Massachusetts Birds and Our Changing Climate

State of the Birds

Mass Audubon
Protecting the nature *of Massachusetts*

Report No. 3 // September 2017

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Cover photo: Currently one of our most common breeding birds in Massachusetts, the Black-capped Chickadee faces an uncertain future in the state.

WELCOME

Birds to the Rescue—Once Again!

Bald Eagle

OUR KNOWLEDGE of the earth's atmosphere and its relationship to the planet's biodiversity and human population is growing, and the relationship is proving to be increasingly complicated. This complexity may make the details of the underlying science nearly incomprehensible to all but a few specialists. But the mounting evidence of shrinking glaciers, rising sea level, increasing ocean acidification, and sustained runs of record-setting weather anomalies—all predicted by chemists and atmospheric scientists—leads us toward one conclusion: The rapid increase in greenhouse gases caused by human activities is changing our planet.

The discrepancy between scientists' knowledge and widespread understanding is potentially dangerous, since actions to thwart a global crisis need to be supported by a broad consensus of the world's population, and people (with good reason) are often reluctant to take strong actions against a threat that they do not fully comprehend or believe in. In addition, climate change is gradual in relation to human life spans, so unless you live on a low-lying oceanic island or in a region that already has an extreme climate, you are unlikely to perceive the changes in your environment as especially dire.

Furthermore, the effects of climate change are notably variable, even within a small place such as Massachusetts, and are actually perceived as positive results in some places. This variability is confusing and undermines the credibility of the argument that universal devastation is at hand. Finally, in an age of social media where alternative "facts" compete with the real kind, where science is demeaned as elitism used to manipulate "ordinary people," and where everyone can find an echo chamber to reinforce unfounded beliefs, it is increasingly difficult to forge coalitions of common interests to effect positive change.

Enter that durable avian meme, the canary in the coal mine. This symbolic evocation of environmental danger forewarned derives its power from a sense that (1) non-human animals, especially birds, are more sensitive to atmospheric change than people are and (2) their message requires no analysis or bewildering explanation by pointy-headed scientists: When Tweety starts wobbling on his perch, it's time to take corrective action in the name of survival.

The most recent vivid example of a looming manmade disaster averted by birds occurred in the 1960s, when birds raised the alarm against the indiscriminate use of pesticides, especially DDT, as eloquently documented in the ominously titled *Silent Spring* by Rachel Carson. Birds did this by dying conspicuously in large numbers. Thousands of dead and dying robins, chickadees, woodpeckers, warblers, and other beloved backyard birds were swept into piles by clean-up crews following the passage of "mosquito trucks" blowing insecticide into the foliage of suburban trees. Subsequent research determined that in addition to direct poisoning, DDT, concentrating up the food chain, inhibited the formation of eggshells by top avian predators, thus shutting down reproduction and eventually putting the Bald Eagle, Peregrine Falcon, and Osprey on the state or federal endangered species lists.

Outlawing the use of DDT in the United States in 1972, was, of course, an act of enlightened self-interest. Ordinary people quickly figured out that if pesticides in the air and water were killing birds outright and damaging their reproductive systems, those chemicals were very likely bad for humans as well—though it took a decade or more of public outcry to convince legislators to take action. But would our present aversion to the promiscuous use of pesticides have been awakened if the problem had been articulated only in the scientific literature? Though carefully researched, *Silent Spring* was widely criticized as unscientific by some credentialed researchers, especially those employed or supported by the chemical and agricultural industries. Additionally, would our alarm have been as high and immediate if instead of dead songbirds falling out of the trees, spraying had resulted "only" in dead squirrels and bats?

In addition to their perceived greater environmental sensitivity, birds occupy a uniquely positive place in our hearts and minds. They seem to represent nature at its most benign and life-enhancing. They are often beautiful. Their varied behaviors are often fascinating or amusing or remind us of ourselves (think of owls or penguins). They sing. And most of them have a skill that almost everyone envies: the ability to fly.

Snowy Egret

The special bond that people feel toward the feathered tribes explains their disproportionate role in the development of the conservation movement. Mass Audubon's founding mothers were able to ignite the public's imagination and eventually make conservation a national priority by promoting a law that prohibited interstate commerce in wildlife products. Exhibit A in their budding protest movement was the slaughter of the "plume birds," egrets and other species that were killed for no better reason than to use their feathers to decorate women's hats. It didn't take long for the case of Snowy Egret v. Greedy Milliner to be decided in favor of the birds and their champions. Is it remotely plausible that the conservation movement could have won over the American public had it been based on the killing of snakes and alligators for use in the leather trade?

In light of all of the above, can birds once again swoop in and save us from another environmental catastrophe—arguably the greatest yet—of our own making? That is the question at the heart of *State of the Birds 2017*, the latest in our series of publications documenting the status of Massachusetts bird life. In it, we tell the stories of bird species that are especially vulnerable to the effects of climate change and the conditions they are likely to face from now until 2050.

As with pesticides, losses for birds due to climate change presage losses in the quality of human life. There will be no room to spread your beach blanket when Piping Plover habitat is gone. And recreational and commercial fishermen are likely to find their quarry in scarce supply once the fish nurseries we call salt marshes go under water.

Piping Plover

There is no credible doubt that the earth's changing climate and its living inhabitants are now on a collision course. Even so, there are many who refuse to acknowledge this, either from self-interest or an understandable denial, based on a lack of knowledge, a distrust of science, a willingness to listen to those who say it is all a hoax, and perhaps an underlying anxiety that it is all true. This third installment of our *State of the Birds* reports is not intended to be alarmist in tone, though you may be forgiven for regarding some of the facts and probabilities presented as alarming. It is, however, a call to action, much like the one Mass Audubon's founders, Harriet Hemenway and Minna Hall, put out in 1896—in effect a plea to keep your eyes on the birds.

— Christopher W. Leahy,
Mass Audubon's Gerard A. Bertrand Chair of Natural History
and Field Ornithology, *emeritus*

EXECUTIVE SUMMARY

AT MASS AUDUBON, we use the best science to inform our education, advocacy, land protection, and conservation efforts, and we work every day to fulfill our vision of a Massachusetts with abundant wildlife and a nature-rich landscape for everyone to enjoy. That commitment is shared with our members and partners and has a long history in our American values. Indeed, we are the nation that has pioneered the protection of wildlife, and Mass Audubon, led by our founding mothers, has been in the forefront since 1896.

Developing a report to summarize the challenges our birds face as the climate changes takes us onto new ground. Our previous editions of *State of the Birds*, released in 2011 and 2013, analyzed data from the field to provide evidence of how our bird populations had changed over time. Those reports looked to the past, measured changes, and identified priority conservation actions.

This report is an effort to look into the future. We use new data to establish the preferred climates for various bird species (their "climate envelopes") and then use projections of the future climate to estimate how the distribution of each species' climate envelope will differ from its current climate envelope distribution by the year 2050.

The changes in climate and sea level that we expect from a warming atmosphere include

- Increased average air temperature year-round
- Longer warm seasons and shorter cold seasons
- More precipitation will fall as rain, rather than snow
- Increased frequency of large precipitation events
- Longer growing seasons
- Continued sea level rise, which is projected to increase an additional 2.4 to 7.4 feet by 2100 in Massachusetts.
- More acidic oceans as carbon dioxide dissolves into the sea

The shifting climate is changing the fundamental way ecosystems work. A few items of highest conservation concern are that

- Urgent action is required.
  - Mass Audubon's previous research indicates 30% of our breeding birds are already declining and are in need of conservation action. Climate change will increase stress on many of those species, as well as additional species, and will do so in both predicted and unpredicted ways. Our climate change projections estimate that 43% of the breeding species we evaluated are Highly Vulnerable to climate change by the year 2050.
- Fundamental processes are being disrupted.
  - Warmer winters will alter marine food webs, affecting a wide range of interconnected fish and wildlife, including fish-eating birds.
  - Increasing temperatures can shift the timing of important events, such as leaf and insect emergence. Those changes in phenology can cause declines in long-distance migrant birds as their arrival on their breeding grounds misses the periods of peak food abundance.

Over 99% of the Osprey's diet is fish.

- Climate change adds stress to already stressed environments. Coastal nesting species are particularly at risk from this additional threat.
  - Rising sea level will reduce nesting areas available for coastal- and salt marsh-nesting birds.
  - Increasing frequency and intensity of storms will contribute to overwash of beaches and salt marsh flooding, adding stress to coastal- and salt marsh-nesting birds.
  - Increasing ocean acidification, caused by atmospheric carbon dioxide dissolving into the ocean, will cause large-scale changes to our shellfish and fish communities. Birds and wildlife that eat marine fish and shellfish will suffer from changes in the abundance of their prey.

One hundred forty three (143) breeding species are evaluated in this report:

- 43% (61 species) are classified as Highly Vulnerable to climate change by the year 2050. An additional 15% (22 species) are classified as Likely Vulnerable.
- 42% (60 species) are classified as Least Vulnerable.
- 70% (7 species) of the salt marsh-nesting species are classified as Highly Vulnerable.
- 56% (9 species) of the coastal-nesting species are classified as Highly Vulnerable.
- 49% (30 species) of the forest breeding species are classified as Highly Vulnerable.
- Our state bird, the Black-capped Chickadee, is Highly Vulnerable, and the projected climate of eastern Massachusetts in 2050 could be unsuitable for the species. Other familiar birds that are Highly Vulnerable in the state, as well as in other continent-wide analyses, are the Yellow-bellied Sapsucker, Ruffed Grouse, Purple Finch, Magnolia Warbler, and White-throated Sparrow.
- Urban- and suburban-nesting birds show the least vulnerability. For 77% (34 species), if climate is the only factor considered, projected climate changes contribute to stable or increasing trends by the year 2050.
- Some species will have an expanding area of suitable climate by 2050. Many of these are urban and suburban nesting species, including the Eastern Kingbird, American Robin, Ruby-throated Hummingbird, Blue Jay, Great Blue Heron, and Orchard Oriole.


Yellow-bellied Sapsucker


American Robin

Protecting our birds, and ourselves, from the most severe projected effects of climate change requires that we support our birds now and reduce our greenhouse gas emissions. This needs to be done at personal, community, state, federal, and international scales. The actions required to achieve these goals largely fall into two basic categories: mitigation (e.g., reducing emissions of greenhouse gases) and adaptation (e.g., reinventing coastal infrastructure to counter sea level rise).

In this report, we provide an overview of the ways that Mass Audubon is already working to ensure that the habitats we manage will continue to support our birds and other wildlife.

In addition, we classify actions that individuals can take into three broad categories:

Protect birds and wildlife at home.

- Keep your cat indoors.
- Landscape your yard for wildlife—and for yourself.
- Reduce window kills by placing feeders closer than 3 feet or farther than 30 feet from a window, and by using window decals to prevent collisions.
- Drink bird-friendly coffee.

Reduce your carbon footprint.

Make the SWITCH

- Make the Switch. Sign up to have your home powered by renewable energy.
- Eat more vegetables, eat less beef, and reduce food waste. Food production has a significant carbon footprint. It takes less fuel to grow vegetables, chicken, and fish than to grow beef. Reducing food waste is also a great way to save money and to reduce your carbon footprint.
- Drive less, and drive smarter. Use mass transit if available, even a few days a week. When replacing your vehicle, choose a car that gets at least 35 mpg. Reduce trips. Carpool to kids' sporting events. Check your tire pressure regularly.

- Aim to reduce the number of flights you take each year, and purchase offsets for greenhouse gas emissions produced by air travel for business or vacations.

Use your voice and take action to advocate for birds, wildlife, and the environment that you cherish.

- Join our Advocacy mailing list to get a list of community action items that will help us protect birds and wildlife. massaudubon.org/advocacy
- Support land protection efforts by Mass Audubon and your local land trusts.
- Get involved in local planning, and support the Community Preservation Act.

Finally, we suggest two significant ways we can ensure we, together as Massachusetts residents, meet global emissions reduction targets:

- Advocate for meeting the greenhouse gas reductions set out in the Paris Agreement.
- Support the efforts of the Commonwealth of Massachusetts to work with other states to stay on track with emissions reductions regardless of the federal position on the Paris Agreement.

Climate change presents enormous challenges for our planet. The threat can feel overwhelming, but if we take meaningful political and personal actions, we can avert the worst projected impacts of climate change.

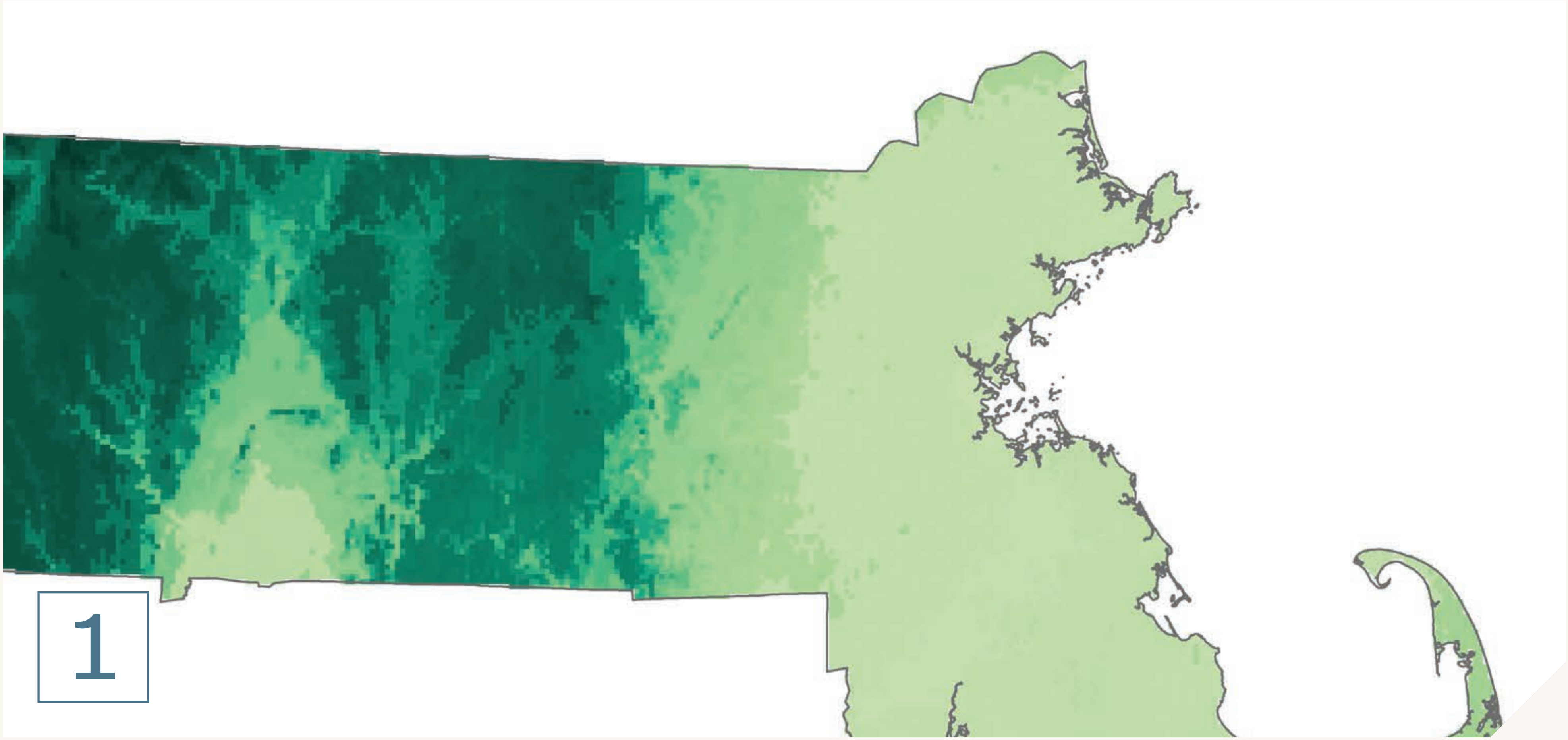
How Do We Respond to Climate Change Threats?

To address the challenges of climate change, we first need to mitigate the central issue: We need to reduce the amount of carbon dioxide and other heat-trapping gases that we put into the atmosphere. We can all contribute to this effort, and we can all be a part of the solution.

At the same time, we need to prepare for the future effects of climate change that are already inevitable. Preparation is increasingly important for owners and managers of conservation land, including land trusts, municipalities, and state and federal agencies. Ecologically, climate change will function as a disturbance, a process that changes an ecosystem. Increased temperatures, changing precipitation patterns, and rising sea level will change the nature of Massachusetts. In response, we must employ a range of strategies to help natural systems adapt to the changes. At Mass Audubon we are using three central concepts to ensure long-term protection and functioning of wildlife habitats:

- **SUPPORTING RESISTANCE** // Ecosystem *resistance* is the capacity of communities or populations to remain essentially unchanged when subjected to a disturbance. A resistant system will absorb and recover from a disturbance. Increasing or maintaining biodiversity is one way to increase the resistance of ecosystems. By supporting resistance in the near term, we will attempt to avoid rapid ecosystem changes.
- **ENHANCING RESILIENCE** // Ecosystem *resilience* is the capacity of a system to absorb disturbance and reorganize while undergoing change, thereby retaining essentially the same identity, structure, functions, and feedbacks. Change is an essential element of resilience. In a resilient ecosystem, disturbance may cause the components, such as species, to change, but the basic functioning of the system will persist. Methods of increasing the resilience of a landscape include restoring aquatic habitat connectivity, allowing beach and salt marsh migration, and ensuring healthy forest regeneration
- **ENSURING REDUNDANCY** // Whole landscapes are more resilient when they consist of a diverse and well-connected network of habitat cores, with each type of habitat represented by several similar, or *redundant*, examples. Increasing redundancy is particularly important for species that have specific requirements for breeding sites, such as colonial-nesting seabirds. If one breeding site is disturbed, a redundant landscape will provide another place for the birds to nest.

Visit our website **massaudubon.org/sotb** for a complete set of our methods and results, as well as links to more success stories about adapting to our changing climate.



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Exploring the Future: Mapping our Breeding Birds in 2050

For some species this is a critical window of opportunity for us to engage in conservation measures that would slow the decline of or buffer the species from the most detrimental climate change effects.

IN PREVIOUS EDITIONS of the *State of the Birds* we used data that had been collected over decades to estimate the trends in the populations of the breeding birds in Massachusetts. From there we developed an evidence-based ranking system to describe our Conservation Concern for each species.

In this edition of *State of the Birds* we are considering the future, and adding information to our Conservation Concern score by developing a Climate Change Vulnerability score. We ask two questions: In light of the additional stress of climate change, how will our breeding birds fare through the year 2050? Which species are projected to benefit from the warming climate, and which face additional stress? This is more than an academic exercise. Developing climate change-driven projections helps us to refine our conservation priorities, and ultimately helps us to set up on-the-ground advocacy, land conservation, science, and education programs.

We looked into the future using a technique called *climate envelope modeling*. This technique requires a series of steps, which we summarize here, and ultimately creates two maps of the range of the suitable climate for each species—one map for the range of current climate suitability, and a second map for the range of future climate suitability.

Modeling the Climate Envelope for Breeding Species

Modeling the Current Climate Conditions for Breeding Species

In order to give each breeding species a Climate Change Vulnerability score we needed to develop a model that, using real bird location data, defined the current climate conditions at both occupied and unoccupied points on a map for each species. The current climate data were drawn from a dataset that uses monthly temperature and precipitation data obtained from weather stations in eastern North America for the years 1960–1990. These data are fitted to millions of cells across the continent, and each cell is approximately 1 km^2. The current bird location data were drawn from eBird records in eastern North America during the months of June and July, are assumed to represent primarily breeding birds, and were not constrained by the year of data collection.

The analysis used the eBird data in conjunction with elevation and 19 climate variables to create a complex equation that predicts the likelihood of a species' occurrence in each of nearly 13 million 1 km^2 cells. For our analysis we clipped the results to restrict the maps to the state of Massachusetts, although the models were built using data from the entire northeastern United States.

The current maps show, for each cell, the likelihood that climatic conditions are suitable for a species. Assuming that these values reflect the likelihood of actual presence of a species, we then calculated the average values across the state for the species' current distribution. The analysis also indicates which of the climate variables were of most importance in the resulting equation.

Modeling the Future Climate Conditions for Breeding Species

Next, we substituted the projected climate values for each of the 19 climate variables for the year 2050 into the equation describing current conditions, and then evaluated how the likelihood of finding each species in each cell might change in the future. We used future climate data that reflects a high emissions scenario (Hadley GEM-2), which assumes that greenhouse gas emissions will continue to increase. As described above, we then made new maps that have a value for each cell in Massachusetts, and calculated the average likelihood of the presence of a species within Massachusetts in the future. These two averages (current and future) were then compared to evaluate projected changes in the distribution of each species within the state.

Uncertainty

The changing climate is quickly transforming our home. Each day the mounting evidence compels us to develop actionable plans for protecting the air, land, and water that sustain our communities and the wildlife that we steward. The scale of projected change, in even the best-case emissions scenarios, is daunting. As with all projections of future conditions, our analysis involves uncertainties. However, the uncertainty of these projections only increases the importance of supporting scientific research on climate change and acting with the best available science to protect the nature of Massachusetts.

Interpreting the Maps: What the Maps Do and Do Not Show

Our models, maps, and statistics estimate only the suitability of the climate across the state for each species. It is essential to remember that birds are not directly responding to the environmental variables used in this analysis. Rather, the environmental variables are surrogates for underlying changes in habitat driven by climate that typically affect distributional patterns of birds.

These projections do not include the possibility that some species may be able to adapt to use climate envelopes that they do not currently occupy. They also do not directly estimate the current or future condition of the vegetation or other components of breeding habitat, the footprint of future development, the effect of greenhouse gas emissions that differ from the Hadley GEM-2 scenario, or the impacts of sea level rise. Further, the models do not include current or future population densities or sizes, and we did not estimate a threshold value of likelihood of occurrence below which a species likely would disappear from a cell, or the entire state. Additionally, sea level rise is not a variable in the projections.

As the climate shifts toward envelopes that are increasingly unsuitable for a species, we anticipate that population declines will be incremental. For some species this is a critical window of opportunity for us to engage in conservation measures (i.e., increasing redundancy, resiliency, and resistance) that would slow the decline of or buffer the species from the most detrimental climate change effects. Such measures could allow some individuals to persist in areas they are projected to have a low likelihood of occupancy.

Coastal Birds Face Additional Challenges

Species that rely on low elevation coastal habitats are vulnerable to the slow-motion declines in climate suitability, but they are at perhaps greater risk to rapid increases in sea level and frequency of intense storms. Most coastal-nesting species are habitat specialists—they will nest only along the immediate coast. The vulnerability of coastal habitats to sea level rise and storm impacts, as well as the lack of redundancy in coastal habitats, puts the salt marsh- and coastal-nesting species at even greater risk than inland species.

Case Study // Interpreting the Climate Envelope Models


Ruffed Grouse drumming display

What the Numbers Mean

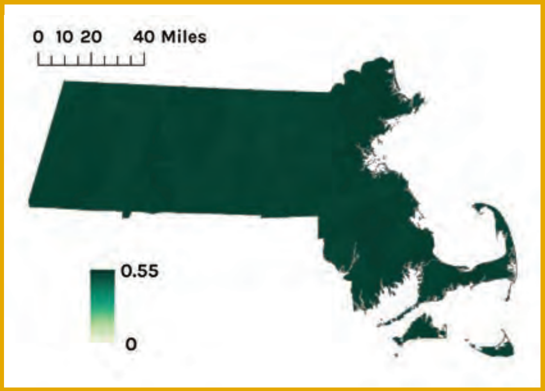
The climate envelope maps show the probability that climate will be suitable for a species at each 1-km² block in Massachusetts. It is important to note that the range of the climate suitability probabilities differs between species. For example, the probability that climate is suitable for Black-capped Chickadees (top right map) ranges from 0 to 0.55 across the state, with the darker green indicating a higher (up to 0.55) probability. However, the probability that climate will be suitable for Ruffed Grouse (bottom right map) ranges from 0 to 0.6 across the state. This means that the maps cannot be directly compared among species since the range of climate suitability probability differs for each species.

Limitations of the Model

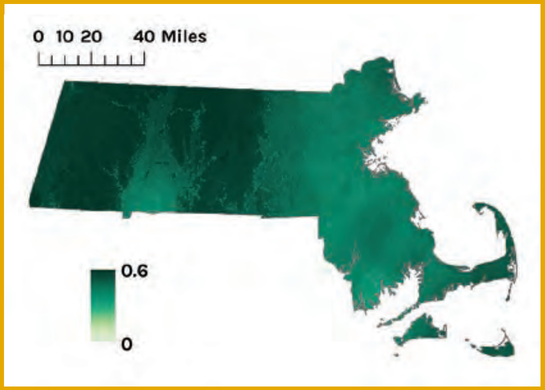
Our models indicate that the current climate of the entire state is suitable for both the Black-capped Chickadee and the Ruffed Grouse (pictured on right). But we know that their actual distributions are quite different: The Black-capped Chickadee is widespread, and the Ruffed Grouse is restricted to specific habitat, so their actual footprints are not perfectly captured by the climate envelope model.

These climate envelope maps show only the suitability of the climate conditions, which acts as an imperfect surrogate for the habitat required by a species. As such, the maps represent an overestimate of the range of a species, as we see with the Ruffed Grouse. You can think of these maps as a best-case scenario for each species—if there is habitat available, the climate will be suitable. But the reverse is not true—if habitat is not available it is unlikely that a species will occur, even if the climate is suitable.

Black-capped Chickadee (current)



Ruffed Grouse (current)



Classifying Vulnerability

Scoring the Vulnerability of a Species

For each species, in both current and future scenarios, we determined a value representing the likelihood of finding the species across the state. The change in the likelihood of occurrence across the state is expressed as a percent change between the current and future maps.

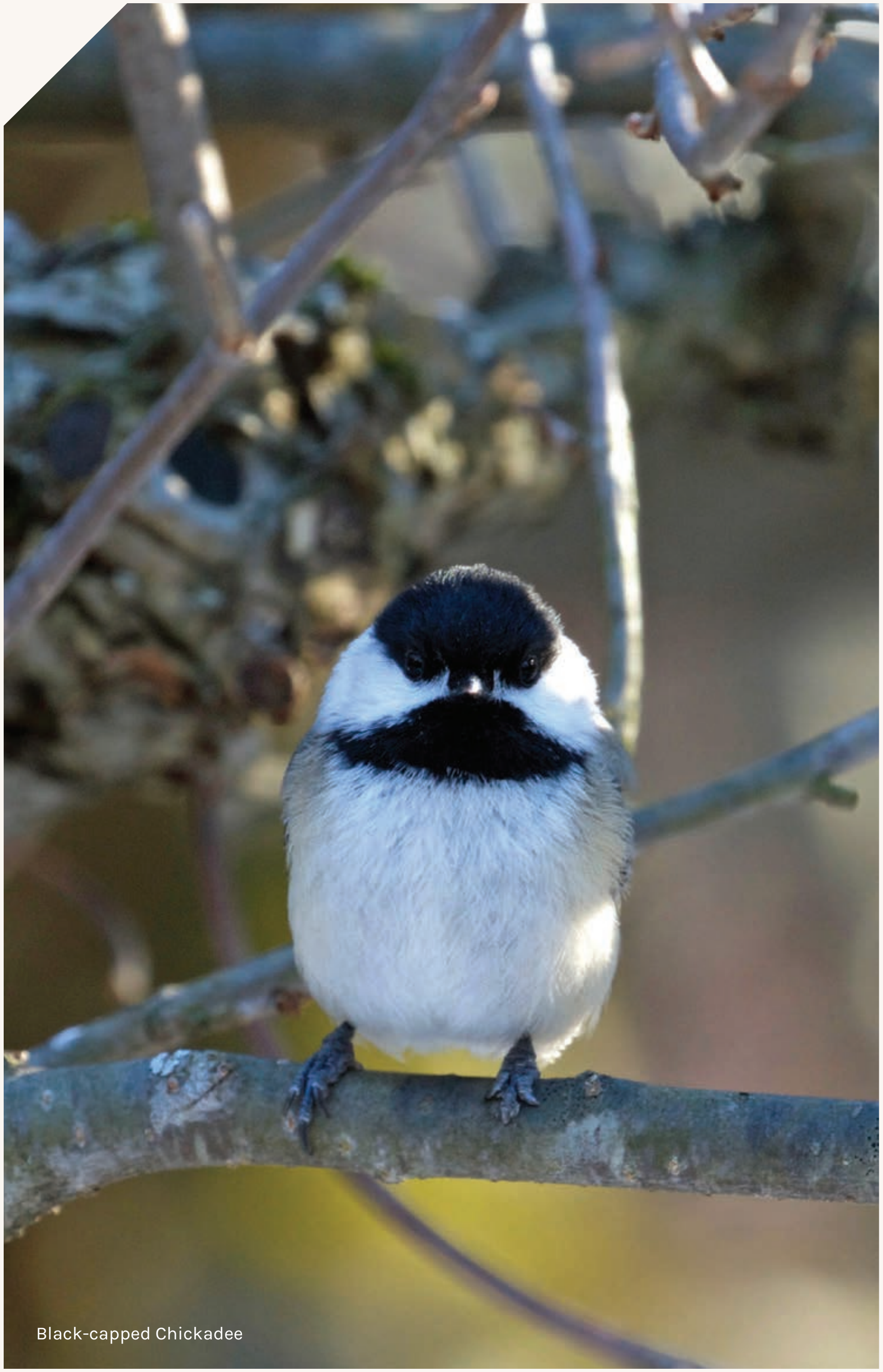
Species were classified as Highly Vulnerable, Likely Vulnerable, or Least Vulnerable based on the change in their likelihood of occurrence. For instance, the Black-capped Chickadee has a current average likelihood of occurrence of 0.52 and a future likelihood of 0.22. The relative likelihood of the Black-capped Chickadee occurring in 2050 would be 0.22 divided by 0.52, or 42%. Since the Black-capped Chickadee's likelihood of occurrence falls to 42% of the modeled current likelihood of occurrence, we scored the species as Highly Vulnerable to climate change.

Future Likelihood Compared to Current Likelihood	Climate Change Vulnerability Score
<80%	Highly Vulnerable
80-95%	Likely Vulnerable
>95+%	Least Vulnerable

Note: Salt marsh- and coastal-nesting species are unambiguously threatened by sea level rise, but the climate envelope models do not include sea level rise as a parameter. Therefore, we classified four coastal- or saltmarsh-nesting species as Highly Vulnerable, rather than using the change in likelihood of encounter from our models. This classification affected the scoring of only Herring Gull, Least Tern, Willet and Seaside Sparrow.

The Big Picture

On our website you can view the full set of climate variables, the climate results by species from both our climate envelope models and the Breeding Bird Atlas data and life history characteristics of each species. www.massaudubon.org/sotb



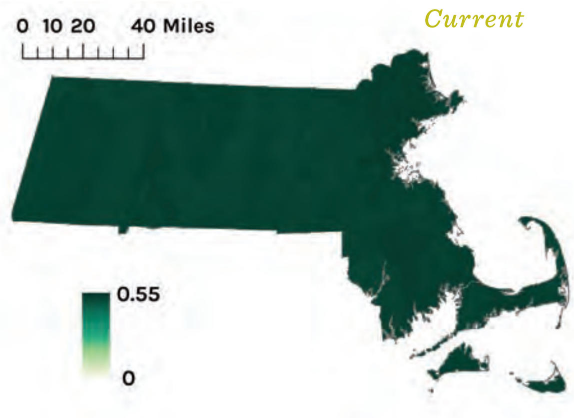
Black-capped Chickadee

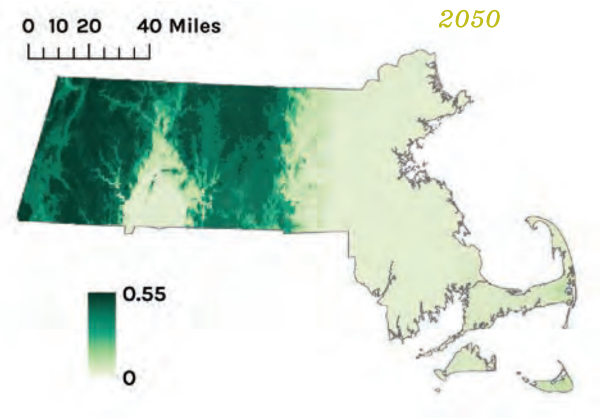
Spotlight Black-capped Chickadee

For information on how to read these maps, refer to page 8.

Breeding Bird Atlas 2 Rank = Stable

Climate Vulnerability Rank = Highly Vulnerable





***Breeding Habitat**: Nests in tree cavities and nest boxes at the edges of mature forests, and in wooded urban or suburban settings.*

The Black-capped Chickadee was an apt choice for the state bird of Massachusetts since few species are as at home in the mix of forest and suburban development that characterizes the Bay State today. Flocks of Black-capped Chickadees are common visitors to backyard bird feeders, where they constantly take seeds away one at a time to be cracked and consumed under the safety of brushy cover.

The species has been widespread in Massachusetts during recorded history, and showed modest gains between 1979 and 2011. However, a warming climate suggests change may be in the air for one of our most familiar birds.

WHAT DOES THE FUTURE LOOK LIKE?

The climate envelope models project a reversal of fortunes for Black-capped Chickadees in Massachusetts by 2050. Under current conditions there is a high likelihood of finding this species across the state. But, when we advance to projected 2050 climate characteristics, we see that the average score for Black-capped Chickadees falls from a 52% likelihood of occurrence to a 22% likelihood, with reduced levels of projected occurrence especially notable in eastern Massachusetts.

Of the 20 environmental variables used in the analysis (elevation and 19 variables describing various aspects of temperature and precipitation patterns), four showed a cumulative influence of more than 60% on the resulting climate model:

- Annual Mean Temperature
- Minimum Temperature of the Coldest Month
- Mean Temperature of Coldest Quarter
- Mean Temperature of Warmest Quarter

These four factors are the most likely to influence the distribution of suitable chickadee breeding habitat; changes in some, or all, of these variables (several of which are related) are likely responsible for the predicted decline in Black-capped Chickadee distribution between current and future time periods.

Temperature appears to be the most important climate component defining where Black-capped Chickadees breed in Massachusetts. It is unlikely that temperature, per se, influences where chickadees breed. Instead, temperature characteristics presumably influence the underlying plant communities that are distributed on the landscape, and those plant communities then dictate which areas represent the best areas for nesting chickadees.

Surprised by the results of our model for Black-capped Chickadees in Massachusetts, we zoomed back out to the scale of the northeastern United States and Canada (the scale that our model was run at) so that we could see what the model predicted for the entire population of the Black-capped Chickadee. At this larger scale, it appears that the Black-capped Chickadee population will shift northward and may in fact increase its range if the habitat is also suitable farther north.

ACTIONS

Up until now no one thought that the Black-capped Chickadee would ever be a candidate for a conservation research program. It is a well-studied species, but there are few long-term studies of breeding or wintering birds in Massachusetts. Given its habit of nesting in and around developed areas, and using feeders and nest boxes, the Black-capped Chickadee presents an excellent opportunity to strenghten our understanding of how our breeding birds respond to shifts in climate. This idea is worth exploring with our partners in Massachusetts, and beyond.

Results by Habitat

Of the 143 species that were modeled

61 species (43%) are Highly Vulnerable

22 species (15%) are Likely Vulnerable

60 species (42%) are Least Vulnerable

The following tables list the species by the habitats they breed in, and by the species' Climate Vulnerability score. They are listed in taxonomic order. Some species breed in several habitats and are therefore included on multiple lists.

Grasslands, Agriculture, and Open Fields

HIGHLY VULNERABLE TO CLIMATE EFFECTS

- American Woodcock
- Vesper Sparrow
- Savannah Sparrow
- Bobolink

American Woodcock

LIKELY VULNERABLE TO CLIMATE EFFECTS

- Tree Swallow

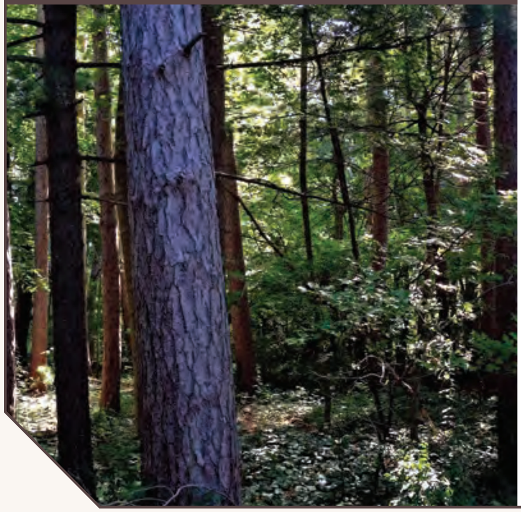
Tree Swallow

LEAST VULNERABLE TO CLIMATE EFFECTS

- Northern Bobwhite
- Killdeer
- American Kestrel
- Horned Lark
- Barn Swallow
- Eastern Bluebird
- Red-winged Blackbird
- Eastern Meadowlark
- Brown-headed Cowbird

Eastern Bluebird

Mature Forest



HIGHLY VULNERABLE TO CLIMATE EFFECTS

- Ruffed Grouse
- Eastern Whip-poor-will
- American Woodcock
- Black Vulture
- Northern Goshawk
- Broad-winged Hawk
- Yellow-bellied Sapsucker
- Least Flycatcher
- Blue-headed Vireo
- Common Raven
- Black-capped Chickadee
- Red-breasted Nuthatch
- Brown Creeper
- Winter Wren
- Golden-crowned Kinglet
- Veery
- Swainson's Thrush
- Hermit Thrush
- Purple Finch
- Pine Siskin
- Evening Grosbeak
- Dark-eyed Junco
- Black-and-white Warbler
- American Redstart
- Magnolia Warbler
- Black-throated Blue Warbler
- Pine Warbler
- Yellow-rumped Warbler
- Black-throated Green Warbler
- Rose-breasted Grosbeak

Yellow-bellied Sapsucker

LIKELY VULNERABLE TO CLIMATE EFFECTS

- Great Horned Owl
- Barred Owl
- Pileated Woodpecker
- Warbling Vireo
- Fish Crow
- Cerulean Warbler
- Worm-eating Warbler
- Ovenbird
- Baltimore Oriole

Tufted Titmouse

LEAST VULNERABLE TO CLIMATE EFFECTS

- Green Heron
- Turkey Vulture
- Cooper's Hawk
- Red-tailed Hawk
- Eastern Screech-owl
- Red-bellied Woodpecker
- Downy Woodpecker
- Northern Flicker
- Eastern Wood-pewee
- Acadian Flycatcher
- Great Crested Flycatcher
- Yellow-throated Vireo
- Red-eyed Vireo
- Blue Jay
- American Crow
- Tufted Titmouse
- White-breasted Nuthatch
- Blue-gray Gnatcatcher
- Wood Thrush
- Chipping Sparrow
- Brown-headed Cowbird
- Orchard Oriole

Young Forest

HIGHLY VULNERABLE TO CLIMATE EFFECTS

- Ruffed Grouse
- Black-billed Cuckoo
- Eastern Whip-poor-will
- American Woodcock
- Northern Harrier
- Least Flycatcher
- White-throated Sparrow
- Blue-winged Warbler
- Nashville Warbler
- Mourning Warbler
- American Redstart
- Chestnut-sided Warbler

Chestnut-sided Warbler

LIKELY VULNERABLE TO CLIMATE EFFECTS

- Common Nighthawk
- Warbling Vireo
- House Wren
- Cedar Waxwing
- Yellow Warbler
- Prairie Warbler

Indigo Bunting

LEAST VULNERABLE TO CLIMATE EFFECTS

- Northern Bobwhite
- Yellow-billed Cuckoo
- Ruby-throated Hummingbird
- Great Crested Flycatcher
- Eastern Kingbird
- White-eyed Vireo
- Blue Jay
- Carolina Wren
- Eastern Bluebird
- American Robin
- Brown Thrasher
- Northern Mockingbird
- American Goldfinch
- Eastern Towhee
- Field Sparrow
- Song Sparrow
- Indigo Bunting
- Brown-headed Cowbird

Rivers, Lakes, Ponds

HIGHLY VULNERABLE TO CLIMATE EFFECTS

- American Black Duck
- Common Merganser
- Common Loon
- Osprey

Common Loon

LIKELY VULNERABLE TO CLIMATE EFFECTS

- Spotted Sandpiper
- Bald Eagle
- Bank Swallow

Bald Eagle

LEAST VULNERABLE TO CLIMATE EFFECTS

- Canada Goose
- Mallard
- Blue-winged Teal
- Red-shouldered Hawk
- Belted Kingfisher
- Purple Martin
- Northern Rough-winged Swallow

Red-shouldered Hawk

Freshwater Marsh

HIGHLY VULNERABLE TO CLIMATE EFFECTS

- American Black Duck
- Wilson’s Snipe
- American Bittern
- Least Bittern
- Northern Harrier
- Marsh Wren
- Swamp Sparrow

American Black Duck

LIKELY VULNERABLE TO CLIMATE EFFECTS

- Spotted Sandpiper
- Tree Swallow

Spotted Sandpiper

LEAST VULNERABLE TO CLIMATE EFFECTS

- Canada Goose
- Mallard
- Blue-winged Teal
- Great Egret
- Green Heron
- Red-shouldered Hawk
- Red-winged Blackbird
- Brown-headed Cowbird

Green Heron

Wooded Freshwater Wetland

HIGHLY VULNERABLE TO CLIMATE EFFECTS

- American Black Duck
- Brown Creeper
- Winter Wren
- Veery
- Northern Waterthrush
- Canada Warbler

Canada Warbler

LIKELY VULNERABLE TO CLIMATE EFFECTS

- Barred Owl
- Willow Flycatcher
- Louisiana Waterthrush
- Northern Parula
- Yellow Warbler

Barred Owl

LEAST VULNERABLE TO CLIMATE EFFECTS

- Mallard
- Great Blue Heron
- Green Heron
- Red-shouldered Hawk
- Acadian Flycatcher
- Eastern Phoebe
- Great Crested Flycatcher
- Eastern Kingbird
- Yellow-throated Vireo
- Blue-gray Gnatcatcher
- Hooded Warbler
- Red-winged Blackbird
- Brown-headed Cowbird

Eastern Pheobe

Salt Marsh

HIGHLY VULNERABLE TO CLIMATE EFFECTS

- American Black Duck
- Willet
- Common Tern
- Osprey
- Marsh Wren
- Saltmarsh Sparrow
- Seaside Sparrow

Osprey

LIKELY VULNERABLE TO CLIMATE EFFECTS

- Tree Swallow

Tree Swallow

LEAST VULNERABLE TO CLIMATE EFFECTS

- Canada Goose
- Red-winged Blackbird

Red-winged Blackbird

Coastal

HIGHLY VULNERABLE TO CLIMATE EFFECTS

American Oystercatcher
Piping Plover
Willet
Herring Gull
Great Black-backed Gull
Least Tern
Roseate Tern
Common Tern
Osprey

American Oystercatcher

LIKELY VULNERABLE TO CLIMATE EFFECTS

Spotted Sandpiper
Bank Swallow

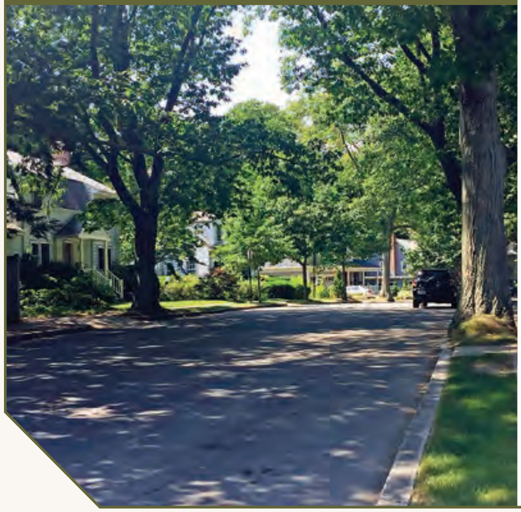
Bank Swallow

LEAST VULNERABLE TO CLIMATE EFFECTS

Great Egret
Snowy Egret
Green Heron
Killdeer
Horned Lark

Snowy Egret

Urban or Suburban



HIGHLY VULNERABLE TO CLIMATE EFFECTS

Common Raven
Black-capped Chickadee

Common Raven

LIKELY VULNERABLE TO CLIMATE EFFECTS

Common Nighthawk
Great Horned Owl
Warbling Vireo
Fish Crow
Bank Swallow
House Wren
Cedar Waxwing
Baltimore Oriole

LEAST VULNERABLE TO CLIMATE EFFECTS

Canada Goose
Mallard
Mourning Dove
Chimney Swift
Ruby-throated Hummingbird
Killdeer
Cooper’s Hawk
Red-shouldered Hawk
Red-tailed Hawk
Eastern Screech-owl
Red-bellied Woodpecker
Downy Woodpecker
Northern Flicker
American Kestrel
Eastern Phoebe
Blue Jay
American Crow
Purple Martin
Northern Rough-winged Swallow
Cliff Swallow
Barn Swallow
Tufted Titmouse
White-breasted Nuthatch
Carolina Wren
Eastern Bluebird
American Robin
Northern Mockingbird
House Finch
American Goldfinch
Chipping Sparrow
Song Sparrow
Northern Cardinal
Brown-headed Cowbird
Orchard Oriole

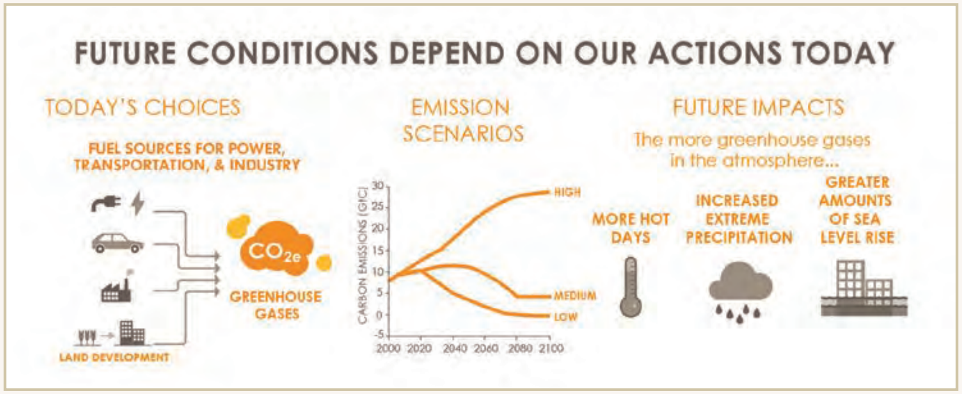
Carolina Wren

2

Humpback whales and Laughing Gulls

What to Expect from Climate Change

Climate change is rapid, and it is accelerating. Many plant and animal species will be unable to adapt to this rapid change, while others will be challenged to survive without sufficient refuges.



©Climate Ready Boston

CLIMATE CHANGE IS BEING DRIVEN BY GLOBAL WARMING, caused by a buildup of greenhouse gases in our atmosphere. The chief greenhouse gas is carbon dioxide, and the increasing concentration of carbon dioxide in the atmosphere is largely the result of human activities, such as burning fossil fuels. We can avoid the most dire effects of climate change by reducing our carbon footprint, as outlined in the What You Can Do section of this report.

Our shifting climate is already affecting the wildlife of Massachusetts—from the smallest phytoplankton to our largest humpback whales. These changes, outlined here, transform the way ecosystems work, including food webs and the timing of seasonal events, such as the emergence of insects and the flowering of trees. As these fundamental shifts accelerate, they will add stress to our natural world, leading to significant effects on our focal group of concern: the birds of Massachusetts.

Core Challenges of Climate Change for Wildlife Conservation

Earth's climate has changed significantly over the ages. But today, changes that previously occurred over thousands of years are happening in the span of a few human generations. Unless we take aggressive action at home and around the globe to reduce greenhouse gas emissions, temperatures in the northeastern United States are expected to warm an additional 4°F to 7°F by the middle of the 21st century.

It is this rapid, unnatural rate of change that creates the core challenges of conservation in a changing climate. While evolution has allowed plants and animals to adapt to natural changes over periods of hundreds or thousands of years, the current rate of climate change may make it impossible for many species to adapt.

In addition, climate change will intensify the stressors that wild species are currently facing. As a result, they face a harsh challenge: Leave, adapt, or slowly succumb to the cumulative stresses.

There are three core challenges at the intersection of climate change and wildlife conservation that make action essential:

- **Urgent Action Is Required**. Climate change is rapid, and it is accelerating. Many plant and animal species will be unable to adapt to this rapid change, while others will be challenged to survive without sufficient refuge. This means we need to expand some habitats, restore degraded habitats, and, in the case of coastal habitats, find ways to provide refuge against rising seas.
- **Fundamental Processes Are Being Disrupted**. Fundamental ecological processes, such as the spring emergence of leaves and insects, are affected by temperature and rainfall. Shifts in these basic characteristics of the climate can have dire consequences for our ecosystems, forcing changes in food webs and disrupting relationships among species. Changes to these basic linkages can cascade through an ecosystem, resulting in an upended, chaotic system and challenging wildlife in all aspects of their lives.
- **Stress Is Being Added to Already Stressed Environments**. Climate change amplifies existing stressors on wildlife and their habitats. Good conservation will still be the best tool in our toolbox. This means we still need to focus on reducing pollution, protecting and connecting large wild areas, restoring degraded areas, and reducing human-caused bird mortality, like collisions with buildings. All of these actions make habitats more resilient and resistant to the additional stress caused by climate change.

Leading by Example: Mass Audubon's Carbon Footprint Reduction Program

Since 2003, Mass Audubon has reduced the annual carbon emissions from its buildings and vehicles by nearly 50%. We have made a variety of investments—some small, some large. Many of the steps we have taken can be copied in your home or in your office. Visit us at massaudubon.org/leadingbyexample for updates and specifics on the ways we are committing to a smaller carbon footprint.

Photovoltaic array at North River Wildlife Sanctuary

Emissions Scenarios

To predict future climate conditions, we use computer models, or simulations, that are based on factors such as the input of energy from the sun, circulation patterns of the ocean, and the concentration of greenhouse gases in the atmosphere. Usually models are run using scenarios that involve different levels of future greenhouse-gas emissions—high, medium, and low. These different scenarios predict different amounts of changes in the climate, with low-emission scenarios resulting in less global warming than high-emission scenarios. A variety of models have been used to predict how human activities will affect the future climate, and all of them have levels of uncertainty that increase with the length of the projection.

Whenever possible, we chose to use the future climate variable ranges for the year 2050. We chose 2050 because the models mostly converge during this timeframe, regardless of the emissions scenario used. It will be our behavior over the next 33 years that will force the climate effects reflected in projections after 2050.

The Signs of Climate Change Are All Around Us

Our climate is warming because of a buildup of heat-trapping greenhouses gases in the atmosphere. As air temperatures rise, the increased heat energy in the atmosphere drives more frequent and powerful storms. The increased air temperature also changes the seasons—winters are shorter and summers are longer. The warm air melts alpine glaciers and continental ice near the poles, causing sea level to rise. The oceans also trap the heat, and when the ocean water is warmed it expands, contributing almost half of the observed rise in sea level.

What follows are some of the observed environmental changes, as well as projected environmental changes, for Massachusetts.

Rising Temperatures in Massachusetts

From 1895 to 2015, Massachusetts warmed by 2.8°F—faster than the national and global rates. If we continue to emit greenhouse gases as we have in the recent past, the Northeast will warm by 4°F to 7°F by mid-century and by 7°F to 10.5°F by the 2100s. If global greenhouse gas emissions are aggressively reduced, temperatures will warm by 3°F to 6°F by 2100. Since the greenhouse gases we emit today will remain in the atmosphere for decades, future warming is inevitable. However, if we aggressively reduce our greenhouse gas emissions we will have less warming over time.

What Does This Mean for the Declining Breeding Birds of Massachusetts?

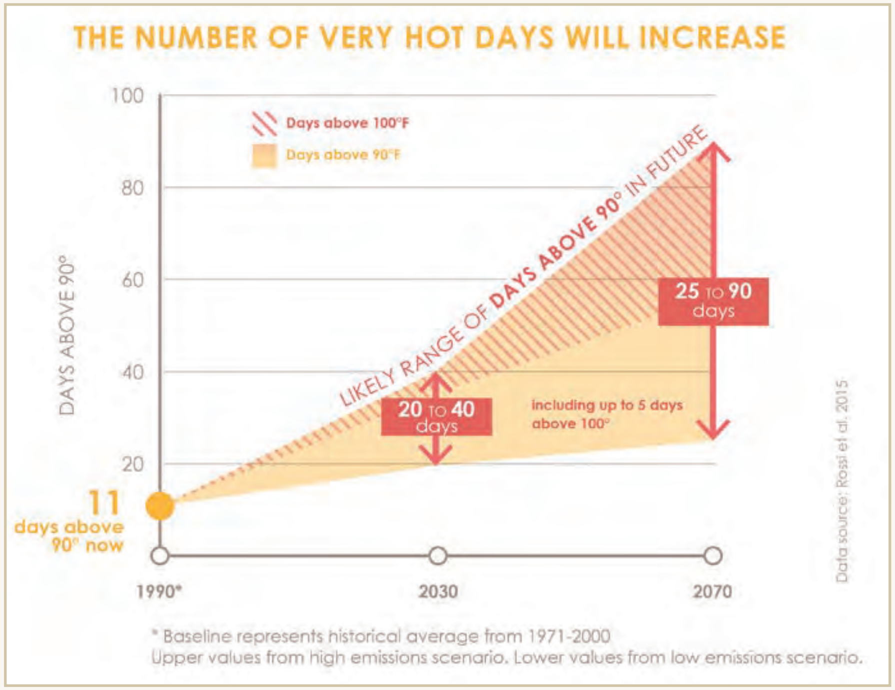
Understanding the effects of climate change is important as we try to assess the vulnerability of our native birds. Although research suggests that some species will be able to tolerate significant shifts in temperature, we know that many species will not be able to cope. This uncertainty requires action, particularly for those species measured as already declining and predicted to face additional challenges due to climate change. The following species were classified in our highest levels of concern, as reported in Mass Audubon's *Breeding Bird Atlas 2*, and are also projected to be Highly Vulnerable to climate change by the year 2050:

- Ruffed Grouse
- Black-billed Cuckoo
- Eastern Whip-poor-will
- Piping Plover
- Wilson's Snipe
- American Woodcock
- Herring Gull
- Great Black-backed Gull
- Least Tern
- Roseate Tern
- Common Tern
- American Bittern
- Least Bittern
- Northern Harrier
- Northern Goshawk
- Broad-winged Hawk
- Least Flycatcher
- Swainson's Thrush
- Purple Finch
- Evening Grosbeak
- Vesper Sparrow
- Savannah Sparrow
- Saltmarsh Sparrow
- Seaside Sparrow
- White-throated Sparrow
- Black-and-white Warbler
- Nashville Warbler
- Chestnut-sided Warbler
- Black-throated Blue Warbler
- Canada Warbler
- Rose-breasted Grosbeak

What's in a Degree?

An increase of a few degrees Fahrenheit may not seem like a very large change. Indeed, during the spring and fall, the day-to-day high temperatures in Massachusetts commonly vary by 30°F or more. But long-term changes in *global average temperatures* represent enormous changes in the amount of energy building up in earth's atmosphere. By comparison, at the end of the last ice age, when ice sheets thousands of feet thick covered the northeastern United States, global average temperatures were only 5°F to 9°F cooler than they are today. That's roughly the magnitude of warming expected to occur during the next 70 years if greenhouse gas emissions continue to increase. And this unnaturally rapid rate of warming is what's forcing our natural environments to change faster than the plants and animals can possibly adapt.

More Hot Days and Extreme Heat

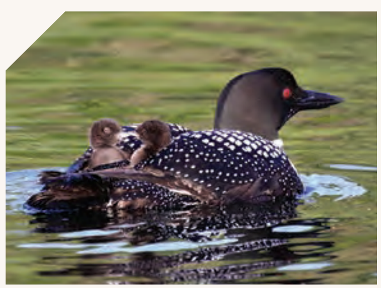


Future number of very hot days in Boston, MA. ©Climate Ready Boston

Warming is expected to be accompanied by an increase in the variability of temperatures. We are expected to have more hot days and extreme and dangerous heat waves, as well as extended warm seasons.

Currently, eastern Massachusetts typically sees fewer than 11 days per year in which temperatures exceed 90°F. Under high emissions scenarios, eastern Massachusetts could see 20 to 40 days per year over 90°F by 2030 and 25 to 90 days by 2070. Of those hot days in 2070, up to 33 could exceed 100°F.

Our data from *Breeding Bird Atlas 2* showed a significant increase in the ranges of formerly southern breeding species in Massachusetts during the years 1979-2013, as well as a decrease in species with ranges centered to our north. The changes are likely due, in part, to the increasing average temperature and extended warm seasons, and we can expect these changes to continue as the average annual temperature and length of warm seasons increase further.



Common Loon with chicks

Mass Audubon models project that all of our breeding species with ranges that are centered to our north are Highly Vulnerable to the effects of climate change in Massachusetts. One such species is the Common Loon, a bird that is currently undergoing a welcome recovery in the Commonwealth.

Species with ranges that are centered to our south show more variability. Of the 25 southern species modeled, 64% are projected to have increased climate suitability. Some of these are species that have recently undergone declines, such as the Northern Bobwhite.

Purple Martin

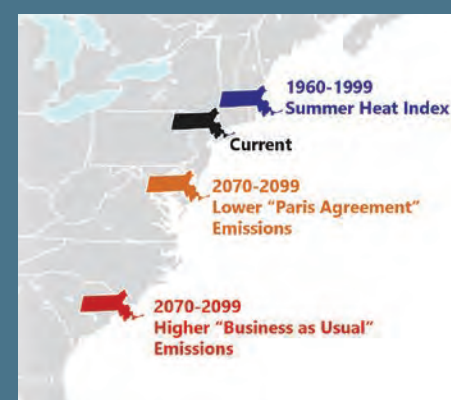
Fewer Cold Snaps but Freeze Risk Persists

By mid-century, we can expect 20 to 30 fewer days with freezing temperatures in a typical year. Fewer freezing days will extend the growing season, but will also enhance the risk of damage from frost to the leaves and flowers that are developing earlier. Warm spring days still have about the same chance of being followed by a deep cold snap that can kill tender leaves and flowers, damage crops,

The Human Perspective: How Different Will It Feel?

To help put future temperature conditions in context, we can compare how Massachusetts summers will feel in the future to what other parts of the country experience today. Even if we aggressively reduce future greenhouse gas emissions from current levels, our future heat index may resemble the conditions typical of Maryland today. If we continue to emit greenhouse gases as we have, our heat index may feel more like present conditions in South Carolina. That climate would be fundamentally different from the New England climate we're accustomed to.

How Summer Temperatures Will Feel Depending on Future Greenhouse Gas Emissions.*



*Based on data and methodology in Hayhoe, K., C. P. Wake, B. Anderson, X. - Z. Liang, E. Maurer, J. Zhu, J. Bradbury, A. DeGaetano, A. Hertel, and D. Wuebbles. "Regional Climate Change Projections for the Northeast U.S." Mitigation and Adaptation Strategies for Global Change 13, no. 5-6 (2008): 425-436.

and disrupt wildlife. This contributes to a greater risk for plants and animals that take advantage of the warmer “shoulder” seasons. But species that are long-distance migrants and sensitive to cold snaps, such as the Purple Martin, may suffer additional setbacks.

Changing Precipitation

The warming climate will alter patterns of precipitation in significant ways, although the form of those changes will vary greatly around the globe. In Massachusetts, annual precipitation totals have increased by about 15% since 1895. Overall, that trend is expected to continue, but the change may not be evenly distributed throughout the seasons. Our wet seasons will likely become wetter, while our summer and early fall seasons may become drier.

Many Massachusetts breeding bird species, as well as many bird species that pass through the state during spring and fall migration, winter in the neotropics or in temperate South America. There is already evidence that changes in precipitation in the Caribbean, Central America, and South America are affecting the wintering habitats of migrant birds, as well as the birds’ survival on the wintering grounds. This additional stressor for long-distance migrants is of great significance as we work to protect them on the breeding grounds.

Our models show that of the 54 species of long-distance migrants that breed in Massachusetts, 36 (66%) are either Highly Vulnerable or Likely Vulnerable to climate change in the state, and 18 (34%) are Least Vulnerable. Our models did not evaluate climate change in the wintering grounds.

Less Snow and More Rain

The future form of our winter precipitation is uncertain, but we should anticipate that less precipitation will fall as snow and that warmer temperatures will result in less snow accumulation. Across a range of projections, we could see a 25 to 60% reduction in the amount of precipitation stored in ice and snow by mid-century, and a 50 to 100% reduction by 2100. These changes may increase opportunities for some species, such as the Northern Bobwhite, which suffers high mortality in years of heavy snowfall.

Northern Bobwhite

Greater Frequency of Strong Storms

The northeastern United States has experienced a greater increase in extreme precipitation than any other part of the country. The amount of precipitation falling in the heaviest 1% of precipitation events increased by 71% from 1958 through 2012, which was mostly due to an increase in very heavy rainfall events.

Locations in Massachusetts are typically seeing an increase of 2 to 4.5 days per year when daily precipitation totals exceed 1 inch. That’s an increase of about 15 to 30%, consistent with the regional trend across New England. Changes in precipitation vary tremendously from place to place, however, and there are locations that have experienced a slight decline in the number of heavy precipitation days.

Belted Kingfishers

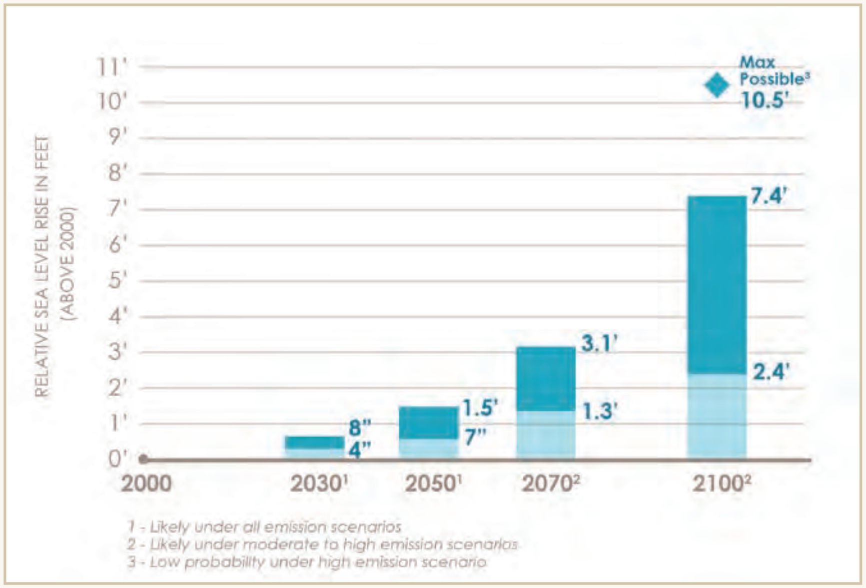
By mid-century, the number of 1-inch precipitation days is expected to increase by an additional 15 to 20%, with the greatest changes projected for southeastern and northwestern Massachusetts. Heavy precipitation events increase the risk of flooding. Bird species that nest in riverbanks or along streams, such as Bank Swallows, Belted Kingfishers, Common Mergansers, and Northern Waterthrushes, could experience a greater frequency of washout events that destroy their nests. Additionally, small ground-nesting species, especially those that nest on less porous soils, like the field-nesting Killdeer, could also experience more frequent washout events during periods of intense rainfall.

Sea Level Is Rising

Earth’s warming climate is causing sea level to rise in two different ways. First, warmer air temperatures are causing alpine glaciers and continental ice to melt. As the meltwater flows into the ocean, the increase in the total volume of water causes the sea level to rise.

Second, about 90% of the heat trapped by greenhouse gases is stored in the world’s oceans. As the ocean water becomes warmer it expands, pushing water farther up along our shores. This expansion accounts for much of the observed rise in sea level during the 1900s.

Since 1922, the sea level in Boston Harbor has risen by 10.4 inches, a rate exceeding the global average of approximately 8 inches since 1900. The primary reason why the sea level is rising faster along the New England coast than elsewhere is land subsidence: our land is slowly settling, relative to sea level.



Future relative sea level rise in Boston, MA ©Climate Ready Boston

Sea level is projected to rise somewhere between an additional 2.4 to 7.4 feet by 2100, depending on the rate of future greenhouse gas emissions. A rise of 7 inches to 1.5 feet is probable by 2050, regardless of greenhouse gas emissions in the next three decades.

American Oystercatcher

The effect of sea level rise will be felt most profoundly by our coastal-nesting birds, many of which nest within a few vertical feet of the high-tide line. In the short term the coastal-nesting species are at risk due to increased flooding events, and in the long term due to habitat loss from the direct effects of flooding, as well as the loss of habitat to rising seas. Colonial-nesting seabirds such as gulls and terns, barrier-beach-nesting species such as American Oystercatchers and Piping Plovers, and salt marsh-nesting species such as Saltmarsh Sparrows and American Black Ducks are all projected to be affected.

Coastal Flooding

By mid- to late-century, what we now call 100-year coastal floods could plausibly occur almost once per year, a change driven mostly by rising sea level. In future scenarios for some coastal locations, it is possible that a "100-year flood" could occur as frequently as high tide. This change has obvious significance for any birds nesting along the coast, including all beach-nesting and salt marsh-nesting birds.

Sea Surface Temperatures

Ocean surface temperatures off the coast of Massachusetts have warmed by 1.5°F to 2°F since 1901. That's close to the average global rate of ocean warming. Year-to-year and local geographic variability of sea-surface temperatures in nearshore areas is high, however. Some areas near shore, such as the Gulf of Maine, have warmed more rapidly at different times in history, while others have warmed more slowly. Overall, for United States coastal waters, temperatures are predicted to rise 4°F to 8°F by 2100.

Even very small shifts in ocean temperatures can cause dramatic upheavals in ecosystems, often affecting fundamental processes at the base of food webs. For species that primarily rely on marine prey in colder water, such as gulls, terns, shearwaters, alcids, and coastal ducks, there is ample evidence that abnormally warm water can cause declines in food resources that result in significant mortality events.

Common Eiders

Common Terns and Roseate Terns

The Coast

We will always have a coastline, but where will it be?

COASTAL HABITATS ARE AT RISK as the effects of climate change increase. Sandy beaches in Massachusetts provide nesting habitat for endangered birds such as Piping Plovers, Common Terns, and Least Terns, as well as recreational opportunities for millions of visitors each year. Our beaches also serve as critical feeding and resting areas for terns and shorebirds during their long spring and fall migrations that sometimes reach from breeding grounds in the high Arctic to wintering areas in South America.

However, with rising sea level, increasing storm intensity, armored coastlines, and increased competition with humans for beachfront real estate, the wildlife that depends on our dynamic shorelines for nesting, resting, and feeding is increasingly threatened. While sometimes contentious, conservation of the rare species nesting on Massachusetts' beaches has served as a model of cooperative management that is the envy of most other coastal states. The challenge now is to maintain these successes in the face of climate change.

Least Terns

Beachfront Basics: They Move

Our beaches are constantly being shaped by currents, tides, winds, and storms, with new channels and sandbars emerging and receding, sometimes seemingly overnight. The sandy beaches of Massachusetts formed after the glaciers departed from our area, approximately 15,000 years ago. Their formation depended upon the erosion of sediments from the land. During periods with greater erosion, the beaches grew more rapidly. Sandy Neck in Barnstable, for example, grew more when sea level was rising quickly than in more stable periods, due to increased erosion of the coastal bluffs that acted as a source of sand.

Today beaches and sand spits are created in much the same way—by the movement of sand, often eroded from coastal cliffs or brought to the coast via rivers and then deposited in relatively calm waters. The action of ocean waves and currents on a barrier beach typically erodes sand from the exposed edge of the beach and moves it both offshore and along the shore.

The Islands of Massachusetts

a.

b.

c.

Coastal islands are also critical breeding sites not only for many seabirds, but also for long-legged wading birds such as egrets and ibises. The nearshore islands are especially important for wading birds, providing safe nesting habitat and a short commute to nearby wetlands for feeding. In Massachusetts, colonial-nesting seabirds and wading birds use rocky islands in Buzzards Bay, Boston Harbor, and along the north shore. Colonial species also nest on sandy islands along the southern Massachusetts coast—most notably at Monomoy National Wildlife Refuge.

Mass Audubon's Kettle Island, off the coast of Manchester-by-the-Sea, hosts the largest breeding colony of wading birds in the state. The constellation of small rocky islands dotting the Essex County coast—comprising the Essex County Rocky Islands Important Bird Area—provide critical habitat redundancy for egrets, ibises, and other species. Islands to the south, too, are essential for the survival of coastal-nesting birds.

Sandy islands are dynamic and are likely to be lost in the near-term to increasing intensity of coastal storms and rising sea level. Rocky islands, on the other hand, are formed of bedrock rather than shifting sands and so have an inherent resistance to erosion from rising sea level. However, their total area will be reduced as low-lying rocks and islets are drowned by the rising sea.

Mass Audubon and partners are assessing the status of breeding birds on rocky and sandy islands and will be working to build resilience in the system. Near-term work will include addressing non-climate stressors such as changes in vegetation, incompatible human use, and the presence of mammalian predators. Planning for their future, as well as our own, must progress quickly or this narrow window of opportunity will close.

a. House Island off of Manchester-by-the-Sea, MA
b. Straitsmouth Island off of Rockport, MA
c. Halfway Rock off of Salem, MA

Planning for Plovers

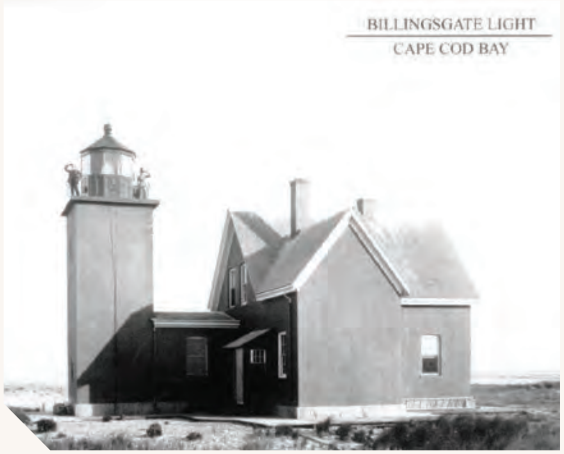
Piping Plover chick

Habitat loss caused by the development and increased recreational use on barrier beaches, including use of over-sand vehicles, is the primary cause of 20th century declines in the Atlantic coast population of the Piping Plover. In areas where beaches cannot naturally migrate landward, sea level rise and storm-induced erosion are expected to further threaten the recovering Piping Plover population in Massachusetts.

The evidence for that projection comes from a study of the barrier beaches on the south shore of Long Island, where researchers found that in the absence of adjacent development, potential plover nesting habitat will grow as sea level rises and beaches naturally move farther inland. But their model also indicated that if there is development bordering the beaches, Piping Plover habitat will shrink as sea level rises. The researchers concluded that, to ensure the future of plover habitat on barrier beaches, managers need to promote natural overwash and habitat migration, while minimizing development adjacent to future breeding habitat. With rising sea level and increased severity of winter storms, blowouts and overwash may occur with greater frequency, thus providing favorable nesting sites for plovers—at least on undeveloped beaches in the short term.

Planning for the Future: We Will Always Have a Coastline, But Where Will It Be?

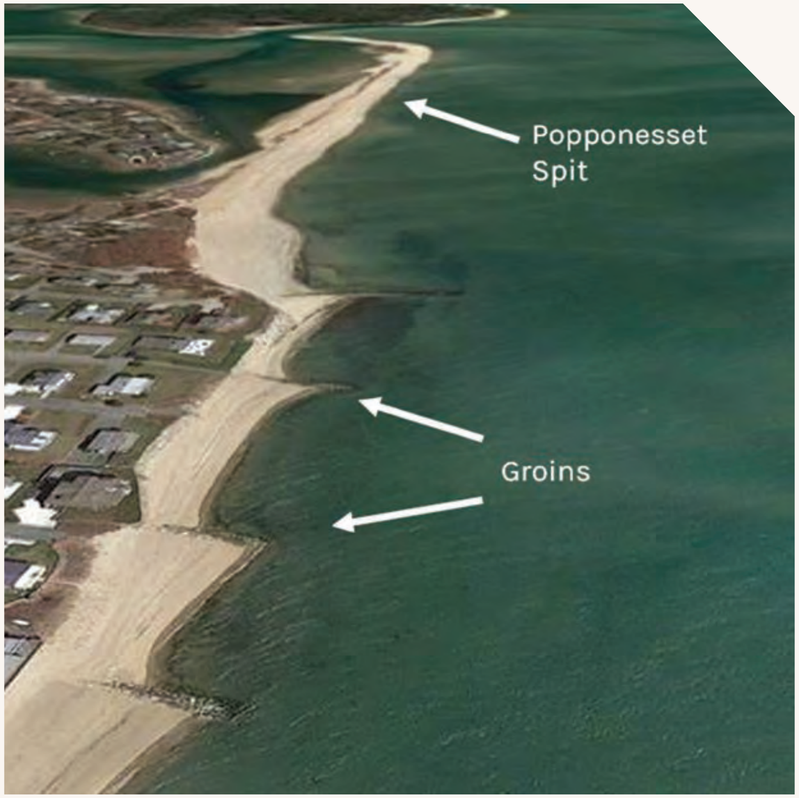
Coastlines are shifting landscapes, but when they are developed—often with significant financial investment—attempts are frequently made to stop their natural migration. Rising sea level and increased storminess will cause beaches to migrate landward. In the coming decades, we will have to decide when to protect existing infrastructure and when to remove or alter it to allow for natural coastal processes.



The barrier islands and sand spits of the Massachusetts coast, such as Plum Island, Duxbury Beach, Sandy Neck, Monomoy Island, and Nauset Beach, are textbook examples of the changing nature of our sandy coastline. So too is the poignant example of Billingsgate Shoal in Wellfleet, formerly Billingsgate Island. In the mid-1800s, Billingsgate Island had a tavern, a post office, a baseball team, and 30 houses. By 1915, the town was gone, a victim of coastal erosion. Today at low tide, its remnant serves as a haul-out spot for seals and a resting area for cormorants and gulls. As sea level rises and storm intensity increases, we may see changes like this within even shorter time frames.

Along natural coastlines, sediments from eroding banks are eventually deposited on beaches, providing beach habitat and protecting the saltmarsh habitats behind the beaches. Today, however, human development is interfering with this process. Many coastal banks are now covered by armor to prevent erosion, thus starving nearby beaches of sand. Additionally, much of the sediment that does erode from banks is intercepted by jetties and groins, preventing it from moving down current to re-nourish beaches.

Mass Audubon's Popponesset Spit is an important waterbird nesting site in Mashpee. Groins and an armored coastline "upstream" from the spit (pictured below) have resulted in a sand deficit relative to natural conditions. In addition, sea level rise and increased storminess have shifted the spit landward. The spit is maintained through annual renourishment using sediments dredged from the channel to Popponesset Bay. Mass Audubon and Save Popponesset Bay are working together on a habitat restoration plan to install "green infrastructure" at the spit for longer-term maintenance.



Roseate Terns, Common Terns, and Sand Lance

Roseate Tern with sand lance

The Roseate Tern, a federally endangered species, nests sparsely around the world in the tropics, with a sub-population nesting on islands in the northern Atlantic Ocean. Most of these northern Roseate Terns nest in four large colonies—Rockabill Island in Ireland, Great Gull Island in New York, and Bird Island and Ram Island in Massachusetts. The Roseate Tern population suffered a decline during the late 1800s, when the birds were frequently killed to be used as ornaments on hats. The population recovered, but again there was a decline during the mid-1900s. Today the population faces stresses from loss of breeding habitat, predation by mammalian predators on nesting islands, and, to a less-well-known degree, hunting during the non-breeding season on their wintering grounds.

Currently the U.S. population is hovering at about 4,200 breeding pairs, and about half of those pairs are nesting in Massachusetts. The Bay State figures even more prominently for Roseate Terns after the breeding season when adults and newly-fledged young from our colonies, as well at those colonies to our north and south, converge on our Cape Cod beaches to prepare for migration.

Curiously, there are no known Roseate Tern colonies known in the North Atlantic where Roseate Terns nest without the more aggressive Common Tern. Adding redundancy to the population of Roseate Terns would include expanding the number of breeding colonies, and any plan to do that would also require the establishment of nesting Common Terns.

It is also important to note that several studies have looked at the prey that Roseate Terns bring to their chicks on both the breeding grounds and also during post-breeding dispersal on the shores of Massachusetts. Most of these studies point to a narrow diet for Roseate Terns—they primarily eat sand lance during the breeding and post-breeding seasons.

These terns already have multiple stressors. Sea level rise threatens their nesting colonies, and it is becoming increasingly important to study the effects of warming water on their most important prey: sand lance. At the same time it is important to maintain and grow the colonies of Common Terns. Without expanding Common Tern numbers it is unlikely that new Roseate Tern colonies will become established.

Hero

CAROLYN MOSTELLO, MASSWILDLIFE

Bird Island in Marion, Massachusetts, provides important nesting habitat for Common Terns and Roseate Terns, as well as other birds, including American Oystercatchers and Common Eiders. Since the island is home to the second-largest Roseate Tern colony in North America, hosting 30% of the endangered North American population, it is critical that the nesting sites on the island be protected against the continued effects of sea level rise.

Carolyn Mostello, a coastal waterbird biologist at the Massachusetts Division of Fisheries and Wildlife (MassWildlife), has been monitoring and managing Bird Island and two other tern islands in Buzzards Bay for 19 years. During those years, she has observed the deterioration of the island habitats due to climate change, as well as other events, such as oil spills. On Bird Island in particular, rising sea level and erosion of the original seawall had turned the beaches where Common Terns formerly nested into salt marsh and salt pannes—thereby forcing the Common Terns to nest closer to the interior of the island, where Roseate Terns nest.

From 2001 to 2015, MassWildlife worked with colleagues in other private, state, and federal agencies, as well as the U.S. Army Corps of Engineers, to design a restoration project for Bird Island. The goal of the project was to restore nesting habitat for both Roseate Terns and Common Terns by raising the elevation of the island, removing invasive plants and planting native plants, and protecting the island from additional erosion. The project was completed in April 2017.

MassWildlife expects that there may be an added benefit beyond protecting Bird Island from sea level rise and increasing storm intensity. Nearby is Ram Island in Mattapoisett, another important nesting site for Roseate Terns and Common Terns. But Ram Island is overcrowded, so the new “real estate” on Bird Island may allow the tern populations to increase in Buzzard’s Bay.

Carolyn Mostello

Bird Island pre-restoration

The Salt Marsh

The nesting season is already challenging for most birds, but for the birds that nest in salt marshes, there is the additional challenge of living within just a few vertical inches of the tideline.

SALT MARSHES ARE AN ICONIC HABITAT OF NEW ENGLAND and a rich habitat for a variety of birds and other organisms, including many plants and animals that are found nowhere else. Like beachfronts, salt marshes are extremely vulnerable to the rapidly rising sea level in Massachusetts. These two habitats are the front lines of the battle against our changing climate.

Observed Changes

As the rate of sea level rise has accelerated over the past several decades, salt marsh growth in parts of Massachusetts and southern New England may no longer be keeping up with the rising water. Scientists studying the salt marshes on Cape Cod and around Narragansett Bay have documented that the surface of the marshes has become wetter in recent years and that saltmarsh hay (*Spartina patens*), a plant of the high marsh that can tolerate only occasional soaking by tidal water, is being replaced by saltmarsh cordgrass (*Spartina alterniflora*), a plant that can thrive even if it is inundated at almost every high tide. In the Plum Island estuary, scientists comparing modern aerial photos with maps from the 1950s have found a definite expansion of the amount of open water on the marsh at the expense of the vegetation. While this phenomenon may seem like a minor shift in the structure of the habitat, it is driven by an increasingly wet marsh, and that is a change that spells trouble for salt marsh-nesting birds.

How to Make a Salt Marsh

Rapidly rising sea level, caused by our warming atmosphere, is driving changes in our marshes by influencing the processes that form the marshes.

As with beaches, we can relate the birth of the extensive salt marshes of Massachusetts to the post-glacial period. The barrier beaches formed of glacial outwash sediments acted as buffers, cutting off shallow river estuaries from direct assault by waves. The calm bays behind the beaches allowed plants to colonize the shallows and mud flats. We see the remnant of this process in the largest marshes in Massachusetts: the Great Marsh in northeastern Massachusetts, Barnstable Great Marsh, and Duxbury Marsh. Each of these formed behind barrier beaches like Plum Island, Sandy Neck, and Duxbury Beach.

Slowly rising sea level, has been the norm for thousands of years. The historic average rate of sea level rise, on the order of 0.04 inch (1 mm) per year, has allowed marshes to slowly expand over the intertidal mud flats. It might seem as if the rising sea would drown the marsh. But that only occurs if the vertical growth of the marsh does not keep up with the rate of rising water.

Hero

LIZ DUFF, MASS AUDUBON

Liz Duff, Education Coordinator of Mass Audubon's Salt Marsh Science Project, has been engaging with high school students and their teachers to help them understand the potential impacts of climate change on their communities. The threat of climate change becomes much more real when students discover that popular beaches, historic sites, and even their own high schools are threatened by rising seas. Learn more about Liz's work at massaudubon.org/saltmarshproject.

Liz Duff with students

To sustain salt marsh growth, a delicate mixture of decomposing marsh grasses and sediments washed down from rivers and shorelines is needed. Because the underground parts of marsh plants decompose very slowly, they form a thick layer of peat on which new plants can grow. In addition, the shoots of marsh plants trap sediments that are carried into the marsh by tides and rivers, thus building up the surface of the marsh. As long as the rate of sea level rise is very slow, the marsh can keep pace and expand outward and upward. Marshes can also build up toward the landward side as sea level rises, as long as the slope of the land is gradual and the inflow of sand and soil is not impeded by human-built barriers, such as sea walls.

The delicate equation of salt marsh growth is based on a very slow rate of sea level rise. As we enter a period of rapid sea level rise, this equation may no longer result in marsh accretion. There are already signs that we are losing our marshes and the plants and animals that live there, such as the Saltmarsh Sparrow.

Case Study // Drowning in the Rising Seas: Saltmarsh Sparrow


Saltmarsh Sparrow

The case of the Saltmarsh Sparrow demonstrates the extreme vulnerability of some coastal species to sea level rise, as well as the unintended effects of development on our shorelines.

As sea level rises, increasingly wetter salt marshes can produce drastic consequences for marsh-nesting birds such as Saltmarsh Sparrows. Their nests are in the high marsh, but even there they are in danger of being flooded by storms and the highest tides. The nesting season is already challenging for most birds, but for the birds that nest in salt marshes, there is the additional challenge of living within just a few vertical inches of tideline. Additionally, the grasses in the high marsh are mostly saltmarsh hay (*Spartina patens*), not the cordgrass (*Spartina alterniflora*) of the low marsh; the line between the two species of grasses is determined by the frequency and depth of tidal inundation at high tide. As marshes become wetter due to rising sea level, the amount of high-marsh habitat will continue to shrink.

In salt marshes, the height of the tide varies, with predictable and unpredictable factors influencing the height. The most predictable factor is the phase of the moon: During full and new moons, the tide is higher; these high tides, which occur twice a month, are called spring tides. Other less-predictable factors that bring higher-than-normal tides, such as storms and wind, can occur at any time.

It takes about 26 days for a Saltmarsh Sparrow to go through egg laying, incubation, hatching, and fledging. Therefore, if a female Saltmarsh Sparrow lays eggs immediately after a spring tide has passed, her eggs and chicks will have to survive only one more spring tide before the young birds are ready to leave the nest. This precarious timetable does have some built-in safeguards: the structure of the nest allows the eggs to float up during an extreme tide and then settle back down when the tide drops. But the very young chicks can't climb up the slender grass fronds to escape a very high tide. So if the tide is high enough to inundate a nest with chicks, then the very young chicks will drown. If flooding happens too often, even older chicks are at risk.

In addition to the increased flooding caused by sea level rise, human development on marshes tends to increase the risk of flooding. Marshes in developed areas are often traversed by roads and railroad beds, which almost always restrict the natural flow of tides. It is possible that this restriction decreases the amount of sediment that would otherwise flow into the marshes, thus reducing the marshes' natural ability to build up. With a lower marsh, flooding events become catastrophic.

Saltmarsh Sparrows can still be found in the salt marshes of Massachusetts, but their population is declining precipitously. Recently a multi-partner and multi-state research project, Saltmarsh Habitat and Avian Research Project (SHARP), was formed to study salt marsh-nesting birds, and Saltmarsh Sparrows are one of the focal species of this project (tidalmarshbirds.org). Researchers at SHARP have done extensive work to evaluate the status of tidal marsh-nesting birds, and the evidence is unambiguous—the future is grim for Saltmarsh Sparrows. The researchers have documented an alarming population decline of about 9% per year along the Atlantic coast—the only place in the world where this species lives. The compounding rate of decline is difficult to imagine. SHARP researchers put it this way: It is as if three out of four Saltmarsh Sparrows have died and not been replaced since the 1990s. Without a massive intervention, it is likely that Saltmarsh Sparrows will be extinct within 50 years.

Razorbill

Seabirds in a Warming World

Our offshore waters are a resource of global significance.

THE MARINE WATERS OFF THE MASSACHUSETTS COAST provide year-round feeding grounds for birds from throughout the Western Hemisphere. In winter, thousands of Common Eiders, Long-tailed Ducks, and Razorbills return from their breeding sites scattered across the high latitudes of Canada and Alaska to gather on our offshore shoals, where they feed on mollusks, crustaceans, and fish. At the end of every summer, most of the Western Hemisphere's breeding population of endangered Roseate Terns uses our coastal waters to feed on sand lance prior to departing for wintering grounds off the coast of South America. Every year those birds are joined by Great Shearwaters, Sooty Shearwaters, and Wilson's Strom-Petrels from the far Southern Hemisphere, making the offshore waters of Massachusetts a resource of global significance.

Great Shearwaters

For generations, the world's oceans and shores have been over-harvested and polluted, and marine habitats have been degraded—and the waters off the Massachusetts coast were no exception. Today there are additional threats. The accelerated warming of the planet's oceans and the increasing acidification of ocean water are rapidly changing the world's marine ecosystems.

The ocean is a complex ecosystem with underlying patterns of circulation, water-column layering, and seasonal productivity, as well as a panoply of interactions among the plants, marine algae, and animals that live in and near the sea. Ecologists and oceanographers have made headway in understanding these complex ocean systems, with the work of Massachusetts research institutions such as the Woods Hole Oceanographic Institution and NOAA's Stellwagen Bank National Marine Sanctuary contributing significantly to this understanding. Our challenge is to steward this globally significant resource through the challenges of our shifting climate.

Observed Changes

Ocean surface temperatures off the coast of Massachusetts have warmed by 1.5°F to 2°F since 1901. From 2004 to 2013, the waters of the Gulf of Maine warmed more quickly than 99.5% of the world's ocean waters, and surface temperatures are projected to increase by another 4°F to 8°F by 2100. This means that the marine organisms of Massachusetts will likely experience the effects of warming water sooner than organisms living elsewhere.

Why Is a Warmer Ocean Less Productive?

The temperature of ocean water is a key factor in determining its productivity. Although it may seem counterintuitive, cold water is actually far more productive than warm water. Cold water holds more oxygen than warm water, and with higher amounts of dissolved oxygen it can support more life. Additionally, cold water that is brought to the surface by the natural process of upwelling is often rich in nutrients. Thus, the upwelling of cold, nutrient-rich water acts as a fertilizer for primary producers such as phytoplankton and marine algae.

Warmer surface water reduces the rate of turnover in marine systems, stalling the process that brings nutrient-rich cold water to the surface. The reduction in ocean productivity will, in turn, affect everything that lives in the ocean.

The Web of Warming

Another profound effect of warming ocean water occurs at the base of the food web. In the spring, phytoplankton—photosynthetic microalgae—begin to reproduce rapidly, accumulating in massive numbers called *blooms*. Phytoplankton blooms are driven by climate-sensitive factors such as temperature and the layering of the water column. As water temperatures increase, phytoplankton blooms occur earlier and earlier in the year, a phenomenon that has already been observed in the Gulf of Maine and off the coast of Martha's Vineyard.

Copepods

The problem with earlier-than-normal phytoplankton blooms is that they throw off the timing of the organisms that feed on phytoplankton. The primary consumers of phytoplankton are zooplankton, including the common tiny crustaceans called copepods.

In the winter, immature copepods enter diapause, a condition similar to hibernation. During that period, copepods move to deeper water and slow their metabolism,

Case Study // From Plankton to Puffins: What Happens if the Restaurants Close?

The impacts of changes in the lower trophic levels are already being seen in the colonies of Atlantic Puffin nesting along the coast of Maine. In the diets of puffin chicks, preferred prey species such as Atlantic herring have declined, while less favored prey species such as butterfish have been increasing, possibly because the less favorable fish are better able to accommodate the environmental shifts occurring in the Gulf of Maine.

During 2012 and 2013, a period of intense warming in the Gulf of Maine, there was a severe decline in the number of Atlantic Puffin chicks that fledged successfully. Then in the summer of 2016, dry weather and unseasonably warm sea-surface temperatures created additional challenges for nesting puffins. On Machias Seal Island in the eastern Gulf of Maine—home to more than 5,000 pairs of nesting puffins—nearly 90% of the chicks died. Remarkably, puffins nesting farther west in the Gulf of Maine that same season had a relatively successful year. Researchers from Project Puffin have suggested that the relative success was the result of a trend in which phytoplankton blooms are increasingly occurring in the western Gulf of Maine but not in the eastern Gulf of Maine.

Atlantic Puffins are helping us to understand the effects of significant climate-related changes at lower trophic levels. At the same time, Atlantic Puffins are also teaching us about resiliency in the face of climate change. Puffins seem to have the ability to readily switch prey sources, a flexibility that may benefit them when their preferred prey becomes unavailable. Also, since Atlantic Puffins currently nest on multiple islands in the Gulf of Maine, a change in the distribution of prey that causes a colony on one island to fail could potentially benefit another colony on a different island.

The struggles of puffins to cope with the effects of a changing climate are just beginning. They are a bellwether of sorts—a new canary in the coal mine. Their fate will likely mirror that of other ocean-dependent birds, and all eyes should be on the iconic "Sea Parrot".

Atlantic Puffin with Atlantic herring

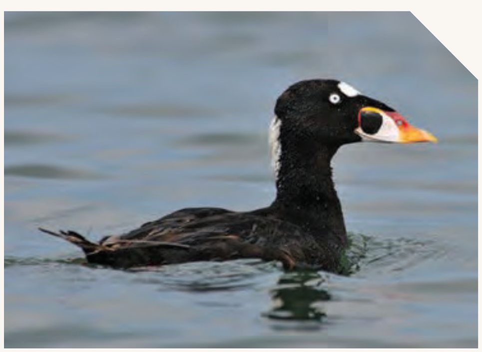
thus delaying their development to the adult stage. When copepods emerge from diapause in spring, they rely on phytoplankton blooms to support their growth and reproduction. If the timing of copepod emergence is out of sync with the peak production of phytoplankton, the phenological mismatch could lead to poor reproductive success in copepods. That, in turn, would affect the copepod's predators. The break in the trophic linkage would be felt first by plankton-eating seabirds, such as the Leach's Storm-Petrel, then by baitfish, such as sand lance, and then by fish-eating seabirds higher in the food web, such as terns and shearwaters.

Leach's Storm-Petrel

Ocean Acidification

In addition to driving global warming, the excess carbon dioxide emitted by burning fossil fuels and other activities leads to ocean acidification, a process sometimes called "climate change's evil twin." Some of the excess carbon dioxide in the atmosphere eventually dissolves into the world's oceans. Once it is in the ocean, it reacts with seawater to form carbonic acid, thus making the ocean water more acidic.

Ocean acidification is a threat to many marine invertebrates. The thin shells of the tiny marine snails called pteropods, for example, can be completely dissolved within a month at the levels of acidity found off our coast. Corals, young oysters, clams, mussels, and crabs are all at risk from increasing acidification.



Surf Scoter

If ocean acidification continues unabated there will be consequences for many of our near- and off-shore birds, such as Surf Scoters, White-winged Scoters, Common Eiders, and Long-tailed Ducks that rely on mollusks and crustaceans as their primary food source.

Hero

STELLWAGEN BANK NATIONAL MARINE SANCTUARY

Even before receiving its official designation as a National Marine Sanctuary in 1992, Stellwagen Bank National Marine Sanctuary has long been recognized as an important refuge for seabirds, marine mammals, and other marine life. Among the priorities of the sanctuary are research, monitoring, and education. Collectively these activities have produced a wealth of information that is of significance to the general public, the commercial fishing community, and scientists. Along with information derived from a number of other prestigious institutions, a growing volume of scientific information is now available to the general public and the research community. Stellwagen Bank National Marine Sanctuary is one of the true heroes working in the Gulf of Maine to ensure the future of this significant marine region. Some of the more important activities undertaken by the sanctuary staff are listed below.

- Systematic survey and study of sand lance populations in the sanctuary
- Tagging and monitoring of cod populations in Stellwagen Bank National Marine Sanctuary
- Satellite-tagging and monitoring of foraging locations of Great Shearwaters
- Systematic, year-round monitoring of seabirds in the sanctuary through the use of staff and volunteer citizen scientists in the S4 Program (Stellwagen Sanctuary Seabird Steward Program)
- Long-term marine mammal monitoring and the regular tagging of humpback whales
- Extensive outreach education for both youth and adults, including use of a spectacular inflatable humpback whale model
- Serving as a national leader in acoustic monitoring of the marine environment.
- Working with tourism centers to inform visitors about safely viewing local marine resources.

The Forest

The simple act of letting our trees grow helps mitigate the effects of climate change.

ABOUT 60% OF THE LAND IN MASSACHUSETTS IS FORESTED, and much of that forest is between 60 and 100 years old. In most of the state, if land is not developed or actively maintained as open farmland, it slowly reverts to forest.

Forests contribute to our quality of life and perform essential ecosystem services that we often take for granted. We can thank our forests for clean water and clean air. Rainfall and runoff are filtered through the forest soils and enter our groundwater improved. In the process of photosynthesis, trees release oxygen—about half of all the oxygen produced on Earth comes from terrestrial plants. Also, as the trees of a forest grow, they take in carbon from the atmosphere, converting it into the biomass of their trunks and roots. In this process of carbon sequestration, the forest acts as a carbon "sink." The simple act of letting our trees grow helps mitigate the effects of climate change.

While the effects of climate change on the forest birds of Massachusetts may be less obvious than the effects on the birds of coastal ecosystems, our forest birds are at risk, and they face their own set of challenges. As with other species, climate influences the basic behavioral and physiological performance of forest birds—from clutch size to metabolic rates. Climate also influences prey abundance on the wintering, migrating, and breeding grounds. Taken together, the shifting climate will cause fundamental changes in most aspects of forest birds' lives.

Effects of Climate Change on Forests

Forests have the capacity to respond to a changing climate, and over very long periods of time the composition of a forest can shift to fit new climatic conditions. However, the current rate of climate change is not slow; rather, it is very fast.

We know that our changing climate is producing warmer winter temperatures, changing the number of freeze-and-thaw cycles, and increasing the frequency of droughts. These changes, and others, have been demonstrated to affect the health of our dominant forest trees.

Forest researchers have developed climate envelope models for dominant tree species, similar to the models used for birds in this report. Their models project that there will be large-scale shifts in the composition of our forests. They predict that the maple, beech, and birch forests currently found in the western part of the state will shift to the pine and oak forests similar to those found in the eastern part of the state. Higher-emission scenarios predict even more substantial changes for Massachusetts forests, and indicate that the climate throughout the state could eventually support forests of oak and hickory—trees that are currently dominant in the forests of the southern United States.

As with our bird climate envelope models, the forest climate envelope models indicate only that the climate would be suitable for certain changes. They do not predict whether or how the current forests will retreat, or whether the potentially expanding species of trees will be able to colonize new areas quickly. What we can expect is that these projected shifts would occur after periods of extreme stress in our forests.

Effects of Climate on Forest Birds

Many forest birds are vulnerable in a changing climate—but what aspects of their ecology are most at risk, and how do we provide for birds and other species in the changing environment?

Shifting Habitat Composition and Quality

Blackburnian Warbler

At a coarse scale, climatic conditions play a defining role in the habitat selection of birds. For example, many songbirds that have a mostly northern range, such as Magnolia Warblers and Blackburnian Warblers, extend their range south along the higher elevations of the Appalachian Mountains, where a similar climate can be found. These songbirds are not simply tracking climate conditions—they are seeking the vegetation and sources of food that they need to breed successfully—and the distribution of those resources is largely determined by climate. The current distributions of our birds give us a clue to the critical role climate can play in determining the range of a species, and a window into the scale of the changes we can expect as the climate warms.

The changing climate is also likely to have a variety of complex effects on the structure of the habitats that our forest birds need. For example, changes in patterns of rainfall are likely to influence the growth of understory plants. Such changes will, in turn, affect forest-nesting birds, such as Wood Thrushes, that rely on thick, well-developed understory layers for hiding their nests.

Distribution Shifts

We can expect climate-driven distribution shifts for our forest birds, and some may already be underway. However, species that shift their distributions are not free of risk, and the risk is amplified if there are multiple stressors on the landscape.

Some species, such as the Blue-gray Gnatcatcher, have already shifted their breeding distributions northward, and other species, such as the American Robin, have moved their wintering distributions northward. Similarly species such as the Magnolia Warbler and Hermit Thrush have moved upwards in elevation as the climate has warmed. But some high-elevation species, including the Bicknell's Thrush, which is now extirpated from Massachusetts as a breeding bird, may simply run out of climate-appropriate mountaintop habitat to call home.

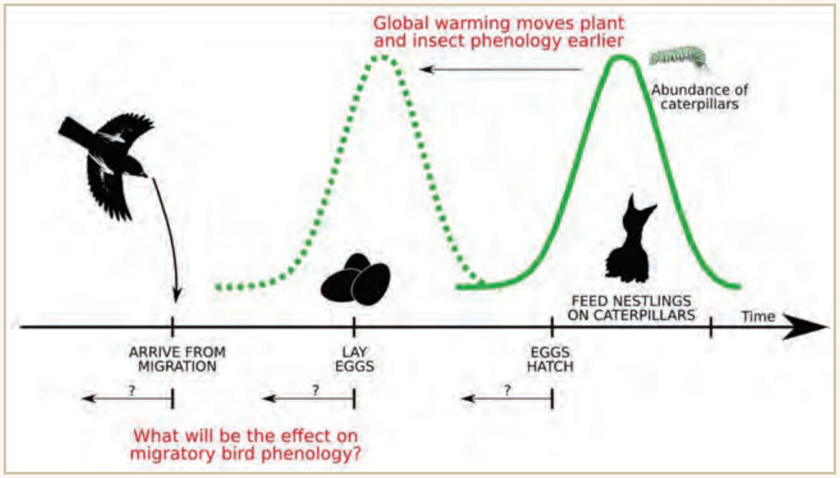
Hermit Thrush

Phenological Effects—Arriving at the Buffet on Time

As with phenological mismatches in the oceans, a key problem for forest birds is the fact that spring is "springing" earlier. Migratory birds, in particular, time their breeding cycles to match peak abundance of food, such as caterpillars. That timing allows them to meet the high energy needs of nestlings. Earlier springs mean earlier peaks in insect abundance. Warming temperatures may also shorten the window of peak insect abundance by increasing the rate of insect development. Resident birds—those that breed and winter in the state—are at an advantage for coping with the earlier supply of prey. But migrant birds, particularly long-distance migrants, are less able to adapt.

For example, how would a bird that winters in Costa Rica know that spring is advancing earlier in Massachusetts? In most cases, long-distance migrants rely on changes in photoperiod—the hours of sunlight in each day—to indicate when they should start migration. Because photoperiod is consistent from year to year, it does not vary with changing climates and earlier springs. Thus the long-distance migrant in Costa Rica will not receive a food "cue" that it is time to leave for the breeding grounds in the north—it will wait for the appropriate photoperiod to arrive, and then arrive late for the insect buffet.

American Redstart



©Kristensen, N.P. et al. 2015. Phenology of two interdependent traits in migratory birds in response to climate change. Proceedings of the Royal Society B 282.

Lagging Behind

Scarlet Tanager

Research indicates that forests are "greening-up" earlier—leaf emergence is advancing by about 5 days every decade. Arrival dates of some migrants are also shifting to keep up with the change, but most migrants are unable to perfectly match the rapid advance of green-up. Scarlet Tanagers, along with other iconic woodland species, are already lagging behind the changes in green-up.

Climate Change in the Wintering Habitats of Long-distance Migrants

Climates are changing worldwide, including the climates of the Caribbean, Central America, and South America, where most of our long-distance migrants spend about half of the year. Climate and habitat conditions on wintering grounds can limit survivorship, and also influence what happens after a bird migrates north and seeks to obtain a high quality nesting territory. Such carryover effects (i.e., physical linkages between the wintering grounds and migratory or breeding grounds) represent the importance of full-life-cycle conservation planning. Because the effects of global warming are expected to be rapid, to result in greater climatic variability, and to vary regionally, these carryover effects must be studied so we can understand their implications on individual species.

Along with warming temperatures, many wintering areas in the neotropics are becoming drier. Precipitation changes are known to affect everything from the types of prevailing vegetation to the abundance of insect prey, and they can quickly alter the habitats that our long-distance migrants have adapted to over the past millennia. Our own work from the *Massachusetts Breeding Bird Atlas 2* reveals that, as a group, long-distance migrants are declining. That decline alone should alarm us. Increasing stress on these species due to climate change makes conservation actions all the more critical.

Wood Thrush nest

Hero

NEW ENGLAND FORESTRY FOUNDATION

NEW ENGLAND FORESTRY FOUNDATION

While unharvested reserves of mature forest provide a wealth of ecological benefits, young forest habitat is critical for a variety of bird species. Young forest habitat is most often created by forest management, and "working forests" are a critical component of a diverse Massachusetts landscape. In Massachusetts there is a challenge to find uses for locally-harvested timber that is not immediately consumed as firewood. Longer-term carbon storage can be achieved by using timber to produce lumber for construction. In addition, the production of lumber for construction can offer stronger markets for landowners.

Technologies now exist to construct mid-rise and high-rise buildings out of engineered wood materials. With their Build It With Wood campaign, New England Forestry Foundation (NEFF) is on a mission to make such construction commonplace in our region. The benefits of building with wood are numerous:

- Carbon is stored indefinitely in the wooden structure of the buildings, and the wood replaces the use of carbon-intensive steel and concrete.
- The buildings are less expensive and aesthetically beautiful, and the wooden beams can be designed to be stronger and more fire-resistant than steel.
- The use of sustainably harvested wood in long-lived building materials can increase overall carbon sequestration from forests, increase overall forest resiliency, and stimulate rural economies.

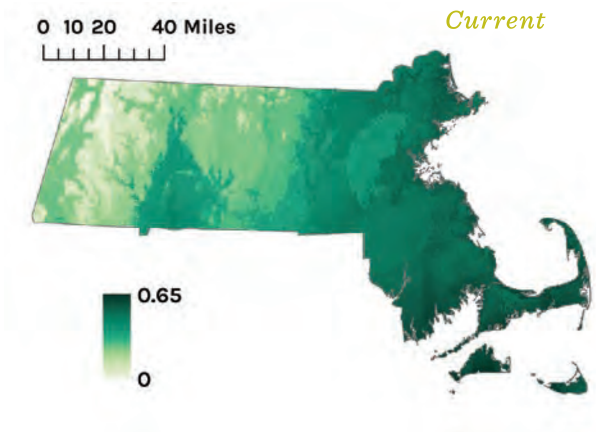
Strategic steps that New England Forestry Foundation is taking include communicating with decision makers and the public about the benefits of building with wood, assessing the market for engineered wood products, and influencing policy changes, such as increasing the inclusion of engineered wood materials in certified green building programs. For more information, visit builditwithwood.org.

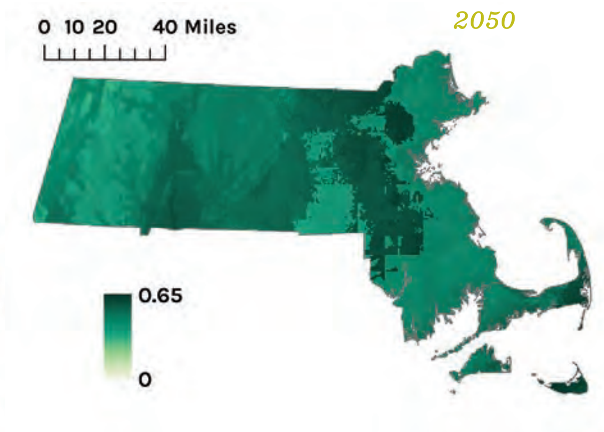
Spotlight Northern Bobwhite

For information on how to read these maps, refer to page 8.

Breeding Bird Atlas 2 Rank = Strong Decline

Climate Vulnerability Rank = Least Vulnerable





***Breeding Habitat**: Near large agricultural field edges, in large forest openings, managed pine plantations, and under large powerline cuts.*

The clear, whistled call of the Northern Bobwhite has long been an essential part of the summer experience in the Massachusetts countryside. These small yet charismatic birds are a favorite among hunters and birdwatchers alike, and they were historically found throughout the Commonwealth. In recent years, however, Northern Bobwhites have declined throughout their range.

Our work with the *Breeding Bird Atlas 2* project demonstrated that since 1979, Northern Bobwhites have declined in range and abundance in Massachusetts, where they are now restricted to breeding mostly on the Cape and Islands.

Declining acres in agriculture, decreasing diversity of plants along edges of agricultural fields, growing development footprints, old fields growing up into forests, and a lack of large-scale management for this species all contribute to its decline.

WHAT DOES THE FUTURE LOOK LIKE?

The climate envelope models project an increasingly suitable climate for the Northern Bobwhite. Under current conditions there is a low likelihood of finding this species in the western portions of the state, with the exception of the Connecticut River Valley. But, when we advance to projected 2050 climate characteristics, we see that the average score for the Northern Bobwhite increases from a 37% likelihood of occurrence to a 41% likelihood, with increased projected climate suitability especially notable in western Massachusetts.

Of the 20 environmental variables used in the analysis, two showed the greatest (>70%) cumulative influence on the resulting climate model:

- Annual Mean Temperature
- Mean Temperature of the Warmest Quarter

These two variables emphasize the factors most likely to influence the distribution of suitable bobwhite breeding habitat. Changes in one, or both, of these variables are likely responsible for the predicted increase in Northern Bobwhite distribution between current and future time periods.

Warming temperature appears to be the most important climate component defining where Northern Bobwhites breed in Massachusetts. It is unlikely that temperature, per se, influences where bobwhite breed. Instead, temperature characteristics presumably influence the underlying plant communities that are distributed on the landscape, and those plant communities then dictate which areas represent the best areas for nesting bobwhites. Additionally, bobwhites in Massachusetts are currently at the northern edge of their range. Warming temperatures could reduce snow cover, which is known to be a significant source of mortality for this species.

ACTIONS

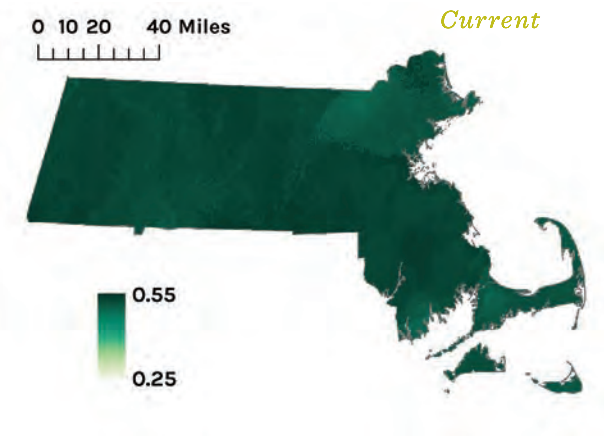
The Northern Bobwhite is a much-sought-after game species, and its decline of has not gone unnoticed. Some introduction programs have met with success, but others have failed. Climate change may make future recovery programs more likely to succeed in the future. Perhaps, like the once-extirpated Wild Turkey, the right combination of breeding stock and habitat management will converge with a generous climate to help restore this iconic species to the Commonwealth.

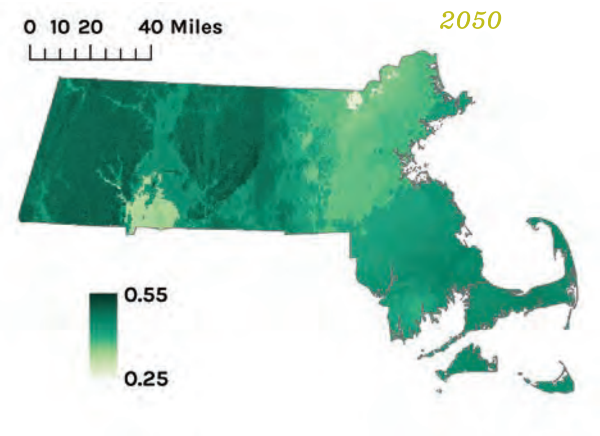
Spotlight Ovenbird

For information on how to read these maps, refer to page 8.

Breeding Bird Atlas 2 Rank = Likely Increasing

Climate Vulnerability Rank = Likely Vulnerable





***Breeding Habitat**: Interior, uninterrupted forests with relatively closed canopies and limited understory.*

Though it looks and sometimes acts like a spotted thrush, the Ovenbird is a New World warbler. Its loud, distinctive, and oft-repeated song, *tea-cher, tea-cher, tea-cher, tea-cher*, is a familiar sound in the spring and summer woods of New England.

Like other birds of mature mixed forest, Ovenbirds were likely plentiful in the time before European ships landed on the shores of the "New World." As the forests began to fall before the fire and axes of the Massachusetts Bay Colony, the majority of Ovenbirds retreated to the remaining forests of the western part of the state until the widespread agricultural period was over. As large areas of contiguous mature forest have gradually returned, Ovenbirds have been quick to recolonize them. The Ovenbird was identified in *Massachusetts Breeding Bird Atlas 2* as a species on the increase, especially in the central and eastern portions of the state. These increases were thought to reflect the increased amounts of suitable forest produced as successional processes responded to reductions in land area being used for agriculture.

WHAT DOES THE FUTURE LOOK LIKE?

Our model shows that Ovenbird distribution in Massachusetts is likely to be adversely affected by the projected future changes in temperature and precipitation patterns. By 2050 the species will continue to occur statewide, but occupancy in eastern areas of the state may decline as the Ovenbird's climate envelope drifts northward, leaving Massachusetts near the southern limit of its continental distribution.

Of the 20 environmental variables (elevation and 19 variables describing various aspects of temperature and precipitation patterns), four showed the greatest (>60%) cumulative influence on the resulting climate envelope model:

- Annual Mean Temperature
- Mean Temperature of Coldest Quarter
- Precipitation Seasonality
- Maximum Temperature of Warmest Month

These four factors are the most likely to influence the distribution of suitable Ovenbird breeding habitat; changes in some, or all, of them are likely responsible for the predicted decline in Ovenbird distribution between current and future time periods.

CONSERVATION CHALLENGES

Maintenance of large tracts of mature forest is important for future conservation of Ovenbirds in Massachusetts. Such areas will continue to be threatened by suburban development and associated habitat fragmentation, and higher temperatures may further reduce the soil moisture levels that affect the food resources used by breeding Ovenbirds.

ACTIONS

Conservation of Ovenbirds demonstrates the broad suite of actions that are important for most of our Neotropical migrant songbirds. Efforts to reduce losses throughout the full annual cycle are important. Prevent forest fragmentation in the breeding range, ensure that your backyard is a bird-friendly sanctuary safe from cats and potential collisions with windows, support efforts to reduce window collisions at tall skyscrapers and other office buildings, support organizations focused on protecting lowland forest habitats in the Caribbean, Mexico, and Central America. All of those efforts will help reduce the pervasive impacts of changing temperature and precipitation patterns on breeding Ovenbirds in Massachusetts.

What Mass Audubon is Doing

We must adapt our land conservation, species protection, and land management actions.

SOME FUTURE CHANGES ARE UNAVOIDABLE, regardless of future greenhouse gas emissions. To respond to these additional stressors on the Commonwealth's birds, we must adapt our land conservation, species protection, and land management actions.

In the What You Can Do section of this report we list tools that you, as an individual, can use to mitigate your carbon footprint and to provide a personal landscape that helps to reduce stress to wildlife. But what are some of the tactics we are using to address the large scale changes that birds, and all wildlife, face across the state? Here are some of the efforts that Mass Audubon is using or testing to help build resistance, resilience, and redundancy into our landscapes.

Saving Salt Marshes

The following actions help the salt marshes and the wildlife that live in them respond fluidly to climate change:

- Restore marshes to ensure natural function
- Remove upstream dams to allow natural sediment input to reach marshes
- Create living shorelines to prevent rapid erosion
- Protect land on the landward margin of salt marshes, to allow for future inland migration
- Maintain barrier beaches to buffer salt marshes from wave action

Salt Marsh Restoration

Salt marsh restoration has been a major focus of government agencies and nonprofit organizations. Some of the commonly used techniques, as well as some experimental techniques, are listed here.

Removing Barriers to Tidal Flow

Repaired culvert at Allens Pond Wildlife Sanctuary

In New England, tidal flow restoration efforts have focused largely on re-establishing natural hydrology in areas where roads and railroads built across marshes have restricted the tides. The effort typically involves increasing the size of culverts to allow more complete flushing by the tides and the removal of rocks and anything else that may be blocking the flow. The increased flow of seawater transports more sediment, allowing increased sedimentation on the marshes, thus enabling the marsh surface to better keep up with sea level rise.

Increased flushing with seawater also helps to reduce the cover of the invasive common reed (*Phragmites australis*), a species that is less tolerant of high salinities than our native salt marsh grasses. Because stands of common reed do not support breeding of the imperiled Saltmarsh Sparrow, such flushing should, at least in theory, benefit the birds.

Osprey

Removing Dams

Salt marsh restoration can begin far upstream, in the rivers that carry sediment to the marshes. Dams trap sediments (sand and silt), and their removal increases the transport of sediments downstream to salt marshes. Many dams in Massachusetts were constructed in the 18th and 19th centuries to power industries that no longer exist, such as grist mills. Allowing the rivers to flow freely would help salt marshes to keep up with sea level rise. It would also remove barriers to the passage of anadromous fish such as river herring, which are important prey of Ospreys and other fish-eating birds, as well as popular game fish such as striped bass.

Coir logs

Building Living Shorelines

Creating a living shoreline at the seaward edge of a salt marsh adds protection from increased erosion due to wave action. A living shoreline often starts with coir logs—biodegradable logs created from plant fiber. The logs are integrated with mussel or oyster beds, sometimes in combination with salt marsh vegetation, and the structure forms a protective edge to the shoreline. Mass Audubon is experimenting with living shorelines at the Felix Neck Wildlife Sanctuary on Martha's Vineyard, in partnership with the Oak Bluffs and Edgartown shellfish constables, the U.S. Environmental Protection Agency, and the University of Rhode Island.

Protecting Land

The protection of undeveloped lands as a buffer around coastal wetlands is of great value to wildlife and the water quality of estuaries. Many land trusts, including Mass Audubon, have made a priority of protecting land at the upland edge of marshes, such as at our Rough Meadows Wildlife Sanctuary in Rowley. This provides a "land-bank" for marshes to expand as the rising sea level renders lower areas no longer suitable for marsh plants. But a salt marsh can only migrate into an adjacent upland if that area has a low gradient and is free from barriers, such as sea walls and other human-made developments. The speed that salt marshes move inland is of concern. In some cases managers may need to jump-start the migration process by removing woody vegetation at the interface of the marsh and upland.

Beach and Island Adaptation

In addition to providing a buffer for salt marshes, restoring and managing beaches will help many of our imperiled coastal-nesting birds.

Beach and Island Renourishment

With the expected increase in the intensity of future coastal storms, beaches and islands are likely to become even more vulnerable than they are now to being breached by storm surges. The increased risk will impede the natural process of beach building. While not appropriate in all situations, beaches and islands can be built up by deposition of dredge material. In addition to maintaining habitat for coastal-nesting birds and migratory shorebirds, renourishment protects salt marshes, eelgrass beds, and estuarine habitats behind barrier beaches.

The results of restoration work for Roseate Terns on Bird Island off of Marion, MA.

Concepts like renourishment need to be explored and expanded with an eye toward creating new locations for colonies of beach-nesting terns—particularly on coastal islands. Currently Massachusetts has only two large colonies of Roseate Terns, but those colonies hold about 50% of the North American population. The goals for the recovery of that population call for several new colonies of moderate size to be established. Renourishment coupled with the installation of nest boxes and appropriate vegetation should be explored as techniques to create more suitable habitat for Roseate Terns. Additionally renourishment on beaches and islands would create habitat for Common Terns, Least Terns, and Piping Plovers, to name a few.

Mass Audubon is currently studying the potential for restoring tern nesting habitat on the rocky islands north of Cape Cod, such as Straitsmouth Island off of Rockport.

Conserving Our Forests Birds: Balancing the Need for Young and Old Forests

A commonly discussed approach to reducing the impacts of climate change on wildlife is to remove or control stressors that are unrelated to climate, thus enhancing the ability of natural systems to adapt to the new "normal." Long-term bird monitoring programs such as the North American Breeding Bird Survey and Mass Audubon's Breeding Bird Atlases show a decline in the abundance of most forest birds in Massachusetts and a reduction in their statewide distribution since the mid-1960s. Included in the list of declining forest birds are birds that breed in young forests as well as some that breed in closed-canopy middle-aged forests.

Much of forest bird declines can be attributed to habitat loss and degradation. We can add resistance, resilience, and redundancy to our forest communities by connecting and protecting forest cores, enrolling private lands in forest conservation programs, promoting carbon storage programs, reducing destructively high herbivore populations, controlling invasive plants and pests, establishing young forest openings to restore declining bird populations, and using small and selective silviculture practices to mimic old-growth characteristics in middle-aged forests.

Protecting Forest Reserves

Forests play a major role in the global carbon cycle, taking up carbon dioxide from the atmosphere and storing, or sequestering, carbon in their collective biomass. When forests are mismanaged, they release significant amounts of carbon dioxide into the atmosphere. Deforestation is currently responsible for about 17% of global carbon dioxide emissions. Meanwhile, the forests of the United States are a carbon sink, sequestering about 10% of our country's annual fossil fuel emissions.

Forest reserves, established on some Massachusetts state-owned land, as well as less-formally established reserves on many Mass Audubon wildlife sanctuaries, can act as large-scale forest conservation areas and also serve as reference areas for comparing managed and unmanaged sites. As these forests age, they will support higher densities of mature-forest birds. They also store the greatest amount of carbon. In fact, they may continue sequestering carbon for centuries after they are considered fully mature. For those reasons alone, forests reserves should remain protected and be expanded.

Protecting large, connected forest reserves will increase the likelihood that mature-forest species, such as the Black-throated Green Warbler, will have appropriate habitat.

Protecting wooded freshwater wetlands, especially those with high shrub and canopy cover, will ensure habitat for the declining Canada Warbler.

Keeping Forests as Forests—Protecting Private Land for Conservation

Mass Audubon's 2014 *Losing Ground: Planning for Resilience* report found that 25% of the land in Massachusetts is in permanent protection and 22% is developed. The remaining 53% of the land is unprotected and susceptible to additional development.

About 75% of the forests in Massachusetts are privately owned, and every year we lose some of those privately-owned forests to development. For those landowners who want to protect their land, there are several tools available. Conservation restrictions or enrolling in the state's current-use tax forest program (also known as Chapter 61), can reduce property taxes and ease the financial burden of owning undeveloped land. Forested land is also often developed when property ownership changes. Landowners should, therefore, also explore conservation-based estate planning to ensure that their land remains as forest after an eventual transfer of ownership.

Exploring Carbon Storage Solutions

When land is cleared for development, the next "crop" is not a young forest—it is a housing or commercial development. Thus, development causes a double loss of carbon storage capacity: It eliminates the carbon storage of the trees that are cut, and prevents the land from returning to its carbon-storage function in the future. There is an obvious economic benefit to a landowner for developing land, but can there be an economic benefit for the ecosystem service provided by keeping the forest as a carbon storage site?

The answer to this question is "yes", and the benefit comes from the California carbon market. California has a robust plan to reduce greenhouse gas emissions in order to slow climate change. One part of the plan is a cap on emissions of carbon dioxide and other greenhouse gases. That cap is slowly being lowered, and it will eventually reduce emissions to their 1990 level. In the meantime, industrial emitters must acquire an allowance from the state for every ton of carbon emitted or purchase offsets from projects that result in increased carbon sequestration elsewhere.

Large landowners can generate income from the stored carbon on their land through the California carbon market. The trees must stay standing for at least 100 years, ensuring the long-term value of the offset.

Starting in 2016, Mass Audubon began to pursue an improved forest management carbon offset sale in the California carbon market. The project involves approximately 10,000 acres of forest from nine wildlife sanctuaries in the Central/West Region of Massachusetts. In addition to the revenue from the sale, an important byproduct of the project will be the regular monitoring of permanent forest inventory plots for the duration of project, which will be 100 years or longer. The monitoring will provide Mass Audubon with valuable insight into long-term forest changes, and could support the monitoring of additional organisms, including birds and amphibians.

Reducing Deer Densities

White-tailed deer

White-tailed deer are present throughout the Commonwealth. However, in the absence of their predators, mountain lions and wolves, their numbers have become unnaturally high. For example, MassWildlife estimated that there may be more than 100 deer per square mile on Mass Audubon's Moose Hill Wildlife Sanctuary in Sharon—five times the ecologically sustainable level. The effects of

Hardly any plants grow beneath the deer browse line in this beech forest at Ipswich River Valley Wildlife Sanctuary.

the high level of browsing by overabundant deer is readily evident at several of Mass Audubon's wildlife sanctuaries, particularly in eastern Massachusetts.

The intense browsing removes habitat structure for nesting birds and other wildlife. It also prevents the growth of saplings, thus eliminating the next generation of forest trees. In a healthy forest, canopy trees that topple due to natural causes are replaced by saplings of native species waiting in the shade of the larger trees; but in an over-browsed forest, there may be no native saplings to fill the gap.

Reducing deer density to sustainable levels is a critical need for enhancing the resilience of our forested lands. Mass Audubon has been working with partners at MassWildlife and The Trustees to assess options for addressing this problem on our properties.

Creating Young Forest

In recent decades, the landscape of Massachusetts has lost a large amount of young forest (up to 20 years old), causing the decline of many species that require that habitat for breeding. The loss of early successional forests is largely due to a reduction in the natural disturbances that create this habitat. For example, fire and flooding have been suppressed, and our middle-aged forests are less susceptible to storm damage.

Creating young forest habitat will help birds, like the declining Eastern Towhee (female pictured here).

Mass Audubon is working with partners to increase young forest habitat in appropriate settings. We recently created a 16-acre forest opening at our Old Baldy property in Otis and are planning similar work at Elm Hill in North Brookfield.

Foresters for the Birds

In 2013 Mass Audubon teamed up with the Massachusetts Department of Conservation and Recreation (DCR) to bring Audubon Vermont's Foresters for the Birds program to Massachusetts. Originally focused on the western part of the state, the program now covers the entire state of Massachusetts. In the program, Mass Audubon ecologists and the DCR forestry team train licensed foresters to manage with birds in mind—whether that means creating young forest, or mimicking the structure of old forests.

Read more at massaudubon.org/forestbirds

Reducing Invasive Plants and Pests

Invasive plants degrade habitat quality in a variety of ways. Their fruits are often less nutritious than those of their native counterparts, they host fewer and less diverse insect prey for birds, and their aggressive expansion displaces and reduces native plant diversity. The stresses and disturbances caused by climate change may exacerbate invasive plant and pest proliferation, and allow them to spread to new areas. Mass Audubon performs targeted invasive species control on many of our wildlife sanctuaries. We also work with partners on the Massachusetts Invasive Plant Advisory Group and other regional partnerships to reduce the spread of invasive plants and pests.

Mimicking Older Forest

The majority of forests in Massachusetts are relatively homogenous, even-aged second growth, resulting from the decline in the clearing of land for agriculture, as well as popular forestry practices. Middle-aged forests often lack structural complexity, such as shrubs and saplings in the understory, gaps in the canopy, standing snags, and dead woody material on the ground—all features associated with high-quality habitat for birds of mature forests. Using forestry practices to create the conditions of mature forests has proven to be a successful conservation strategy. Mass Audubon has taken steps to mimic old growth conditions at Graves Farm Wildlife Sanctuary in Whately and are planning more at Elm Hill in North Brookfield.

Mass Audubon also partners with and supports the efforts of many other conservation organizations. To learn more about more projects, visit our website massaudubon.org/our-conservation-work

American Goldfinch, a popular backyard bird

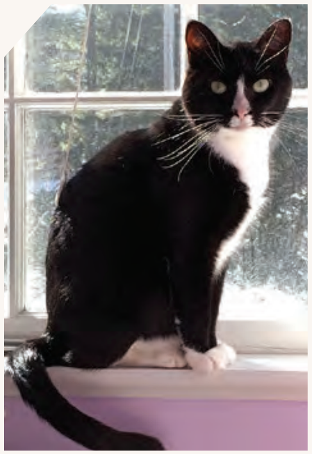
What You Can Do

Climate change is a problem we can solve.

CLIMATE CHANGE PRESENTS ENORMOUS CHALLENGES FOR OUR PLANET. THE THREAT MAY FEEL OVERWHELMING, BUT IT IS A PROBLEM WE CAN SOLVE.

The most effective actions you can take to protect wildlife and be responsible stewards in the face of climate change fall into three broad categories: 1) reduce existing stressors, 2) minimize your carbon footprint, and 3) advocate and vote for policies that advance green energy, clean air and water, sound planning, land conservation, and wildlife protection. Fore more information on any of these steps visit massaudubon.org/sotb.

Protect Birds and Other Wildlife



Mia, a very happy indoor cat.

Keep Cats Indoors

Free-roaming and feral domestic cats kill at least one billion birds annually, and they represent one of the most serious threats to birds in North America. Many of these deaths can be avoided, and bird populations can grow, if we move toward a new cat-owning ethic that mimics the ethic we have for the responsible ownership of dogs. All cats should be kept indoors, where they are safer from disease and injury and where they can do no harm to native wildlife. Adopting this simple and no-cost practice is the single most important thing a person can do to protect wild birds, and to protect the cat members of our families.

Make Your Yard a Sanctuary

Plant a garden for birds, butterflies, and bees (and yourself!). Plant native trees and shrubs, reduce the area covered by lawn, and install nest boxes. Eliminate the use of herbicides and insecticides on your lawn and trees. Then show your friends and neighbors how beautiful your yard is and encourage them to do the same! Visit our website for tips on how to landscape for birds and wildlife. massaudubon.org/landscapeforbirds

Gray Catbird on bird bath

Reduce Window Kills

Collisions with windows and man-made structures are estimated to kill one billion wild birds each year. Fortunately, there are some simple fixes that can greatly reduce the hazard. At home, you can place feeders within 3 feet of or farther than 30 feet away from windows, and you can use window decals or tape to break up large expanses of glass. In office buildings, you can advocate for the use of bird-safe glass and a seasonal Lights Out policy.

Buy Bird-Friendly Coffee

Choosing bird friendly coffee is a simple way to help protect high-quality bird habitat in the tropics. You can search online to find bird-friendly coffee distributors near you, and you can also buy it at the Mass Audubon shop in Lincoln, MA. shop.massaudubon.org

Reduce Your Carbon Footprint

Make the Switch to Renewable Energy

The most effective thing you can do to reduce your carbon footprint is to purchase your electricity from clean and green renewable sources like wind and solar energy. It takes just a few minutes to sign up for our Make the Switch program. Joining the program has an enormous positive effect and doesn't require you to change anything about your daily routine. massaudubon.org/maketheswitch

Eat More Veggies, Eat Less Beef

Eating more vegetables and reducing food waste in your home can have a large effect on your carbon footprint. One simple option is to eat less beef. Compared to other meats, getting beef to the dinner table results in 5 to 10 times more greenhouse gas emissions, requires 28 times more land, and uses 11 times more water.

Choose Low-Emissions Transportation

Walk, bike, or use public transit whenever possible. Organize a carpool for kids' sports teams, school events, and camps. When it comes time to purchase a new vehicle, a hybrid or an electric vehicle is the most cost-effective option overall. Owning a car that gets more than 35 miles per gallon is a good goal to set. And if you're a frequent flyer, aim to reduce the number of flights you take each year, or purchase offsets for the carbon created by your travel.

Use Your Voice

Get Involved in Local Planning, Open Space Protection, and Adopting the CPA

Most local officials are citizen volunteers. By getting involved with community planning efforts, you can have a tremendous positive effect. You can guide development to allow for large, interconnected open spaces that filter the air, clean water, sequester carbon, and protect habitat for plants and animals.

The Community Preservation Act (CPA) gives Massachusetts towns an additional tool for protecting open spaces, funding preservation projects, and remaining resilient to climate change. communitypreservation.org/content/cpa-overview

To take the first step in ensuring sound community planning, visit massaudubon.org/shapingthefuture. You can also learn about prioritizing land in your community for protection by using our easy online mapping tool at massaudubon.org/mappr.

Advocate for the Environment

Join our Advocacy mailing list and take action.
Sign up at massaudubon.org/advocacy.

This simple step will give you alerts so you can take action and voice your concern for wildlife and clean air and water. We will help you support the growth of clean energy development and advocate for the wise management of our public parks and wilderness areas. Join us in protecting the state and federal Endangered Species Acts, the Clean Air and Water Acts, the Migratory Bird Treaty Act, and the host of other regulations that make Massachusetts and the United States leaders in wildlife protection.

Join and Support Local Land Trusts

Actions begin at home. Massachusetts is home to hundreds of land trusts, and all of them need your support. Find a local or statewide land trust, make friends, and help to permanently protect the land and water near your home.

Honoring the Paris Climate Agreement

In 2015, 196 countries voluntarily agreed to reduce greenhouse gas emissions. This historic Paris Climate Accord is the world's first comprehensive climate change agreement, setting a long-term goal for limiting the increase in global average temperature, as well as improving adaptation strategies and providing enhanced support for developing countries.

Although the U.S. Administration subsequently withdrew from the accord, many governors and mayors, including officials from Massachusetts, pledged their commitment to upholding the goals of the Paris agreement at the state and local levels. Massachusetts also continues to implement the Global Warming Solutions Act, with statewide greenhouse gas reduction goals of 25% below 1990 levels by 2025 and 80% by 2050.

We can all help achieve these goals through our own personal actions, from choosing to purchase electricity from renewable sources (see Mass Audubon's "Make the Switch" program) to speaking with friends and neighbors as well as public officials at all levels of government. Let your municipal officials and state and federal representatives know that action on climate change is a priority and that you support policies that help meet the goals of the Paris agreement. The state and local communities also need to plan and take action to help both people and nature adapt to the unavoidable impacts of climate change already underway. Support adaptation through state legislation, policies, strategy and funding.

Together, we can continue to preserve the birds, wildlife, and the places we love for future generations. Get outside! Enjoy nature! Share it with a child and with your friends. Visit a Mass Audubon sanctuary—for more than 120 years our members, donors, and staff have been building the sanctuary network just for you, your children, and your grandchildren.

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