *Catharus guttatus*
American Robin, *Turdus migratorius*

Part III: Species Interpretations

Species Interpretations

This section focuses on specific features of the results for individual bird species. It is likely that many species will respond similarly to climate change: the southern limits of northern species will move north under warming climatic conditions or indirectly through dependence on tree species that themselves are limited by warming conditions. The reverse is true of the northern limits of southern species. As a result, many birds show similar patterns in distribution change. A second source of similarity originates in the differences between the CCC and Hadley scenarios. In the Eastern United States, CCC projects a hotter and drier climate, while Hadley projects a wetter and only slightly warmer climate. Also, CCC projects more dramatic distribution changes (often shifts northward) than Hadley both for birds and trees. As another example, regional changes along the Atlantic Coast occur with Hadley but not with CCC. Thus, rather than repeat essentially the same comments, we often characterize species response as that of a northern or southern species. The extent of the difference between the two scenarios by county, is depicted in the histogram provided on each species page.

It also is important to emphasize that when we use the words "project" or "predict" in the following text, we mean that our models -- both the tree models from Iverson et al. (1999a) and the bird models represented here -- show these outputs with no set date associated with them. With the $2xCO_2$ scenarios of CCC and Hadley, the changed climate is expected to occur by the end of this century. However, biological organisms, especially trees, have long lag times such that it could be another hundred years or more before the full impact of these changes in climate on species distributions would be observed. Thus, when using the terms project or predict, we mean the habitat and not necessarily the actual distribution of the organisms are modeled to change, by the end of this century.

From our analysis, there is no way to differentiate whether a predictor variable that helps describe and map a bird species is actually a driving variable for the bird (a specific ecological or physiological relationship) or is a coincidentally correlated variable not related to the bird's distribution. In the following discussion, we have attempted to identify those models that appear to be blatantly coincidentally correlated, but it is inevitable that some portion of the remaining predictor variables in the tree diagrams will actually be only coincidentally correlated.

In the section that follows, bird species are listed in the standard taxonomic order followed by the American Ornithologists Union (AOU), though species also are listed alphabetically at the end of this atlas. Using the AOU format allows the normal scientific practice of placing accounts of taxonomically related species close to each other. Related species often share similar ecological features and this order results in the most interesting distributional comparisons being between relatives. For additional information on the projections for tree species discussed in this section, see Iverson et al. (1999a).

Common Loon
(Gavia immer)
Map section page 16
Projections for this species, with CCC predicting extirpation from the Eastern United States, are almost certainly overestimates. The common loon has no known ecological dependence on paper birch or on balsam fir despite the contemporary correlation of the bird and these tree species. The latter are strongly favored by specific soil conditions and the presence of clays, and these conditions are likely to be correlated with the topography and lake types frequented by breeding loons. Because paper birch and balsam fir are projected to migrate northward, our model projects a major contraction in the loon's range. However, the actual contraction in range and numbers will be smaller than estimated here and confined to lakes affected by the loon's association with January temperatures.

Ring-billed Gull
(Larus delawarensis)
Map section page 18
Although well modeled in the northern distribution of this wetland species, our model failed to capture patches of low incidence in the South. In fact, this model produced one of our least successful outcomes for variance explained. As is true for many wetland species, the habitat of the ring-billed gull is sensitive to summer heat and to rainfall patterns, and both CCC and Hadley project major reductions in range and abundance.

Laughing Gull
(Larus atricilla)
Map section page 20
For this species, which is highly sensitive to elevation, both CCC and Hadley project little overall change, but a marked decrease in abundance along the North Carolina coast, Florida, and Louisiana due to a secondary dependence on winter temperatures.

Black Tern
(Chlidonias niger)
Map section page 22
Although predicting well for the northern part of its distribution, our model failed to predict known breeding populations in Nebraska, Iowa, and Michigan. This implies that the distribution of this species is sensitive to variables other than those in our model, which is dominated by temperature variables. Both CCC and Hadley project a northward retreat and total or nearly complete extirpation of the species in the Eastern United States.

Mallard
(Anas platyrhynchos)
Map section page 24
Both CCC and Hadley project a marked contraction northward in the range of this temperature-sensitive species, as well as a significant loss of high-density populations. The model overgeneralized contemporary occurrence in the South, where the mallard is absent according to BBS data.

Blue-winged Teal
(Anas discors)
Map section page 26
Although our model captured the northern core of the population, it failed to capture certain populations in the South, which is influenced by seasonality. Both CCC and Hadley project a contraction in range toward the northwest.

Canada Goose
(Branta canadensis)
Map section page 28
This species depends heavily on average temperature and both CCC and Hadley project a contraction northward. However, the Canada goose currently is expanding in range and abundance due to human activities, which could outweigh future climate-change phenomena and thus affect future distribution. Our model failed to capture contemporary small populations across the Carolinas, Georgia, and Tennessee.

White Ibis
(Eudocimus albus)
Map section page 30
Our model projects expansion northward for this species, which is dominated by winter temperatures. Hadley projects increases in population density and a minor expansion in range, while CCC projects a 150-percent expansion in range into North Carolina, Tennessee, Arkansas, and Oklahoma.

American Bittern
(Botaurus lentiginous)
Map section page 32
This northern wetland species is limited primarily by January temperatures. A weak dependence on the distribution of balsam fir probably is a surrogate for soil conditions. CCC predicts total extirpation in the Eastern United States; Hadley allows for local persistence in Minnesota, North Dakota, and northern New England.

Great Blue Heron
(Ardea herodias)
Map section page 34
Both CCC and Hadley project major decreases in abundance in the Great Lakes States despite the absence of causal links between vegetation predictors in our model and the ecology of the great blue heron. Thus, the possibility of artifact due to confounding variables cannot be dismissed.

Great Egret
(Ardea alba)
Map section page 36
This largely southern species apparently is limited by winter temperatures, though our model failed to capture its presence in South Dakota, Minnesota, and Wisconsin. CCC and Hadley project expansion northward and to the northwest (as far as Pennsylvania with CCC and as far as Kansas with Hadley).

Snowy Egret
(Egretta thula)
Map section page 38
This southern species, limited by elevation and winter temperatures, is projected to expand northward under both CCC (250 percent) and Hadley (120 percent). The snowy egret's incidence could decrease locally along the Gulf and Atlantic Coasts under CCC, though few counties will be affected (see histogram).

Little Blue Heron
(Egretta caerulea)
Map section page 40
Another southern species limited by winter temperatures, the little blue heron is projected to expand northward under both CCC and Hadley; expansion under CCC is twice that of Hadley.

Cattle Egret
(Bubulcus ibis)
Map section page 42
This species is particularly abundant along the Gulf Coast, with scattered populations along the Atlantic Coast into New Jersey. Because of its strong sensitivity to temperature, the cattle egret is projected to expand northward as far as the Great Lakes States under CCC. Local differences in temperatures between CCC and Hadley resulted in significant differences in projected abundances between the two climate scenarios (see histogram).

Green Heron
(Butorides virescens)
Map section page 44
No change is range for this widespread species is projected by CCC or Hadley. However, the green heron is projected to increase in abundance in the northern half of the United States as the result of its dependence on average temperature.

Yellow-crowned Night-Heron
(Nyctanassa violacea)
Map section page 46
This southern species apparently is limited along the northern edge of its range by low winter temperatures. Both CCC and Hadley project expansion northeast through the Atlantic States from Georgia to New Jersey. CCC projects additional expansion throughout Alabama and Georgia and into Tennessee and Kentucky.

Sora
(Porzana carolina)
Map section page 48
Our model captured the core of the species distribution in the northwestern portion of the study area, but failed to predict its occurrence in several counties in Maine and in the Gulf States. The sora relies on wetlands and January-July temperatures influence our model. Both CCC and Hadley predict significant contraction in range northward.

American Coot
(Fulica americana)
Map section page 50
Our model captured the core of the species distribution in the northwestern portion of the study area where the influence of the January-July temperature range is dominant, but it failed to predict the occurrence in pockets of peripheral counties and in the Gulf States. Both GCM scenarios predict a drastic contraction in range northward.

Common Snipe
(Gallinago gallinago)
Map section page 52
Both CCC and Hadley predict a retreat northward due primarily to this species' dependence on average temperature. Total or nearly complete extirpation from the Eastern United States is predicted by CCC and Hadley, respectively.

Spotted Sandpiper
(Actitis macularia)
Map section page 54
Both CCC and Hadley predict a retreat toward the Canadian border (farther north with CCC).

Killdeer
(Charadrius vociferus)
Map section page 56
Both CCC and Hadley project little or no change in the range of this widespread species. However, there are projected increases in density toward its south and southeastern edges as well as some contraction in density within the core of the killdeer's range.

Gray Partridge
(Perdix perdix)
Map section page 58
Both CCC and Hadley predict a shift in the range of this species in the Eastern United States to areas in North Dakota and Minnesota. CCC also projects near extirpation of the gray partridge from the United States. These projections are based on the shifts in the July-September temperature range and potential evapotranspiration.

Northern Bobwhite
(Colinus virginianus)
Map section page 60
Both CCC and Hadley predict expansion northward for this temperature-dependent species. These scenarios also project partial (Hadley) or complete (CCC) colonization along the Canadian border, where the northern bobwhite currently is absent.

Ruffed Grouse
(Bonasa umbellus)
Map section page 62
Both CCC and Hadley predict the withdrawal of this species from the coastal regions of the Northeast and from the southern portion (Hadley) or the entire (CCC) Great Lakes region. This loss would follow the near extirpation of paper birch over most of the Eastern United States, i.e., buds of this tree are a major component of the diet of the ruffed grouse in the northern part of its range.

Ring-Necked Pheasant
(Phasianus colchicus)
Map section page 64
Our model slightly overgeneralized areas of low density, resulting in a contemporary distribution that includes northern Minnesota, Michigan's Upper Peninsula, and parts of northern Vermont, New Hampshire, and Maine. Both CCC and Hadley project a northern shift in distribution, greater under CCC but ameliorated by Hadley for this precipitation-sensitive species. CCC's predicted expansion to Georgia and Florida is unlikely due to local ecological conditions that we were unable to model.

Rock Dove
(Columba livia)
Map section page 66
Neither CCC nor Hadley project changes in the range of this species. However, there is a projected redistribution in numbers throughout the Eastern United States, resulting in net losses in abundance. The climate scenarios differ with respect to how individual counties will be affected.

Mourning Dove
(Zenaida macroura)
Map section page 68
Little response to climate change is projected for this ubiquitous, temperature-dependent species except for minor population increases in northern Minnesota, Wisconsin, and Michigan's Upper Peninsula. These are areas in which balsam fir is expected to decrease in abundance. Habitat studies indicate that the mourning dove is more common in coniferous forests dominated by pine than fir.

Common Ground-Dove
(Columbina passerina)
Map section page 70
Largely associated with the distribution of slash pine, in which this species occurs primarily in open, scrubby areas, the common ground-dove is correspondingly limited to the Southeastern United States. Both CCC and Hadley project major population reductions in Florida, with expansion along the northern edge of the bird's range. CCC predicts expansion as far north as Kentucky and southern Missouri.

Turkey Vulture
(Cathartes aura)
Map section page 72
The substantial variation in the regional abundance of this species is reflected in the different projections by CCC and Hadley. Both climate scenarios predict an increase in abundance in areas where turkey vulture populations are low, particularly along a belt from southern Oklahoma to North Carolina. CCC predicts a wider belt northward and population increases and range expansion from Iowa to the north and northeast and in New York and New England.

Black Vulture
(Coragyps atratus)
Map section page 74
This species decreases in density northward from the Gulf Coast in response to winter temperatures. Both CCC and Hadley project extensive expansion northward as well as an increase in abundance. The projected range of the vulture extends from South Dakota to Pennsylvania (CCC) or from Kansas to Virginia (Hadley).

Mississippi Kite
(Ictinia mississippiensis)
Map section page 76
This species shows a strong correlation with July temperatures but also is associated with the distribution of hackberry and water tupelo. The latter is indicative of bottomland forests in the Southern United States. Substantial increases in range are predicted by CCC (from Iowa into West Virginia) and Hadley (from Tennessee northward). We view this large expansion and the "jumping over" a broad center belt as a modeling artifact.

Northern Harrier
(Circus cyaneus)
Map section page 78
The distribution of this species is primarily a function of seasonality, precipitation, and the abundance of quaking aspen. Both CCC and Hadley project a contraction in range in New England and population reductions in the northwest, particularly in areas where Iverson et al. (1999a) project reductions in the abundance of aspen. In Wisconsin, aspen provides nesting cover for the northern harrier and the bird's density is reduced where aspen populations have been reduced. CCC predicts colonization of Florida resulting from changes in precipitation, but concerns related to habitat and competition likely will preclude widespread colonization.

Red-tailed Hawk
(Buteo jamaicensis)
Map section page 80
Both CCC and Hadley project substantial increases in abundance, particularly across the northwestern and central portions of the Eastern United States. Small losses are projected in Nebraska (CCC) and along the Piedmont (Hadley).

Red-shouldered Hawk
(Buteo lineatus)
Map section page 82
Both CCC and Hadley project expansion northward for this species, which is dependent on winter temperatures. CCC projects expansion to South Dakota through Michigan; Hadley projects expansion to Kansas and northern Missouri. Losses in abundance are confined to the counties along the Gulf Coast.

Broad-winged Hawk
(Buteo platypterus)
Map section page 84
CCC projects a general decrease in abundance while Hadley projects an increase in abundance. Both scenarios predict a shift in range with losses in northern areas; CCC also predicts considerable losses in Louisiana and Mississippi due to a decrease in precipitation. Dominant predictors for this species in addition to annual precipitation are the abundance of red maple and maximum elevation. Projected increases in precipitation in the southern areas by Hadley correspond to predicted increases in the broad-winged hawk along the southeastern coastal region and Mississippi River (from Mississippi to Tennessee).

American Kestrel
(Falco sparverius)
Map section page 86
Both CCC and Hadley predict considerable losses in abundance from southern Michigan, Minnesota, Wisconsin, Indiana, Ohio, and Kentucky, with smaller losses throughout the Northeast. Population gains are projected in the Western States under both scenarios, with Hadley also projecting increases along the Appalachian Mountains in Virginia, West Virginia, and North Carolina. Both scenarios project an expansion in range throughout the Gulf States.

Great Horned Owl
(Bubo virginianus)
Map section page 88
Little change is projected for the eastern populations of this species under CCC and Hadley as neither dominant predictor (red maple and elevation) will shift with climate change. The areas of increased abundance are most concentrated in Iowa, Minnesota, and South Dakota.

Yellow-billed Cuckoo
(Coccyzus americanus)
Map section page 90
Both CCC and Hadley project an increase in abundance from South Dakota to Maryland and along the Appalachians to North Carolina. This increase closely parallels predicted shifts in the dominant predictor in our model (average temperature). The predicted increase in Florida corresponds to a change in seasonality.

Black-billed Cuckoo
(Coccyzus erythropthalmus)
Map section page 92
Both scenarios predict a contraction of this species to the north. Our model is dominated by winter temperatures, and CCC correspondingly projects the black-billed cuckoo to retreat farther north to remain within a suitable climate envelope. Note that it is the summer breeding distribution that is correlated with winter temperature, so the distributional constraint is indirect and may be dependent on the bird's insect diet.

Downy Woodpecker
(Picoides pubescens)
Map section page 94
Both CCC and Hadley project a loss in abundance in the southern portion of the range of this species, which is influenced by annual precipitation. However, these losses are offset by predicted population gains to the north.

Yellow-bellied Sapsucker
(Sphyrapicus varius)
Map section page 96
This species is dominated by the abundance of balsam fir, which it often uses for nesting. CCC projects total extirpation of the sapsucker from the Eastern United States in conjunction with the predicted extirpation of balsam fir. Hadley predicts continued persistence in balsam fir remnants along the Great Lakes and in northern New England.

Pileated Woodpecker
(Dryocopus pileatus)
Map section page 98
CCC predicts population gains from eastern Iowa north to Michigan and across to New York and Massachusetts for this species, which is influenced by winter temperatures. Hadley also predicts gains but along a much narrower band from central Illinois to southern Pennsylvania. Both scenarios predict losses in abundance in the northwestern portion of the study area due to projected losses of eastern white pine (Iverson et al. 1999a).

Red-headed Woodpecker
(Melanerpes erythrocephalus)
Map section page 100
The distribution of this species corresponds to that of red maple, the most abundant tree species in the East (Iverson et al. 1999a). Both CCC and Hadley project increases in abundance of the woodpecker throughout the eastern areas from Virginia to Maine, and in northern Minnesota, Wisconsin, and North Dakota. Hadley projects an increase in population along the southern Atlantic States. The shift in seasonality predicted by CCC accounts for projected population decreases in Kansas, Missouri, Illinois, and Indiana.

Red-bellied Woodpecker
(Melanerpes carolinus)
Map section page 102
For this temperature-sensitive species, both CCC and Hadley predict increases in abundance in the northern portion of its range and in the Appalachian Mountains at higher elevations. Our model slightly overestimated the current range of the woodpecker into New England and northern Minnesota.

Chuck-will's Widow
(Caprimulgus carolinenis)
Map section page 104
This species, which is dominated by average temperature, is predicted to expand northward to the Great Lakes by CCC and to slightly below this northern limit by Hadley. The two scenarios differ substantially with respect to affected counties (see histogram).

Whip-poor-will
(Caprimulgus vociferus)
Map section page 106
The distribution of this species is patchy in the Eastern United States, causing our model to smooth estimates of abundance, which is influenced by the abundance of white oak and annual temperature. Both CCC and Hadley project the range of the whip-poor-will to expand northward, though a decrease in overall abundance also is projected.

Common Nighthawk
(Chordeiles minor)
Map section page 108
Our model overgeneralized the range and abundance of this species in the East in part because the BBS census protocol is poorly adapted to mapping species that are active at dusk and during the night. Both CCC and Hadley project a dramatic decrease in abundance for the nighthawk, which is dominated by winter temperatures. This major change in abundance is related to a predicted change in potential evaportranspiration in the northwestern portion of the study area.

Chimney Swift
(Chaetura pelagica)
Map section page 110
Little change in abundance is predicted for this species, which is associated with precipitation. The larger increases projected in Michigan, northern Wisconsin, Minnesota, and the Dakotas are likely to be offset by numerous smaller decreases over the entire range within the Eastern United States.

Ruby-throated Hummingbird
(Archilochus colubris)
Map section page 112
This species is dominated by the abundance of black tupelo, which is projected to expand to the north and west. Both CCC and Hadley predict population gains in the Midwest and losses in the South, but differ with respect to the counties affected (see histogram).

Scissor-tailed Flycatcher
(Tyrannus forficatus)
Map section page 114
This southern species shows one of the largest relative increases in range and abundance among the birds examined due to its strong dependence on summer temperatures and precipitation. These increases are facilitated by the projected expansion of Osage-orange northward from Kansas to Minnesota and North Dakota. CCC projects a more northerly expansion than Hadley.

Eastern Kingbird
(Tyrannus tyrannus)
Map section page 116
This species is associated with red maple and hickories, and with precipitation, January temperatures, and seasonality. Within the study area, CCC predicts a decrease in abundance in much of the southeast but increases in the northeast and northwest. Hadley projects only local decreases.

Eastern Phoebe
(Sayornis phoebe)
Map section page 118
This species, with its unusually patchy distribution across the study area, is influenced by seasonality, summer temperatures, and elevation. Both CCC and Hadley project a shift in the phoebe's eastern population to the north and northwest.

Eastern Wood-Pewee
(Contopus virens)
Map section page 120
Both CCC and Hadley project an increase in abundance over much of the study area. The latter predicts greater gains in the Piedmont region of the Carolinas and Virginia because of our model's dependence on precipitation.

Acadian Flycatcher
(Empidonax virescens)
Map section page 122
Both CCC and Hadley project a northward shift in the distribution of the population core of this species, primarily because of its strong association with January temperatures. However, because this bird occupies the Eastern United States only during the summer months, this temperature association is indirect. Examples of indirect effects include competition from species directly limited by winter temperatures and food limitation due to the effect of winter conditions on the eggs or pupae of insects that the Acadian flycatcher later feeds on.

Willow Flycatcher
(Empidonax traillii)
Map section page 124
Both CCC and Hadley project a considerable retreat northward in the range of this species, which is influenced indirectly by winter temperatures. Because the willow flycatcher occupies the Eastern United States only during the summer (breeding months), this temperature association is indirect in that it relates to the composition of the resident bird community and/or the availability of insects for food.

Least Flycatcher
(Empidonax minimus)
Map section page 126
Because this species shows a strong association with the distribution of paper birch, the near extirpation of which in the Eastern United States is projected, both CCC and Hadley predict a marked decrease in the abundance of the least flycatcher, with only a remnant population in New Hampshire and northwestern Maine.

Horned Lark
(Eremophila alpestris)
Map section page 128
Both CCC and Hadley project a patchy reduction in the abundance of this species in the Eastern United States, with the greatest losses along the eastern edge of its range. The horned lark's association with hickories in our model may be indirect, e.g., with hickory species indexing the nearby presence of the open areas typically favored by this bird.

Blue Jay
(Cyanocitta cristata)
Map section page 130
Both CCC and Hadley predict a decrease in abundance throughout the Eastern United States for this species, which is associated with projected changes in the abundance of red maple as well as seasonality and summer temperatures. The histogram reveals considerable local (county by county) differences between the two climate scenarios.

American Crow
(Corvus brachyrhynchos)
Map section page 132
Both CCC and Hadley project a decrease in the abundance throughout the range of this species, which is associated with July temperatures and red maple.

Fish Crow
(Corvus ossifragus)
Map section page 134
Both CCC and Hadley project an increase in abundance and range for this species, which is associated with winter temperatures. Our model slightly overestimated the range of the fish crow, but this output had little effect on our estimates of change.

European Starling
(Sturnus vulgaris)
Map section page 136
Little change is predicted for the European starling, which is the most ubiquitous bird species in our analysis.

Bobolink
(Dolichonyx oryzivorus)
Map section page 138
Both CCC and Hadley project a dramatic contraction northward in the range of this northern breeding species, which is dominated by winter temperatures. Both scenarios also predict a corresponding decrease in abundance across the Eastern United States.

Brown-headed Cowbird
(Molothrus ater)
Map section page 140
Little change is projected by CCC and Hadley for this ubiquitous species. Losses in abundance are predicted along the Gulf States due to changes in winter temperatures, and along the Atlantic Coast in association with an increase in the abundance of slash pine (Iverson et al. 1999a). Both scenarios project minor population increases in Maine, Michigan's Upper Peninsula, and northeastern Minnesota.

Yellow-headed Blackbird
(Xanthocephalus xanthocephalus)
Map section page 142
Our model is representative only with respect to the eastern edge of the range of this largely western species, which has a strong relationship with seasonality. Both CCC and Hadley predict a northward contraction in range, with only a remnant population along the border of North Dakota and Minnesota (CCC). These projections are largely peripheral with respect to possible changes in the range of the yellow-headed blackbird in the Western United States.

Eastern Meadowlark
(Sturnella magna)
Map section page 144
This species model is strongly associated with annual precipitation and to lesser extent with temperature and elevation. Both CCC and Hadley project an increase in abundance to the east and northwest, with minor decreases in Maine and Minnesota (Hadley).

Orchard Oriole
(Icterus spurius)
Map section page 146
For this species, which is dominated by average yearly temperature, CCC projects a substantial increase in abundance but losses in Georgia, South Carolina, and northern Florida that correspond to a decrease in precipitation. The slight overgeneralization by the model of the contemporary range had little effect on these projections. Some local increases projected in central Florida result from the increase in seasonality projected there, though underlying habitat conditions may nullify this increase.

Baltimore Oriole
(Icterus galbula)
Map section page 148
Both CCC and Hadley project considerable losses in abundance with only isolated increases in range for this species, which is influenced by minimum temperature. The model's overgeneralization of contemporary range had little effect on our estimates of change.

Brewer's Blackbird
(Euphagus cyanocephalus)
Map section page 150
Extirpation from the Eastern United States except for counties in northern Minnesota (Hadley) is projected for this largely western species, which is dominated by January temperatures.

Evening Grosbeak
(Coccothraustes vespertinus)
Map section page 152
Near extirpation is projected for this northern species, which currently is common only in the states bordering Canada. Balsam fir, a major food source for the evening grosbeak, dominated our model; this bird is projected to follow the retreat of fir into Canada.

Purple Finch
(Carpodacus purpureus)
Map section page 154
Both CCC and Hadley project a considerable contraction in range northward and a substantial loss in abundance throughout the Eastern United States for this species, which is associated with the predicted near or total extirpation of balsam fir. The persistence of the purple finch in much of New England and the northern portions of Minnesota, Wisconsin, and Michigan corresponds to the persistence of eastern hemlock in those areas.

House Finch
(Carpodacus mexicanus)
Map section page 156
Both CCC and Hadley project losses in abundance throughout much of the range of this species, which is influenced by sweet birch, sourwood, and black cherry. Because the concentration of the house finch in the Northeast reflects its release in New York during the 1940s, it might not yet be in equilibrium with its environment. As a result, our model could change over time due to factors that are unrelated to climate change.

American Goldfinch
(Carduelis tristis)
Map section page 158
Because the distribution of this species is shaped primarily by climate variables, particularly average summer temperature, both CCC and Hadley project extensive losses in abundance across the range of the American goldfinch. The loss in abundance is greater under CCC than Hadley.

Vesper Sparrow
(Pooecetes gramineus)
Map section page 160
Both the CCC and Hadley scenarios project substantial losses in sparrow abundance and a northern contraction in range, which is dominated by January temperatures.

Savannah Sparrow
(Passerculus sandwichensis)
Map section page 162
Both CCC and Hadley project substantial decreases in the abundance and range (northward) of this species, which is dominated by average yearly temperature. The contraction in range is greater under CCC than Hadley.

Grasshopper Sparrow
(Ammodranus savannarum)
Map section page 164
Both CCC and Hadley project decreases in the abundance and range of the grasshopper sparrow. Since the major predictors in its model (elevation and the range of red maple) are not anticipated to change under the two climate scenarios, the shifts in our model depend on the abundance of Virginia pine and drought sensitivity in July and August.

White-throated Sparrow
(Zonotrichia albicollis)
Map section page 166
The contraction in range northward projected for this species corresponds to the predicted near or total extirpation of balsam fir in the Eastern United States. Hadley predicts remnant populations of the sparrow in Maine, Vermont, New Hampshire, and portions of New York and Minnesota due to the persistence of balsam fir and eastern hemlock in those areas.

Chipping Sparrow
(Spizella passerina)
Map section page 168
Both CCC and Hadley project widespread losses in the abundance over the entire range of this species, with only minor local increases. Much of this predicted loss is linked to projected losses of northern red oak, though changes in potential evapotranspiration and summer temperatures are contributing factors.

Clay-colored Sparrow
(Spizella pallida)
Map section page 170
Both CCC and Hadley project a substantial contraction in range and a decrease in abundance for this temperature-sensitive species. CCC predicts total extirpation while Hadley projects remnant populations in several northern counties of Minnesota.

Field Sparrow
(Spizella pusilla)
Map section page 172
Projected increases in abundance in the Northern States result from shifts in the distribution of balsam fir and warmer winter temperatures. In the South, predicted decreases in abundance correspond to shifts in the distribution of northern red oak (CCC) and changes in climate (Hadley).

Dark-eyed Junco
(Junco hyemalis)
Map section page 174
Both CCC and Hadley project substantial decreases in conjunction with predicted losses of striped maple. Both scenarios also project major refuges in the Appalachians at higher elevations; Hadley also projects additional populations in Maine and Minnesota.

Bachman's Sparrow
(Aimophila aestivalis)
Map section page 176
Both CCC and Hadley project increases in range and abundance for this southern species. Expansion northward is associated with the future distribution of slash pine as well as increases in average annual temperature. The only predicted decrease in abundance is associated with changes in summer drought in Florida.

Song Sparrow
(Melospiza melodia)
Map section page 178
Both CCC and Hadley predict a contraction in range northward and a decrease in abundance due to warming conditions. Abundance will remain high only in the Appalachians, where the persistence of chestnut oak, which is favored by the song sparrow, is projected.

Lincoln's Sparrow
(Melospiza lincolnii)
Map section page 180
Near (Hadley) or total (CCC) extirpation is projected for this northern species in the Eastern United States. Our model is dominated by balsam fir and Lincoln's sparrow is projected to follow the retreat of fir into Canada.

Swamp Sparrow
(Melospiza georgiana)
Map section page 182
This species model is closely associated with quaking aspen, for which substantial losses are projected. CCC predicts a contraction in range nearly to the Canadian border, while Hadley projects continued persistence throughout much of New England, western New York, Wisconsin, North Dakota, Minnesota, and northern Michigan.

Eastern Towhee
(Pipilo erythrophthalmus)
Maps section page 184
This species is projected to decrease in abundance across the Eastern United States in association with a corresponding loss of yellow-popular and changes in annual precipitation and seasonality. Projected population increases in Iowa, southern Wisconsin, Illinois Missouri, Nebraska, and Kansas are associated with predicted local increases in yellow-poplar.

Northern Cardinal
(Cardinalis cardinalis)
Map section page 186
Projected increases in temperature by CCC and Hadley allow for potential increases in abundance in the northern areas for this species, which is strongly influenced by low winter temperatures.

Rose-breasted Grosbeak
(Pheucticus ludovicianus)
Map section page 188
Decreases in abundance and a contraction in range northward are projected for this species. These changes are dominated by winter temperatures, and also are linked to the predicted decrease in the abundance of quaking aspen.

Blue Grosbeak
(Guiraca caerulea)
Map section page 190
Both CCC and Hadley project a dramatic expansion in range northward that is driven by predicted increases in yearly temperature and potential evapotranspiration. Also predicted is a substantial population increase in association with projected increases in cherrybark oak and loblolly pine.

Indigo Bunting
(Passerina cyanea)
Map section page 192
A predicted decrease in abundance is the South corresponds to projected increases in yearly temperature, with the indigo bunting confined to a narrow band from South Carolina through the southern portions of Georgia, Alabama, Mississippi, and Louisiana (Hadley). CCC projects continued persistence in Oklahoma south to the Gulf Coast. Because this species is also closely associated with precipitation, Hadley projects a minor overall increase in abundance due to significant increases in precipitation in the northwestern portion of the study area.

Painted Bunting
(Passerina ciris)
Map section page 194
This species changes habitats regionally, though often concentrated in scrub and shrub environments not quantified within our model. This may be why our model slightly overgeneralizes the distribution of the bunting to include Mississippi, Alabama, and Georgia. Because this species model is dominated by summer temperatures, Hadley projects an increase in abundance within its current range, with expansion into Maryland and southern Nebraska. CCC projects an expansion northward into South Dakota and much of Illinois and Indiana.

Dickcissel
(Spiza americana)
Map section page 196
An expansion in range is projected for this species, particularly by CCC. Because this is primarily a grassland and cropland species and the northern edge of its range has been linked with sorghum planting (unpublished data), the ability of the dickcissel to expand into heavily forested eastern counties might be restricted.

Summer Tanager
(Piranga rubra)
Map section page 198
Increases in abundance and range northward are projected for this southern species, which is dominated by winter temperatures even though the summer tanager occupies the Eastern United States only during the summer (breeding) months. This suggests that this temperature association is indirect.

Purple Martin
(Progne subis)
Map section page 200
This species has a complex distribution, with areas of locally high and low abundance throughout much of the Eastern United States. As a result, our model overgeneralized abundance. Both CCC and Hadley project an increase in abundance, which is linked to the distribution of sweetgum (Iverson et al. 1999a).

Cliff Swallow
(Petrochelidon pyrrhonota)
Map section page 202
Both CCC and Hadley project a contraction in range northward for this species, which is influenced by several climate variables, particularly winter temperatures.

Barn Swallow
(Hirundo rustica)
Map section page 204
Both CCC and Hadley predict only slight decreases in the abundance of this ubiquitous species, which is influenced by winter temperatures. Decreases are projected from South Carolina west to Texas and eastern Oklahoma.

Tree Swallow
(Tachycineta bicolor)
Map section page 206
Our model shows a strong correlation with the distribution of quaking aspen. CCC projects a contraction in range northward to North Dakota, the northern portions of Minnesota and Wisconsin, Michigan's Upper Peninsula, and northern New England. The predicted retreat of the tree swallow is less severe under Hadley. Our model failed to capture small populations of this species in Arkansas, Kentucky, southern Illinois, and Indiana.

Bank Swallow
(Riparia riparia)
Map section page 208
Both CCC and Hadley project a significant decrease in the abundance of this species, which is sensitive to annual temperature. CCC predicts greater contraction in range northward than Hadley. Although our model reasonably depicts the current range, it overgeneralized the patchy nature of the current distribution of the bank swallow.

Cedar Waxwing
(Bombycilla cedrorum)
Map section page 210
Both CCC and Hadley project a substantial decrease in the range and population of this species across the Eastern United States. These decreases are associated with the projected shifts of potential evapotranspiration (the dominant variable in our model).

Loggerhead Shrike
(Lanius ludovicianus)
Map section page 212
Both CCC and Hadley project an increase in the abundance (greater under CCC) throughout the study area for this species, which is strongly influenced by shifts in July temperatures.

Red-eyed Vireo
(Vireo olivaceus)
Map section page 214
The slight decrease in abundance projected for this species by CCC and Hadley corresponds to the predicted reduction of red maple abundance over much of its current range.

Warbling Vireo
(Vireo gilvus)
Map section page 216
Although our model predicted well the species range, it does not capture the patchy distribution of the warbling vireo. Both CCC and Hadley project a decrease in the abundance of this species. CCC projects a contraction in range northward while Hadley predicts range expansion, primarily in southern Virginia, North Carolina, and Tennessee. These shifts are linked to projected shifts in seasonality.

Yellow-throated Vireo
(Vireo flavifrons)
Map section page 218
Slight increases in abundances primarily in the northern areas projected for this species coincide with a predicted northward shift in the distribution of yellow-poplar. Our model cannot capture the considerable variation in this species' contemporary distribution, so it should be viewed as a rough model of species distribution.

Blue-headed Vireo
(Vireo solitarius)
Map section page 220
The significant contraction in range projected for the blue-headed vireo is expected to follow the predicted retreat of striped maple and balsam fir in the eastern and western portion of its range. The predicted persistence of this species in parts of the Appalachians is related to its sensitivity to elevation.

White-eyed Vireo
(Vireo griseus)
Map section page 222
CCC projects an increase in range throughout the study area and an increase in abundance throughout the northern portion of the range of this species. Hadley projects range expansion into South Dakota, northern Illinois, Michigan, and western New York in conjunction with changes in winter temperatures.

Black-and-white Warbler
(Mniotilta varia)
Map section page 224
Decreases in abundance along the Canadian border and increases elsewhere are associated with a projected decrease in balsam fir and increase in blackgum, respectively. Predicted high populations of this species also are related to the presence of eastern hemlock, indicating a net increase in abundance and range for the black-and-white warbler.

Prothonotary Warbler
(Protonotaria citrea)
Map section page 226
Both CCC and Hadley project a substantial increase in range northward in response to predicted increases in abundance of water oak and winged elm, both of which are found in the bottomland hardwood forests inhabited by the prothonotary warbler. However, an overall decrease in population is projected due to the loss of this species across its southern range.

Worm-eating Warbler
(Helmitheros vermivorus)
Map section page 228
Although the worm-eating warbler is closely associated with the presence of chestnut oak in the Appalachians, CCC projects a decrease in abundance there associated with projected increases in temperature and changes in seasonality. Our model overgeneralized some regional variation in bird density to infer a link with blackgum. We suspect that local factors involving predictors not included in our analysis shape the details of much of the low-density portions of the range of this species. However, these density factors have little effect on our estimates of the future distribution of this bird.

Blue-winged Warbler
(Vermivora pinus)
Map section page 230
The projected contraction northward and decrease in abundance throughout the range of this species parallels the predicted loss of sassafras and changes in potential evapotranspiration. Severe population losses of the blue-winged warbler are predicted in West Virginia, Ohio, and Kentucky, where it currently is the most abundant.

Golden-winged Warbler
(Vermivora chrysoptera)
Map section page 232
Both CCC and Hadley project a contraction in range northward or into the Appalachians at higher elevations in response to predicted major losses of yellow birch and quaking aspen. CCC projects total loss of this species from the western areas within the study area.

Nashville Warbler
(Vermivora ruficapilla)
Map section page 234
CCC projects the total extirpation of this species in the Eastern United States in association with the corresponding predicted near extirpation of balsam fir and shifts in summer temperature. Hadley projects the withdrawal of the Nashville warbler from the southern portion of its range.

Northern Parula
(Parula americana)
Map section page 236
Predicted dramatic losses of this species in the Northern States in connection with predicted losses of balsam fir are expected to be partially offset by population increases along a broad band from Nebraska to Kansas east to Maryland and north along the Massachusetts coast. These increases correspond to predicted increases in the abundance of common persimmon as well as climate changes in the extreme southern portion of the range of this bird.

Yellow Warbler
(Dendroica petechia)
Map section page 238
Both CCC and Hadley project a decrease in abundance and in range northward for this species, which is influenced by July temperatures.

Black-throated Blue Warbler
(Dendroica caerulescens)
Map section page 240
CCC and Hadley each projects both a contraction in range and a decrease in the abundance of this species in Virginia and North Carolina at higher elevations and northward to northwestern New England. These changes are associated with projected substantial decreases in the abundance of striped maple and yellow birch in the study area.

Yellow-rumped Warbler
(Dendroica coronata)
Map section page 242
CCC predicts the total extirpation of this species from the Eastern United States in conjunction with a similar prediction for balsam fir. Hadley projects the persistence of small populations in northwestern New England and in northeastern Minnesota.

Magnolia Warbler
(Dendroica magnolia)
Map section page 244
A significant decrease in the abundance of this northern species throughout its current range is projected in association with the predicted near extirpation of balsam fir. However, the persistence of small populations of the magnolia warbler in the Eastern United States is projected in response to suitable climate and elevation and the presence of yellow birch.

Cerulean Warbler
(Dendroica cerulea)
Map section page 246
Both CCC and Hadley project a decrease in abundance and a shift in range northward in association with similar predictions for both sassafras and sourwood. These tree species were dominant in our model and are common where the cerulean warbler is most abundant.

Blackburnian Warbler
(Dendroica fusca)
Map section page 248
For this species, which is dominated by July temperatures, CCC projects total extirpation from the study area, while Hadley allows a remnant population in northwestern New England and in several counties in Minnesota. These predictions are associated with projected decreases in balsam fir and striped maple.

Yellow-throated Warbler
(Dendroica dominica)
Map section page 250
The predicted decrease in abundance in the southeastern portion of the range of this species is driven largely by projected shifts in winter temperatures and in potential evapotranspiration. Evidence of overgeneralization within the model might negate the apparent additional influence of yellow-poplar, pignut hickory, and swamp tupelo.

Black-throated Green Warbler
(Dendroica virens)
Map section page 252
Substantial decreases in abundance and contraction in range predicted for this species are associated with predicted losses of balsam fir, striped maple, and yellow birch resulting from climate change.

Pine Warbler
(Dendroica pinus)
Map section page 254
Although this species is dominated by the abundance of loblolly pine, there are disjunct populations along the Canadian border that are associated with balsam fir. The loss of these northern populations projected by CCC likely will be offset by predicted gains in the South. Hadley predicts more widespread decreases in abundance and a substantial net population loss.

Prairie Warbler
(Dendroica discolor)
Map section page 256
The expansion in range northward projected for this species is related to the presence of blackgum and sourwood. A decrease in the abundance of the prairie warbler in the Southeast is associated with predicted changes in precipitation patterns.

Ovenbird
(Seiurus aurocapillus)
Map section page 258
Both CCC and Hadley project a substantial decrease in abundance and a contraction in range northward for this species. In the southern portion of its range, the ovenbird is expected to retreat into the Appalachians. Our model, which is dominated by annual temperatures and the abundance of red maple and eastern white pine, projects that substantial numbers of this species will persist in the northern areas where an increase in white pine is predicted.

Northern Waterthrush
(Seiurus noveboracensis)
Map section page 260
Both CCC and Hadley project a decrease in abundance and contraction in range northward in association with the predicted loss of balsam fir. However, CCC projects remnant populations in northwestern New England and several counties in New York due to the presence of yellow birch, while Hadley predicts the persistence of the northern waterthrush in several additional counties in New England and Michigan, Wisconsin, and northern Minnesota.

Kentucky Warbler
(Oporornis formosus)
Map section page 262
Both Hadley and CCC project an increase in abundance and expansion in range northward resulting from changes in winter temperatures. Also predicted is a decrease in abundance in the southern portion of the range of the Kentucky warbler due to a predicted shift northward in the distribution of white ash.

Mourning Warbler
(Oporornis philadelphia)
Map section page 264
CCC projects the total extirpation of this species in conjunction with a similar prediction for northern white-cedar. Hadley predicts the persistence of the mourning warbler in portions of Minnesota and Michigan and in the northwestern New England in association with projected changes in summer temperatures and precipitation.

Common Yellowthroat
(Geothlypis trichas)
Map section page 266
A substantial decrease in abundance within its current range is predicted for the common yellowthroat, largely in response to projected shifts in potential evapotranspiration.

Yellow-breasted Chat
(Icteria virens)
Map section page 268
The projected expansion in the range of this species throughout New England and west into Minnesota and South Dakota is expected to be offset largely by a predicted decrease in abundance along the Gulf Coast and southern Atlantic States due to higher winter temperatures.

Hooded Warbler
(Wilsonia citrina)
Map section page 270
CCC projects an increase in abundance and an expansion in range northward into Wisconsin, the central counties of Michigan, and along coastal Maine. Both CCC and Hadley project a decrease in abundance along the Appalachians and Gulf and Atlantic Coasts. Seasonality is the dominant predictor in our model and drives much of the projected changes for this species.

Canada Warbler
(Wilsonia canadensis)
Map section page 272
Projected substantial decreases in the abundance and range of this species by CCC and Hadley are closely associated with predicted losses of balsam fir, striped maple, and yellow birch.

American Redstart
(Setophaga ruticilla)
Map section page 274
A decrease in abundance in the northern portion of its range, particularly in Michigan, Wisconsin, and Minnesota, is predicted for this species. However, these losses likely will be offset by a projected increase in abundance and expansion in range from Illinois west to eastern Nebraska and Kansas. These shifts are predominantly in conjunction with predicted changes in average July and yearly temperatures.

House Sparrow
(Passer domesticus)
Map section page 276
This ubiquitous, exotic species, which was introduced to the United States during the 19th century, is strongly associated with urban areas and agricultural lands. Both CCC and Hadley project only a slight increase in abundance in the Northern States resulting from predicted climate change.

Northern Mockingbird
(Mimus polyglottos)
Map section page 278
An increase in abundance throughout the northern third of the study area is predicted for this species, which is dominated by January temperatures. Our model overgeneralized the current range of the mockingbird into Wisconsin, Minnesota, and the Dakotas.

Gray Catbird
(Dumetella carolinensis)
Map section page 280
Decreases in abundance in the central portion of the study area along with additional losses to the north (CCC) and in the southern Atlantic States (Hadley) are predicted for this species, which is dominated by July temperatures.

Brown Thrasher
(Toxostoma rufum)
Map section page 282
This species is commonly associated with regenerating forests and is scarce in heavily forested areas. The dominance of eastern hemlock, a shade-tolerant species, in our model serves as an indicator of heavily forested areas. The northward population shift projected for the brown thrasher is driven by expected shifts in both the abundance of eastern hemlock and July temperatures.

Carolina Wren
(Thryothorus ludovicianus)
Map section page 284
Both CCC and Hadley project an increase in abundance and expansion in range northward for this species, which is dominated by winter temperatures.

House Wren
(Troglodytes aedon)
Map section page 286
Both CCC and Hadley project a decrease in abundance and contraction in range northward, resulting from a predicted increase in winter temperatures. Both scenarios project a band (wide under CCC vs. narrow under Hadley) of losses from Kansas to western North Carolina and north along coastal New England.

Winter Wren
(Troglodytes troglodytes)
Map section page 288
A decrease in abundance and contraction in range are predicted for this species. The winter wren is associated with older coniferous forests, and our model may be capturing this association by the dominance of balsam fir in the species model. Both CCC and Hadley project remnant populations (slightly higher under Hadley) in western Maine, northern Vermont, New Hampshire, and New York.

Sedge Wren
(Cistothorus platensis)
Map section page 290
Both CCC and Hadley project a decrease in abundance and contraction in range for this species, which is dominated by January temperatures. CCC predicts a more severe contraction, with low populations persisting in Minnesota, southern Wisconsin, and Michigan. Our model slightly overgeneralized the range of the sedge wren into northwestern New England.

Brown Creeper
(Certhia americana)
Map section page 292
This species feeds on insects and forages directly on the trunks of numerous tree species for which decreases in abundance are predicted. As a result, both CCC and Hadley project a decrease in the abundance of the brown creeper, with remnant populations in New England, New York, Pennsylvania, Michigan, Wisconsin, and Minnesota.

White-breasted Nuthatch
(Sitta carolinensis)
Map section page 294
Both CCC and Hadley project an increase in abundance and expansion in range southward for this species in response to projected changes in late-summer temperatures. This cavity-nesting species forages directly on tree trunks and is closely associated with mature forests, particularly those dominated by northern red oak.

Red-breasted Nuthatch
(Sitta canadensis)
Map section page 296
The predicted decrease in the abundance of this species is linked to the predicted loss of balsam fir. CCC projects remnant populations only in northwestern New England; Hadley predicts the persistence of the red-breasted nuthatch across the northern portion of the study area.

Brown-headed Nuthatch
(Sitta pusilla)
Map section page 298
Both CCC and Hadley project a decrease in the abundance of this species in east Texas, Louisiana, Arkansas, and along the southeastern Atlantic Coast, resulting in a net loss in population under Hadley. CCC predicts an expansion in range northward to Kansas and Delaware in response to the projected increase in winter temperatures.

Tufted Titmouse
(Baeolophus bicolor)
Map section page 300
Both CCC and Hadley project an increase in abundance (particularly to the north) within the current range of this species. In our model, January temperature is the dominant predictor.

Black-capped Chickadee
(Poecile atricapillus)
Map section page 302
Both CCC and Hadley project a decrease in abundance and contraction in range northward in response to the projected shift in January temperatures and the projected decrease in the abundance of yellow birch. Although certain counties in Georgia and Florida appear to be suitable for this species under the CCC scenario, the black-capped chickadee is unlikely to expand into this region due to intense competition from the Carolina chickadee.

Blue-gray Gnatcatcher
(Polioptila caerulea)
Map section page 304
The predicted increase in the abundance of this species across the northern areas and its possible expansion in range northward are linked to January temperatures and the projected shift northward in the distribution of flowering dogwood.

Wood Thrush
(Hylocichla mustelina)
Map section page 306
Our model for this species reflects its breeding habitat in eastern broadleaf forests, with strong correlations with red maple, yellow-poplar, and American beech. Both CCC and Hadley predict reductions in numbers over its range in eastern forests, largely paralleling projections for these tree species by Iverson et al. (1999a).

Veery
(Cathharus fuscescens)
Map section page 308
Both CCC and Hadley project a substantial decrease in abundance and a contraction in range for the veery in the Eastern United States. These losses are in conjunction with the predicted contraction in the range of eastern white pine, decrease in abundance of sweet birch, and climate shifts.

Swainson's Thrush
(Catharus ustulatus)
Map section page 310
CCC predicts the total extirpation of this predominantly northern species from the Eastern United States in association with a similar prediction for balsam fir. Hadley projects relict populations in northwestern New England and in one county in Minnesota.

Hermit Thrush
(Catharus guttatus)
Map section page 312
This species breeds in moist forests containing balsam fir and eastern hemlock. The predicted decrease in abundance and contraction in range for the hermit thrush corresponds to similar losses predicted for those tree species. Both CCC and Hadley project remnant populations in New England, Pennsylvania, Michigan, Wisconsin, and Minnesota.

American Robin
(Turdus migratorius)
Map section page 314
The breeding distribution of this species is strongly associated with January temperatures and weakly correlated with summer temperatures. As a result, the range of the American robin is projected to expand southward, with populations reaching the Gulf Coast as far east as the panhandle of Florida. However, some local decreases within the southern portion of its current range also are predicted in response to expected changes in seasonality.

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Matthews, Stephen; O'Connor, Raymond; Iverson, Louis R.; Prasad, Anantha M. 2004. **Atlas of climate change effects in 150 bird species of the Eastern United States.** Gen. Tech. Rep. NE-318. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 340 p.

This atlas documents the current and potential future distribution of 150 common bird species in the Eastern United States. Distribution data for individual species were derived from the Breeding Bird Survey (BBS) from 1981 to 1990. Regression tree analysis was used to model the BBS data as functions of contemporary climate and elevation variables and the current distribution of 68 tree species that occurred in the bird models. The model for each bird species is described. These models were projected onto two scenarios of global climate change. Depending on the global climate model used, as many as 78 bird species are projected to decrease in abundance by at least 25 percent, while as many as 33 species are projected to increase in abundance by at least 25 percent.

Keywords: birds; global climate change; trees; species distributions; range; distribution; regression tree analysis

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