Modeling the Potential Impacts of Climate Change on the Summer Distributions of Massachusetts Passerines

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Introduction

The Earth's climate is changing. According to the World Meteorological Organization (1999), the 1990s was the warmest decade, and the 1900s the warmest century of the last 1000 years. Of the more than 100 years for which instrumental records are available, 1998 was the warmest year on record, and seven of the top ten warmest years occurred in the 1990s. Even 1999, largely expected to be cooler than average due to the effects of La Niña, was the fifth warmest year on record and the twenty-first year in a row where the average global surface temperature was above normal. The annual global mean temperature is now 1.3^{o}F (0.7^{o}C) above that recorded at the beginning of the century. Limited data from other sources indicate that the global mean temperature for the twentieth century is at least as warm as any other period since approximately 1400 A.D. (Intergovernmental Panel on Climate Change [IPCC] 1996).

Water vapor, carbon dioxide (CO_2) and some trace gases in the Earth's atmosphere act much like the glass in a greenhouse, helping to retain heat by absorbing infrared radiation. This greenhouse effect acts to keep the Earth's surface temperature significantly warmer than it would otherwise be. Compared with preindustrial times, there have been significant increases in the amount of CO_2, methane (CH_4), and nitrous oxide (N_2O) in the atmosphere (IPCC 1996), leading to an enhancement of the natural greenhouse effect. Increases in these greenhouse gases can be attributed largely to human activities including the burning of fossil fuels and land use changes (such as deforestation). This information, in part, led to the IPCC (1996) statement that "the balance of evidence suggests that there is a discernable human influence on global climate." The increases in greenhouse gases (past and projected), coupled with the length of time these gases remain in the atmosphere, are expected to cause a continued increase in global temperatures. Models estimate that the average global temperature, relative to 1990 values, will rise by 3.6^{o}F (range 1.8^{o}F - 6.3^{o}F; 2^{o}C, range 1^{o}C - 3.5^{o}C) by the year 2100 (IPCC 1996).

Warming due to increases in greenhouse gases is expected to be even greater in some areas, especially land areas in the Northern Hemisphere. For the northeastern United States, models project an annual average temperature increase of between 5^{o}F and 10^{o}F (2.8^{o}C - 5.6^{o}C; Vegetation/Ecosystem Modeling and Analysis Project [VEMAP] 2000). Many climate models also project an increase in evaporation leading to some increases in precipitation but, when combined with temperature increases, to overall declines in soil moisture. This could lead to reductions in runoff and possibly lead to reduced river flows and lower lake levels (USEPA 1997). These changes could have an effect on Massachusetts vegetation as well. Some models estimate that thirty to sixty percent of the state's hardwood forests could ultimately be replaced by a mix of pines and hardwoods (*op. cit.*). Some of the species that may be extirpated include Sugar Maple, Yellow Birch, hemlock and beech (Davis and Zabinski 1992).

The summer ranges of birds are often assumed to be tightly linked to particular habitats. This is only partially true. While certain species are usually only found in certain habitats (e.g., Kirtland's Warbler breeds in Jack Pines), others are more flexible in their habitat use. Species found in a particular habitat type throughout their summer range may not be found in apparently equivalent habitat north or south of their current distribution. Birds are also limited in their distributions by their physiology and the availability of food. The link between physiology and the winter distributions of many species is well known (Kendeigh 1934; Root 1988a, 1988b); recent research shows that physiology also plays a strong role in limiting summer distribution (Dawson 1992; T. Martin, *pers. comm.*). While habitat selection, food availability, and competition may all play a role in influencing the local distribution of a given bird species, looking at a species' overall distribution often yields different results. Building on earlier work that found that many winter bird distributions are associated with climate variables (Root 1988a, 1988b), this study examines the association between summer bird distributions and climate and how these distributions may change with climate change.

Ultimately, the greatest impact on wildlife and vegetation may not be from climate change itself, but rather from the rate of change. Given enough time, many species would likely be able to adapt to shifts in the climate. However, the current projected rate of warming is thought to be greater than has occurred at any time in the last 10,000 years (IPCC 1996). This rate could lead to alterations in Massachusetts avifauna.

Methods

To determine how the summer distributions of birds might change, it is first necessary to look at whether there is any association between bird distributions and climate. If an association exists, then an examination of projected future climates can be used to see how bird distributions might change. I used logisitic regression to develop models of the association between bird distributions (from Breeding Bird Survey data) and eighteen climate variables. These climate variables included average seasonal temperature and precipitation, temperature and precipitation ranges, extreme values (e.g., temperature in the hottest and coldest months, precipitation in the wettest and driest months) and combinations (e.g., precipitation in the hottest month, temperature in the driest month). The climate variables used in these models act as surrogates for the many factors that may limit a species' distribution, including physiology, habitat, and food availability and are similar to those used in other bioclimatic studies. The models that were developed for this study were then checked to see how well they predicted the occurrence of a species at an independent location (statistically validated). The models were also checked to see how well the predicted species distribution map (Fig. 1B) matched a map of the actual distribution (Fig. 1A) based on similar bird data (Price et al. 1995). The results indicated that at least a portion of the summer distributions of many North American birds can be modeled quite well based on climate alone.

The next step was to examine how bird distributions might change in response to a changing climate. For this study I used the climate projections from the Canadian Climate Center's General Circulation Model (CCC-GCM2). This model projects what the average climate conditions may be once CO_2 has doubled from pre-industrial levels, sometime in the next 75 to 100 years, and is one of the standard models used in impact analyses. The differences between the modeled current climate and the modeled future $2xCO_2$ climate, both derived from the CCC-GCM2, were then applied to the original climate variables used in developing the bird-climate models. This was done in order to correct for some of the potential errors in the climate change model itself and is a standard practice in climate change impact studies (versus simply using the model's projection of future climate). For example, for a given point, the difference in average summer temperature between the current and future (both model-derived) climate may be $+2^oC$. This value is then added to the actual average summer temperature at that point to estimate what the climate at that point may be with a doubling of CO_2. All of the bird distribution models were run using the $2xCO_2$-derived climate variables. The combined bird-$2xCO_2$ climate models were then used to create maps of the projected summer distributions of many North American birds (see Figure 1C for an example). A complete explanation of the methods used to develop the models and maps has been published elsewhere (Price 1995, Price in press).

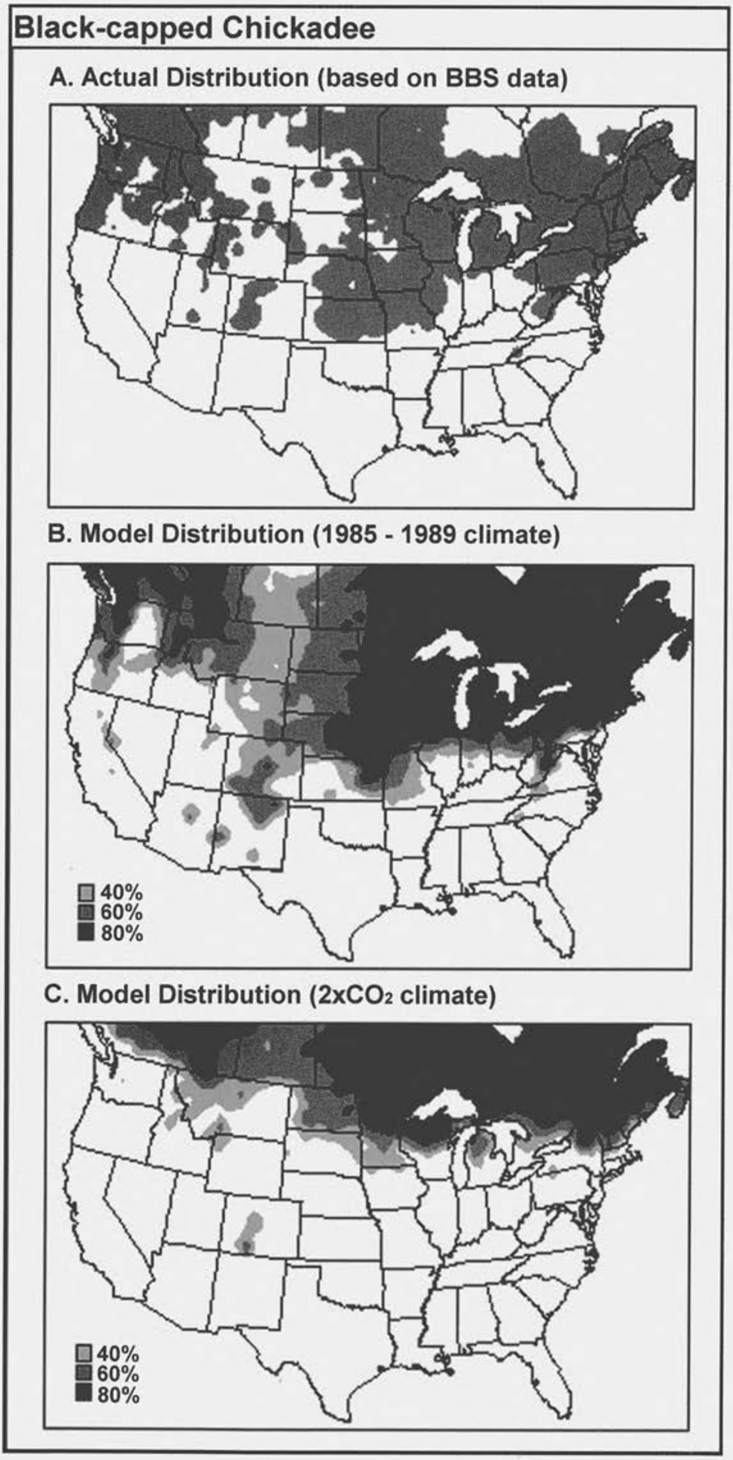
Distributional models and maps have been developed for almost all passerine bird species. While the results of the models cannot be used to look at the fine points of how a given species' distribution might change, they can provide an impression of the direction and potential magnitude of the change. The following list of changes to Massachusetts avifauna was prepared by comparing the maps of projected summer bird ranges with the maps and information found in *Birds of Massachusetts* (Veit and Petersen 1993).

Results

Species that may be extirpated as summer residents in Massachusetts

Olive-sided Flycatcher, Yellow-bellied Flycatcher, Alder Flycatcher, Willow Flycatcher, Least Flycatcher, Tree Swallow, Bank Swallow, Cliff Swallow, Red-breasted Nuthatch, Winter Wren, Blue-headed Vireo, Nashville Warbler, Chestnut-sided Warbler, Magnolia Warbler, Black-throated Blue Warbler, Yellow-rumped Warbler, Black-throated Green Warbler, Blackburnian Warbler, Northern Waterthrush, Mourning Warbler, Hooded Warbler, Canada Warbler, Vesper Sparrow, Savannah Sparrow, Swamp Sparrow, White-throated Sparrow, Dark-eyed Junco, Bobolink, Rusty Blackbird, Purple Finch, Pine Siskin, and Evening Grosbeak.

Facing: Figure 1. **A.** Map depicting the distribution of Black-capped Chickadee as detected by the Breeding Bird Survey. This map is based on the one found in Price et al. (1995). **B.** Map depicting a model of the current distribution of Black-capped Chickadee based solely upon the climate of 1985-1989. Scale represents the probability of the occurrence of the species; shaded areas depict the distribution of the species. **C.** Map depicting the possible distribution of Black-capped Chickadee under the doubled CO_2 climate conditions projected by the CCC-GCM2. Scale represents the probability of the species' occurrence; shaded areas depict the distribution of the species.


Black-capped Chickadee
A. Actual Distribution (based on BBS data)
B. Model Distribution (1985 - 1989 climate)
40%
60%
80%
C. Model Distribution (2xCO2 climate)
40%
60%
80%

Species whose summer range in Massachusetts may contract

Black-capped Chickadee, House Wren, Warbling Vireo, Blue-winged Warbler, Yellow Warbler, American Redstart, Rose-breasted Grosbeak, Song Sparrow, and House Finch.

Species whose summer range in Massachusetts may expand

Acadian Flycatcher, Horned Lark, Purple Martin, Carolina Wren, Northern Mockingbird, White-eyed Vireo, Yellow-throated Vireo, Pine Warbler, Prairie Warbler, Cerulean Warbler, Prothonotary Warbler, Louisiana Waterthrush, Yellow-breasted Chat, Grasshopper Sparrow, and Orchard Oriole.

Species whose future range may include Massachusetts

Carolina Chickadee, Loggerhead Shrike, Yellow-throated Warbler, Kentucky Warbler, Summer Tanager, Blue Grosbeak, and Dickcissel.

Discussion

These lists are not all-inclusive, since the results obtained from the models of some species were not adequate to assess how their ranges might change. Nor do the lists include those species whose ranges may undergo little change. Finally, these lists are based on the output from a single, commonly used climate model. There are many different models, and the results vary between them. While the magnitude of the temperature increase is somewhat similar between models, the projected precipitation changes are often different. The use of output from different climate models may therefore yield somewhat different results. In addition, the geographic scale of these models, like those of the underlying climate change model, is quite coarse. As such, the models are unable to take into account localized topographic changes and the possible existence of suitable microclimates — along rivers, for example. Therefore, some of the species projected to be extirpated from an area may be able to persist if a suitable microclimate is available, especially in higher montane areas, on north facing slopes, or in riparian areas.

Projected sea-level rise could also impact Massachusetts avifauna. In many areas of the state sea levels are already rising, mostly due to land subsidence. By the year 2100, models project the sea level at Cape Cod to have risen between ten and forty inches, with a fifty percent probability of a twenty inch rise (USEPA 1997). This could lead to increased erosion of migratory bird staging and breeding areas. Coastal wetlands could also be inundated leading to greater losses of this avian habitat. In some areas these wetlands might be able to shift inland, depending upon the rate of change and what barriers exist.

How quickly these distributional changes might occur is unknown. The rate of change will largely depend on whether the limits to a given species' distribution are more closely linked with climate, vegetation, or some other factor. The rate of change will also likely be tied to the rate of change of the climate itself. If the climate changes relatively slowly, then species may be able to adapt. However, changes could occur relatively quickly. In a pilot study I found that the average latitude of occurrence of forty-three percent of the warblers has already shifted significantly farther north in the last twenty years, by an average distance of greater than forty-three miles (70 km). In contrast, only three species (6 percent) were found significantly farther south. In most of the remaining warbler species, the latitudinal change showed a northward trend, but not enough to be statistically significant (Price, unpublished data).

Shifts in the distributions of individual species are only part of the story. It is unlikely that the ranges of coexisting species will shift in concert. Bird communities, as we currently know them, will probably look quite different in the future. As species move, they most likely will face new prey, predators, and competitors. So-called optimal habitats may no longer exist, at least in the short term. The potential rates-of-change of birds and the plants that shape their habitats are often quite different. While most birds may be able to respond quickly to a changing climate, the ranges of plants may take from decades to centuries to move (Davis and Zabinski 1992).

Do changes in bird distributions even matter? Ignoring aesthetic and stewardship issues (both important), there are still cultural, economic and ecological reasons to be concerned about changes in bird distributions. For example, how will Massachusetts citizens react to the replacement of their Yankee state bird by a southern interloper? True, many people will not be able to tell the two species apart but they may notice the decidedly southern accent of the new species. Birdwatching also contributes to Massachusetts' economic health. Watching and feeding wildlife (primarily birds) contributed more than $595 million to Massachusetts' economy in 1996 (US DOI 1997). Estimating how changes in bird distributions might affect the economics of watching and feeding birds is difficult. Although some birdwatchers might adjust to changes in distributions and diminished species richness, there could also be changes in the amount of money spent watching wildlife in Massachusetts as people travel elsewhere to see the birds.

Birds are critical components of their ecosystems. The ecological services provided by birds include, but are not limited to, seed dispersal, plant pollination, and pest control. Their role in the control of economically important insect pests should not be underestimated. Birds have been known to eat up to ninety-eight percent of the overwintering Codling Moth (*Cydia pomonella*) larvae in orchards (Kirk et al. 1996), and several species of warblers are thought to be largely responsible for holding down numbers of Spruce Budworm (*Choristoneura fumiferana*) larvae, eating up to eighty-four percent of the non-outbreak larvae (Crawford and Jennings 1989).

In summary, a high probability exists that climate change could cause changes in the distributions of birds. Even a relatively small change in average temperature could impact bird distributions within the state. These changes could occur (and probably are occurring) relatively quickly. While these changes may have some ecological and, possibly, economic effects, the magnitude of these effects is unknown.

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