Charting a Healthy Future for North America's Birds

100 Years After the Migratory Bird Treaty, Innovative Conservation and Technology Essential to Overcome New Challenges

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BOREAL SONGBIRD INITIATIVE
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International Migratory Bird Day
Environment for the Americas
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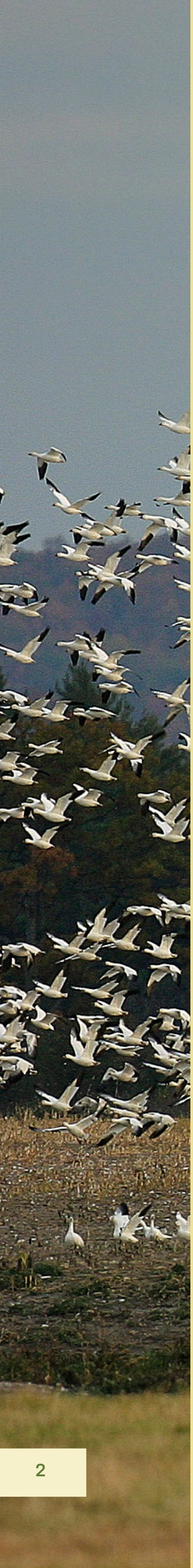

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ABOUT THE BOREAL SONGBIRD INITIATIVE

The Boreal Songbird Initiative (BSI) is a non-profit organization dedicated to outreach and education about the importance of the Boreal Forest region to North America's birds, other wildlife, and the global environment.

ABOUT THE CORNELL LAB OF ORNITHOLOGY

The Cornell Lab of Ornithology is a world leader in the study and conservation of birds, and an educational hub for the biodiversity sciences. Its hallmarks are scientific excellence and technological innovation, advancing the understanding of nature, and engaging people of all ages to learn about birds and protect the planet. Founded in 1915, the Cornell Lab is a non-profit unit of Cornell University supported by 100,000 members and friends.

ABOUT DUCKS UNLIMITED INC.

Ducks Unlimited Inc. (DU) is the world's largest non-profit organization dedicated to conserving North America's continually disappearing waterfowl habitats. Established in 1937, DU has conserved more than 13 million acres thanks to contributions from more than a million supporters across the continent. Guided by science and dedicated to program efficiency, DU works toward the vision of wetlands sufficient to fill the skies with waterfowl today, tomorrow and forever.

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Ducks Unlimited Canada (DUC) is the leader in wetland conservation. A registered charity, DUC partners with government, industry, non-profit organizations and landowners to conserve wetlands that are critical to waterfowl, wildlife and the environment.

ABOUT ENVIRONMENT FOR THE AMERICAS

Environment for the Americas (EFTA) is a non-profit organization that houses the organizing efforts around International Migratory Bird Day and other projects and programs dedicated to increasing bird conservation education. EFTA works with partners and programs throughout the Western Hemisphere.

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The Lesser Scaup is one of several North American waterfowl species that have experienced decline in recent decades.

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The decline of the fittingly named Canada Warbler has spurred researchers to monitor the species more closely in recent years.

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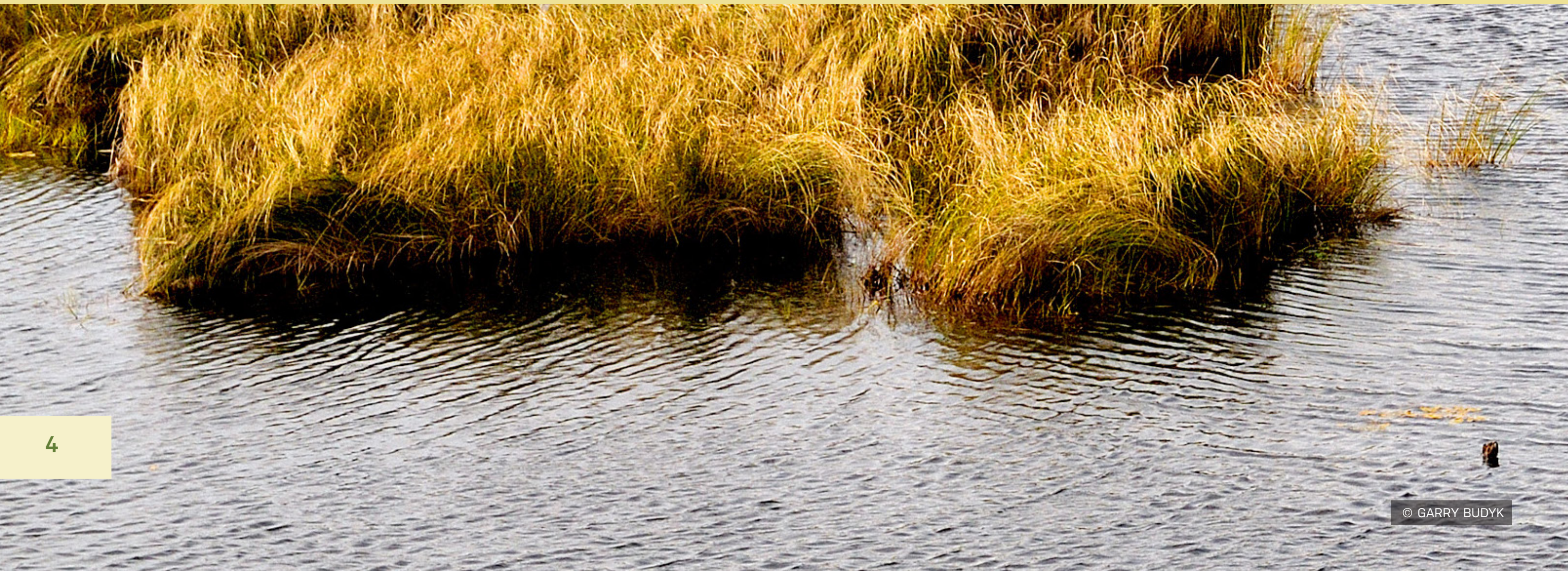
The Rusty Blackbird has shown one of the largest population drops among birds in North America, declining by over 90% since the 1960s.



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Executive Summary

As Canada and the United States mark the 100-year anniversary of the Migratory Bird Convention this year, our nations have much to celebrate. The convention has emerged as one of the most successful environmental treaties in history. It helped countless bird species rebound from near extinction and brought the people of Canada and the United States together to protect shared migratory birds.

The treaty was a breakthrough for its time, curbing the unchecked hunting that threatened many bird species. Today, migratory birds face new threats. Complex forces ranging from habitat loss to climate change have caused some bird populations to decline 70 percent to 90 percent in the past five decades.

It's time for another breakthrough in bird conservation. Cutting-edge technological advances are shedding new insights on bird migration and reshaping conventional understanding of bird flyways—the notion that most birds migrate within four predictable corridors. Findings from this new research reinforce that billions of birds start their migration in one important region: North America's Boreal Forest. And they strengthen the scientific consensus around a bold approach for protecting the Boreal.

Together these technologies are helping unleash the next century of migratory bird conservation.

KEY FINDINGS: NEW INSIGHTS ON SCOPE OF MIGRATIONS AND ROLE OF THE BOREAL FOREST

Recent technological developments are helping uncover the mysteries of bird migration, yielding detailed data about the hemispheric-scale movements of migratory birds. Most importantly, these technologies provide information about what we can do to better protect birds:

- Satellite tracking and geolocator technologies are providing detailed accounts of when and where birds move and the places they stop in between, revealing critical areas of habitat for potential protection;
- Radar and audio sorting technologies paint new pictures of nocturnal migration, including the discoveries of previously unknown rest stops that songbirds rely on during migration;
- The analysis of isotopes and genetic markers connect regional subpopulations within species' breeding and wintering ranges, which helps provide better insight into the causes behind regional and overall population fluxes;
- Internet-based platforms allow millions of observations gathered by everyday citizens to be uploaded and analyzed instantly, making it possible to identify larger patterns, such as the shifting of distribution or timing of migration;
- Taken together, these technologies reinforce that billions of birds begin their migration in North America's Boreal Forest, and that it is a vital breeding ground for North America's birds.

The overarching, and most critical, finding from the application of these and other technologies is that migratory birds need intact habitats across vast scales that encompass all parts of their life cycles, from breeding to wintering ranges and the stopover habitats in between.

In many parts of the world, large-scale conservation of intact, pristine habitats is simply no longer possible. In North America's Boreal Forest, there is still such an opportunity—perhaps the last opportunity in human history—to retain large portions of the landscape free of large scale industrial disturbance. The oreal annually "exports" some 3 billion - 5 billion birds each fall to populate the winter ecosystems of the Americas from southern Canada and the U.S. south through Mexico, the Caribbean, and Central and South America. This critical nesting ground, however, is at risk due to increasing development pressures and climate change.

Maintaining vast areas of healthy intact landscapes in the Boreal Forest will allow birds to raise their young and launch their migrations across North America for generations to come.

RECOMMENDATIONS: BOLD AND CREATIVE SOLUTIONS FOR THE NEXT CENTURY

In the past several years, two ambitious conservation solutions have been proven to restore and strengthen migratory bird populations: setting vastly higher benchmarks for land protection, and empowering Indigenous communities and governments in land-use planning and management. Conservation success in the Boreal Forest will require embracing these solutions.

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Camp at Mushua-nipi in northern Quebec.

Canada is starting to put these solutions in place. The governments of Ontario and Quebec have articulated commitments to protect at least half of their northern landscapes, through the Far North Act and Plan Nord, respectively. Indigenous governments and communities are showing some of the most ambitious leadership, developing new land use plans and management models in places like the Pimachiowin Aki site in Manitoba and Ontario; the Dehcho, Lutsel'ke and Deline First Nations of the Northwest Territories; the Eeyou Istchee (Cree Nation) of Quebec; the Kitchenuhmaykoosib Inninuwug and Moose Cree First Nations of Ontario; and the Innu Nation of Labrador.

To fully realize the potential of these solutions to conserve bird populations, we recommend the following:

- At least 50 percent of intact boreal ecosystems should be protected. Modern conservation science has shown that maintaining the full diversity of species and ecosystem functions requires setting aside at least half of intact ecosystems from large-scale industrial development. This vision is articulated in the Canadian Boreal Forest Conservation Framework, the principles of which have been endorsed by more than 1,500 scientists worldwide;
- Conservation of lands must accommodate Indigenous traditional uses of the land and should be managed or co-managed by Indigenous governments. All land-use decisions should follow Free Prior and Informed Consent (FPIC) principles which state that Indigenous peoples have the right to determine and develop priorities and strategies for the development or use of their lands and other resources;
- Federal and provincial governments should make large-scale investments in providing financial resources for communities to train and hire Indigenous land-use planners, managers, and on-the-land guardians or rangers; and
- Research into the migratory routes, connectivity, timing and other aspects of migration must continue to be encouraged and funded. In particular, cross-cultural and cross-border partnerships and collaborations that work toward full life-cycle conservation of species should continue to be supported and developed.

Bird migration research continues to spotlight the shared stewardship responsibilities of nations across the Americas. And bold solutions offer our best path forward for ensuring a hundred more years of bird conservation success.

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Innovations in Bird Migration Research

The Boreal Forest—North America's Bird Nursery—irrupts with billions of migratory birds heading south each fall. Their precise migrations have long been mysteries, but recent technological advances are uncovering clues as to when, where, and how these species navigate their way through the Americas.

Radar Imaging

Bird migration can be observed en masse using Doppler radar. A wave of migrants begins to cross Lakes Erie and Ontario in May as they head toward breeding grounds further north. Darkness of color reflects density of birds detected.

Citizen Science

Bird observations from everyday citizens can be compiled in internet databases and used to detect migratory patterns. Observations of Canada Warblers are shown here prior to their shift north in April and May.

Geolocators

Geolocators record changes in light levels to determine location. A Blackpoll Warbler made a non-stop flight from the Maritimes to the Caribbean before continuing to Venezuela. It took a more land-based route back the following spring to Vermont.

Radio Telemetry

Birds fitted with radio transmitters alert equipped radio antennas whey they come into range. A Gray-cheeked Thrush in northern Colombia in April was detected a month later near the Hudson Bay coast of Manitoba.

Genetic Markers

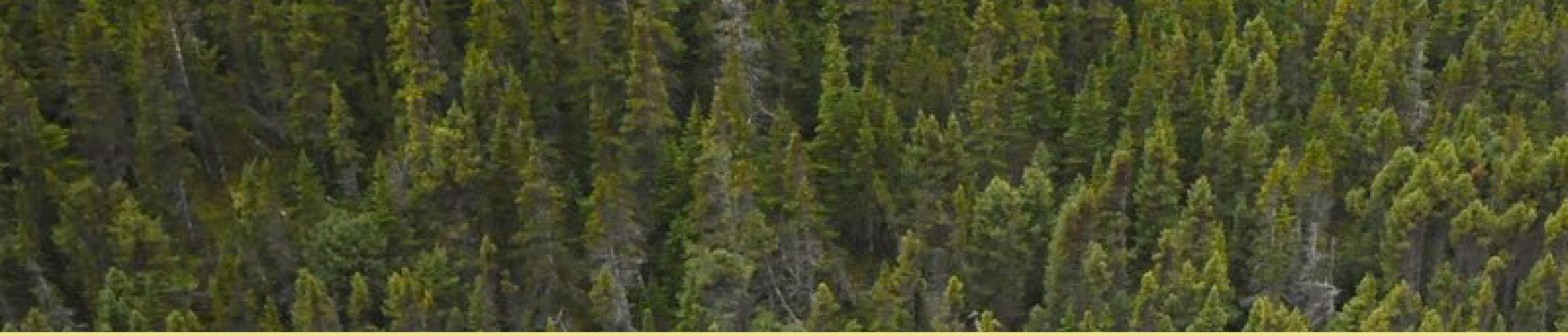
Embedded in DNA from birth, genetic markers show which portion of the species' breeding range individuals came from. Wilson's Warblers sampled in the winter in western Mexico were found to have come from the northwestern portion of its breeding range.

Isotope Analysis

The regions a bird spent portions of its life in can be deduced through analyzing isotopes in feathers or claws. A White-throated Sparrow sampled in Manitoba was found to summer in the central-western Boreal Forest and winter in the southeastern U.S.

Satellite Tracking

Satellite transmitting devices provide real-time movement updates. The migration of a Whimbrel was tracked from its breeding grounds in Canada's Mackenzie River Delta to its wintering grounds in Brazil and back again the following spring.



Known for its eerie call that often echoes across lakes, the Common Loon relies heavily on the Boreal Forest for breeding and can be found throughout much of the contiguous U.S. during winter.

The 1916 treaty signed by representatives from the U.S. and Canada protected hundreds of migratory bird species, including the Cape May Warbler.

The Bay-breasted Warbler is one of dozens of wood warbler species that can be found in the U.S. and Canada.

Introduction

One hundred years ago, one of the world's first and most significant environmental treaties was negotiated and signed by representatives from the United States and Canada (Dorsey 1998, Cioc 2009, Sandlos 2013). The terms of that 1916 treaty, the Migratory Bird Convention, were then implemented through legislation in Canada (the Migratory Bird Conventions Act passed in 1917) and the U.S. (the Migratory Bird Treaty Act passed in 1918).

The treaty and the legislation recognized that birds were a crucial resource shared between Canada and the U.S. and that, because most of the birds of North America are migratory, conserving that resource meant that both nations had to share similar bird hunting laws and policies if bird populations were to be maintained into the future.[1] It was not until 1979—more than six decades later—that the world saw any other similar type of broad-scale treaty designed to conserve migratory wildlife, when the Convention on the Conservation of Migratory Species of Wild Animals (also known as the Bonn Convention) was signed (Boere 1991, Baldwin 2011).[2]

The Long-billed Dowitcher and Short-billed Dowitcher (pictured) were not officially split as species until 1950.

Despite the foresight of those who drafted and signed the 1916 treaty and its subsequent implementing legislation, there was much that was still largely unknown about where many of the birds nested and wintered, or how they moved between northern nesting grounds and southern wintering areas. For instance, the breeding range of the Whooping Crane, one of the world's most endangered birds (there were only 15 left in 1941) and one of North America's largest, was not known to ornithologists until 1954—38 years after the signing of the Migratory Bird Convention (Wells 2007). The first Harris's Sparrow nest was not found and described by scientists until 1931 despite it being long-known as a regular winter visitor to bird feeders in the Midwest U.S. (Semple and Sutton 1932). Similarly, the nesting behavior of the Marbled Murrelet, a small seabird related to the more well-known puffin, was not confirmed until 1974, when it was discovered that they nested high up on the branches of trees in old-growth forests (Nelson 1997). In fact, not only were the geographic ranges of a number of species unknown in 1916, but the species limits of a number of bird groups were not even clarified. For example, Long-billed and Short-billed Dowitchers were not officially split into two species until 1950 (Jehl et al. 2001). Understanding where these birds nested and wintered would be unimaginable before first identifying them as two similar-looking species.

A MIGRATION RESEARCH REVOLUTION

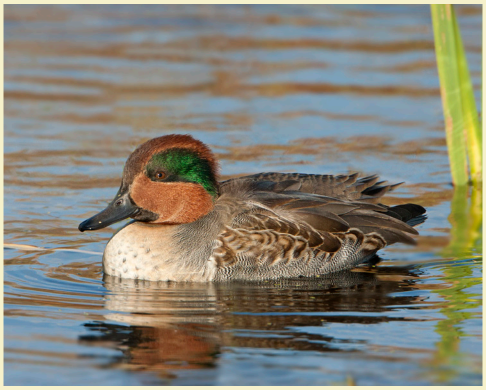
In the last three decades, however, several new technological advances have revolutionized the study of migration, opening our eyes to the secrets of where, when, and how birds migrate (Robinson et al. 2010, Marra et al. 2011, Laughlin et al. 2013). Smaller and smaller radio-transmitters and satellite-tags now allow us to follow the

[1] One well-known flaw in the treaty and implementing legislation was the lack of acknowledgement of the traditional subsistence hunting rights for Indigenous peoples, particularly in Canada and Alaska where communities continued to rely on spring harvests of waterfowl for survival. The resolution of the issue took far too long to be officially resolved but now the traditional rights of Indigenous people for hunting are recognized and acknowledged in modern legislation. Other questions related to Indigenous rights and treaty obligations and the relationship between Indigenous governments and Canadian and Alaskan governments are continuing to be discussed and tested in the legal system.

[2] Neither Canada nor the United States are parties to this treaty.

The Olive-sided Flycatcher has shown a steep decline over the past half-century. More than half of the species' global population breeds within the Boreal Forest.

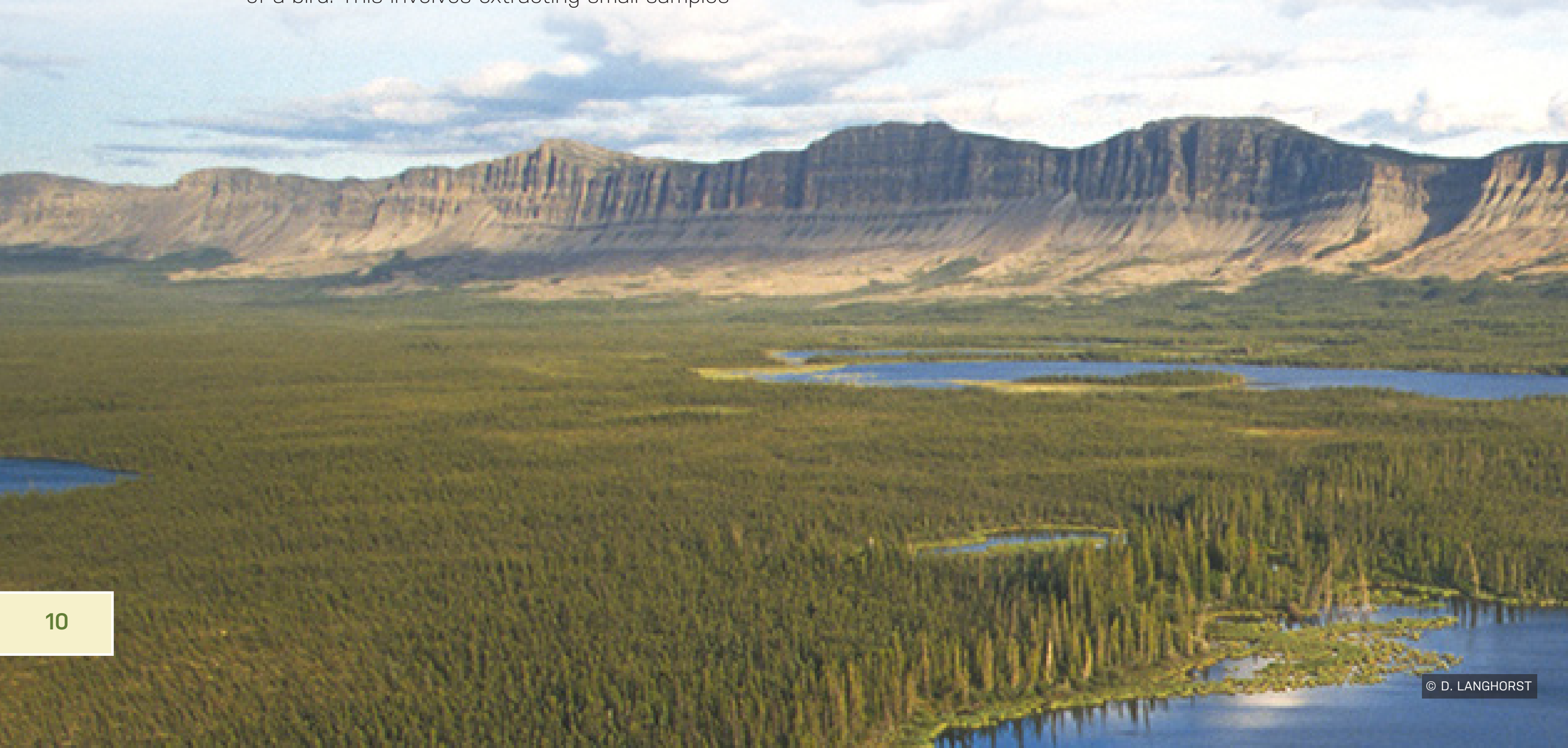
The Lesser Yellowlegs is a candidate for future inclusion on Canada's list of threatened or special concern species.



80% of the waterfowl species commonly found in the U.S. and Canada regularly breed in the Boreal Forest, including the Green-winged Teal.

hemispheric scale movements of birds ranging from albatrosses, eagles, hawks, shorebirds, and even birds as small as thrushes (Bridge et al. 2011, Faaborg et al. 2010). Light-level geolocators, tiny devices that store information about day length and sunrise/sunset times from which location coordinates can be extracted, have been attached to even smaller birds like warblers to record their movements to and from breeding and wintering locations (Stutchbury et al. 2009, Bridge et al. 2013, McKinnon et al. 2013). Other technologies allow larger numbers of individual birds to be sampled but provide more generalized information about wintering and breeding areas. The best known of these techniques makes use of geographic variation of isotope ratios of common elements to determine the likely geographic origin of a bird. This involves extracting small samples of feathers or claws from birds to determine their isotope ratios, which shows where the birds were located when the feather or claw was grown (Hobson 2007, Coiffait et al. 2009, Hobson et al. 2015). New techniques are also just being pioneered that use genetic markers to determine the generalized localities where birds came from during the nesting season when sampled during migration or in wintering grounds (Coiffait et al. 2009, Irwin et al. 2011, Ruegg et al. 2014).

At the very broadest scales, several modern technological tools are providing increasing detail about bird migration. Radar technologies are now being used to document the geographic variation, timing, direction, and gross volume of nocturnal bird migration (Gauthreaux 1992, Gauthreaux and Belser 2003, Gauthreaux et al. 2003, Robinson



et al. 2010, Bridge et al. 2011, Buler and Dawson 2014, Lafleur et al. 2016), while audio recording and computer sorting algorithms are providing details of the particular species involved (Keen et al. 2014, Sanders and Mennill 2014, Smith et al. 2014, Farnsworth 2005). Internet platforms have been developed and implemented over the last few decades that now collect citizen-science bird sighting reports numbering in the millions from across the world, allowing detailed real-time tracking of the simultaneous migration movements of bird populations at continental scales (Wood et al. 2011, Laughlin et al. 2013, Sullivan et al. 2014).

All of these new research tools are helping to document the fine-scale details of migration in birds upon which further applied bird conservation research questions can be tested. New migration research has shown that birds breeding in a particular area may have any number of patterns of connectivity to their wintering grounds, sometimes showing complete mixing of populations and geographic separation that can vary in surprising ways. Much of the research has shown the previously unknown locations of breeding or wintering grounds for some birds and often has documented unknown migratory pathways. This kind of information is vital to understanding what limits populations of a particular bird species and learning what is required to maintain or increase bird populations. All of this new research highlights the fact that vast areas of habitat are required for migratory stopover habitat (Wilcove and Wikelski 2008, Faaborg et al. 2010, Runge et al. 2015).

NEW PROBLEMS AND NEW SOLUTIONS

Not only did the state of knowledge of bird migration change in major ways in the decades after the signing of the Migratory Bird Convention, so did the major issues impacting bird populations. Unregulated market hunting was the major bird conservation problem when the treaty was signed, and legislation in Canada and the U.S. that resulted from the treaty was highly successful in controlling the problem and allowing most at-risk bird species to bounce back (Wells 2007). Today, there are a larger number of issues impacting bird populations across the Americas, but the most pressing ones are habitat loss and degradation and climate change (Wilcove et al. 1998, Pimm and Raven 2000, Sala et al. 2000, Gaston et al. 2003, Jetz et al. 2007). Worldwide, the number of declining, threatened and endangered bird species continues to grow, with more than 10 percent threatened with global extinction today (BirdLife International 2013).

The Boreal Forest region of Canada and Alaska, at 1.5 billion acres and stretching from Alaska in the west to Newfoundland in the east, is one of the largest intact forest ecosystems left on Earth (IBCSP 2013). Its intactness is the critical reason

it has remained one of the world's most important breeding reservoirs for migratory birds, supporting an estimated 1-3 billion nesting birds each summer (Wells and Blancher 2011). Each fall, it annually "exports" some 3-5 billion birds once the young have hatched and migrated to populate their wintering ranges, from southern Canada and the U.S. south through Mexico, the Caribbean, Central America and South America (Robertson et al. 2011, Wells and Blancher 2011, Wells et al. 2014).

Even common backyard feeder birds such as the White-throated Sparrow have witnessed decline in recent decades.

Sadly, there are a growing number of boreal bird species in steep decline. Boreal-dependent birds like the Rusty Blackbird, the Olive-sided Flycatcher and the Canada Warbler have shown massive declines in abundance over the last half-century. All three are now on Canada's list of Threatened or Special Concern species. Boreal-breeding waterbirds are also featured on that list, including the eastern populations of Barrow's Goldeneye and Harlequin Duck, and the western populations of Horned Grebe, Yellow Rail, and Red-necked Phalarope (Wells et al. 2014). The candidate species for future inclusion on that list include a number of shorebirds that are highly reliant on boreal wetlands for breeding, including Lesser Yellowlegs, Hudsonian Godwit, Semipalmated Sandpiper, Short-billed Dowitcher, Stilt Sandpiper, and Pectoral Sandpiper (COSEWIC 2016). Many other boreal-breeding species have seen steep declines in the last 50 years, including Black, Surf, and White-winged Scoters, Lesser Scaup, Long-tailed Duck and even well-loved backyard feeder birds like White-throated Sparrow and Dark-eyed Junco (Slattery et al. 2011, Sauer et al. 2015).

We now understand better than ever the habitat needs of migratory bird species on their breeding and wintering grounds and at migration stop-over locations in between. Migration research demonstrates the hemispheric-scale movements of migratory birds and the necessity of considering the needs of birds across cultural, political, and geographic barriers. These studies also show that birds are facing different and more complicated threats than unregulated market hunting, which was the overriding issue 100 years ago. Research has clearly documented that the most prominent factors that are driving declines in most birds today are habitat loss and

degradation and climate change (Wilcove et al. 1998, Pimm and Raven 2000, Sala et al. 2000, Gaston et al. 2003, Jetz et al. 2007). To counter these issues, modern bird conservation's most pressing need is to protect very large areas of habitat on breeding grounds, wintering grounds and at migration stop-over sites (Wells 2010).

Conservation science demonstrates that in order to maintain the full complement of biodiversity and ecosystem functions, and to build in resilience to impacts associated with climate change, it is necessary to protect a much larger proportion of habitat than has previously been targeted—at least 50% in large intact landscapes (Schmiegelow et al. 2006, IBCSP 2013, Locke 2013, Carlson et al. 2015, Wilson 2016). Fortunately, in North America's Boreal Forest region, Indigenous governments and communities and some provincial governments have developed land-use plans or policy that calls for protection of at least 50 percent of boreal landscapes under their jurisdiction (IBCSP 2013, Wells et al. 2013, Carlson et al. 2015, Wells et al. 2015). This idea of protecting at least half of this region in a responsible way has been embraced by a variety of industry, environmental organizations, scientists, Indigenous governments, and even provincial governments (Carlson et al. 2015). In 2003, the Boreal Forest Conservation Framework set forth a vision for achieving this goal in a way that recognizes Indigenous participation and sustainable development standards in areas reserved for future development. The idea has since been endorsed by 1,500 scientists worldwide.

Inspired by the Boreal Framework, the Boreal Birds Need Half initiative was launched in 2015 by the Boreal Songbird Initiative and Ducks Unlimited, and is now supported and endorsed by a host of conservation non-profit groups and businesses.[3]

As we celebrate the 100-year anniversary of the Migratory Bird Convention and the many new discoveries about bird migration that have taken place since that time, we also need to look ahead to the next 100 years of bird conservation and embrace the idea of protecting large landscapes for birds in the Boreal Forest and far beyond.

[3] Conservation groups include, but are not limited to, the Canadian Parks and Wilderness Society, SNAP, Bird Protection Quebec, Nature Canada, Bird Studies Canada, Ontario Nature, Canadian Wildlife Federation, The Pew Charitable Trusts, Audubon, Ontario Field Ornithologists, Nature Calgary, Environment for the Americas, Cornell Lab of Ornithology, American Bird Conservancy, Montana Audubon, Massachusetts Audubon, Maryland Ornithological Society, and Nature Needs Half. Corporate endorsers include Aikens Lake Wilderness Lodge, Wild Bird Centers, Swarovski Optik, Zeiss, Eagle Optics, Field Guides, Eagle-Eye Tours, and Birdzilla.

Unlocking the Mysteries of Migration

Much has been learned about bird migration since the signing of the landmark 1916 treaty. However, we still do not know the intricacies behind the migrations of many species—the exact timing, places they stop along the way, or even the general route in some cases. As technologies have become more powerful, efficient, smaller and more affordable, scientists are beginning to uncover the fine-scale details of bird migration.

Satellite tracking and geolocator technologies are providing detailed accounts of when and where birds move to and from and the places they stop in between, identifying critical areas of migratory stopover habitat for potential protection in the process. The use of radar and audio sorting technologies are painting new pictures of nocturnal migration, including the discoveries of previously unknown parts of the landscape that songbirds rely on for food and shelter from predators during their daily migratory rest stops. The analysis of isotopes and genetic markers is beginning to connect regional subpopulations within species' breeding and wintering ranges, which helps differentiate between regional and overall population fluxes and, ultimately, provides better insight into the causes behind them. Internet-based platforms, which allow millions of observations gathered by everyday citizens to be uploaded and analyzed instantly, are making it possible to identify larger patterns, such as the shifting of distribution or timing of migration.

In the following sections, we describe seven innovative new bird migration technologies and showcase some of the most compelling discoveries related to birds breeding in the Boreal Forest of North America that have resulted from the application of those technologies. While we discuss each technology separately, it is important to recognize that each technique has its strengths and weaknesses. Increasingly researchers are combining the use of multiple technologies to understand where, when and how birds migrate and what we can do to better protect them at all stages of their life cycle.

BANDING AND BEYOND

Although we do not highlight in detail what has been learned from the banding of birds, the practice continues to be a critical research tool. Banding was the first technology applied in attempts to better understand bird migration. In North America, John James Audubon applied a prototype band (a silver thread) to some Eastern Phoebe nestlings in 1803, and discovered two of these birds in the same area the following year.

More concerted bird banding research projects began in the U.S. and Canada in the early 1900s, and the federal governments of Canada and the U.S. established bird banding programs and regulations in the 1920s soon after the Migratory Bird Convention was signed (USGS 2016). Much of our knowledge about the general migration routes and wintering areas of some species resulted from projects that banded large numbers of birds at specific locations. The bands were later retrieved (usually after death) in migratory or wintering habitat.

The banding station at Willow Lake in the Northwest Territories is run by a USFWS biologist and two banding assistants from the nearby Sahtu community of Tulita.

Ducks and geese in particular, commonly hunted birds, had higher rates of band return, so government scientists learned much more about waterfowl migration patterns than in most other bird groups.

Modern banding studies have used color bands, wing and leg tags, and neck collars (mostly on geese) with colors and numbers that can be observed on live birds with high-quality telescopes and binoculars. This allows researchers and recreational birders to spot and report re-sightings of live birds without recapture, and often provides more information about movements of marked birds.

Banding continues to provide important insights into bird migration and is the most inexpensive method of marking large numbers of birds. However, because very few banded birds are ever recovered or spotted, the technique typically provides less detailed information about the scale, timing, and path of migratory movements than modern techniques (Webster et al. 2002, Coiffait et al. 2009, Marra et al. 2011).

AUTOMATED RADIO TELEMETRY

Radio telemetry tracking has been used in bird research for decades (Kenward 2001). The most basic configuration is a small VHF transmitter that sends out a continuous signal that can be picked up by an antenna.

Swainson's Thrushes were part of a study tracking movements from wintering grounds in South America back up to North America during spring migration.

Early versions of this technology were heavy and could only be used on larger birds like eagles, hawks, and waterfowl (Fuller et al. 2005). However, modern radio transmitters are now incredibly small (as small as ~0.2g) and light (some can even be used on insects) and have various permutations that transmit at particular intervals and frequencies, allowing relatively large numbers of birds to be marked and followed (Taylor et al. 2011, Brown and Taylor 2015).

One drawback to this method is that the signals can only be picked up if they are relatively close to an antenna, usually within tens of kilometers or less. One way to address this problem has been to establish antenna arrays—multiple antennas in a grid—so that movements of tagged birds can be tracked in detail within the array (Taylor et al. 2011, Woodworth et al. 2014, Francis et al. 2016). If there are enough arrays in key places, the signal from the bird may be picked up at multiple locations across its migratory pathway.

One of these, the Motus Wildlife Tracking System, a program of Bird Studies Canada in partnership with collaborating researchers and organizations, is a coordinated hemispheric network to collect, organize, disseminate and archive automated radio telemetry data (Mills et al. 2011, Taylor et al. 2011, Mitchell et al. 2012, Brown and Taylor 2015, Francis et al. 2016). Since 2013, over 100 collaborators have embarked on more than 50 Motus projects and tagged over 5,000 animals of more than 65 species, including eight species of bat and 2 insects (www.birdscanada.org/motus). One study utilizing Motus in 2015 by researchers at Selva, Bird Studies Canada, and Environment and Climate Change Canada showed the potential power of this method when it tracked the migrations of a number of Swainson's Thrushes and Gray-cheeked Thrushes from their wintering grounds in the mountains of Colombia to various parts of Canada. One Swainson's Thrush left Colombia on April 14th and was detected in Saskatchewan on May 19th, having traveled a distance of 6,000 kilometers. A Grey-cheeked Thrush was detected on its migratory pathway along Lake Ontario less than two weeks after leaving Colombia, and another tagged in Colombia was found on its breeding grounds near Hudson Bay in Manitoba (to view an animation of these flights visit: http://motus-wts.org/data/demo/thrushes2015.html).

Another radio tracking study carried out by the James Bay Shorebird Monitoring Project, a partnership between Environment and Climate Change Canada, the Ontario Ministry of Natural Resources and Forestry, Royal Ontario Museum, Trent University, Bird Studies Canada, and the Moose Cree First Nation, placed small radio tags on Semipalmated Sandpipers, White-rumped Sandpipers, and Red Knots along the southwestern coast of James Bay in Autumn of 2013-15. They tracked surprising single overnight flights of these birds from James Bay to coastal New England and the Maritimes, some as far south as New Jersey, before many made their way further south to South America, presumably across the Atlantic Ocean (to view an animation of these flights visit: http://motus-wts.org/data/demo/thrushes2015.html).

Radio Telemetry

SWAINSON'S THRUSH & GRAY-CHEEKED THRUSH MIGRATIONS

Participating researchers can tap into an array of antennas set up to detect wildlife that have been fitted with transmitters. The array may change slightly from year to year depending on which projects researchers are participating in at any given point in time. In 2015, researchers fitted Swainson's Thrushes and Gray-cheeked Thrushes at two locations in Colombia, of which individuals were detected weeks later in Texas, Saskatchewan, Manitoba, and Ontario. Arrows display the general direction taken to reach the detection site and are not intended to reflect the specific migratory paths taken.

SATELLITE & GPS/GSM TRACKING

Perhaps no modern technology better captures the precise timing and movements of migratory birds than satellite transmitters.

Because the transmitters use satellites instead of land-based receiving systems, researchers can track the movements of tagged birds with high location accuracy over large distances and through remote regions, such as over an ocean or in a remote area lacking communication towers (Bridge et al. 2011, Gill et al. 2009, 2014).

Over the last decade, there have been numerous applications of satellite tagging technology to bird migration studies. A Bar-tailed Godwit tagged in Alaska, for example, made the longest non-stop flight ever recorded for a bird, traveling 11,500 kilometers (7,145 miles) over nine days to its New Zealand wintering grounds (Gill et al. 2005, 2009, 2014).

A research team from the Center for Conservation Biology tagged spring migrant Whimbrels—a chicken sized shorebird with a long down-curbed beak—along the southeastern U.S. coast found that birds flew all the way to Canada's Northwest Territories to breed (Watts et al. 2008). One bird made a nonstop, 146-hour journey from the coast of Georgia 5,700 kilometers (3,600 miles) north to the Mackenzie Delta. In the fall, the tagged birds made similarly spectacular flights to mangrove wetlands of the Caribbean and northern South America. Another Whimbrel, affectionately named Pingo by the research team, tagged in the summer of 2012 in the Mackenzie Delta started its fall migration by flying across the country to Nova Scotia. Pingo then took off from Nova Scotia and flew non-stop over the Atlantic Ocean for days until running into headwinds from Hurricane Isaac. Pingo eventually veered around the hurricane and, after many days of non-stop flying over thousands of kilometers, made it to the coast of Brazil (Wells 2012).

Researchers working to better understand the factors contributing to declines in sea ducks have been using satellite-tagging technology to study the movements of many species, including Black Scoters, a jet-black heavy-bodied sea duck with a bright orange bill. Surprisingly, their research showed that some Black Scoters that nest in the Northwest Territories fly eastward to spend winters on the Atlantic Coast of North America, while others fly westwards to winter on the Pacific Coast (Baldassarre 2014, Sea Duck Joint Venture 2015). Similar work on the tiny Harlequin Duck, a remarkable species that seeks out remote rocky wave-tossed coastlines in winter, shocked researchers when they discovered that some male birds moved from wintering areas on the Maine coast to nesting grounds in Labrador, and then flew across to the coast of Greenland for part of the summer (Chubbs et al. 2008, Robert et al. 2008, Thomas et al. 2008).

Another clever use of satellite tracking technology was employed over several recent winters in a study of the movements of Snowy Owls called Project SNOWStorm, which took advantage of new GSM transmitters that send text messages of location to cell phone towers. Snowy Owls wintering in parts of the eastern U.S. have been tracked with near minute-by-minute precision to show their intricate movements. When a tagged bird flies out of cell tower range, as Snowy Owls do when they migrate back to the Arctic, the entire dataset is stored and is transmitted to researchers once the bird comes back into range. For example, a Snowy Owl named Buckeye that was tagged in winter of 2015 stopped transmitting locations in April. When it came back into range 10 months later, it showed that it had flown north up to the shore of Hudson Bay before moving to a point even further north above the Arctic Circle. Another new research collaborative that is expected to become operational in 2017 named the Icarus Initiative (http://icarusinitiative.org/) will establish a set of antennas on the Space Station that can activate and receive signals from small transmitters on birds and other animals and track them across the globe (Holland et al. 2007).

Satellite Tracking

WHIMBREL MIGRATION ROUTE

A Whimbrel named Pingo was fitted with a satellite transmitter near its breeding grounds in the Mackenzie River Delta. In its first annual migration cycle, Pingo began navigating to its wintering grounds on the Brazilian coast, stopping in Hudson Bay and on Cape Breton Island in Canada before embarking on its long non-stop journey over the Atlantic Ocean. It narrowly skirted around Hurricane Isaac before landing in Brazil. The following spring, it took a more western route back that included stops in Texas and southern Alberta before making its way back up to its breeding grounds in the Mackenzie Delta.

LIGHT-LEVEL GEOLOCATORS

Beginning in the 1990s, researchers studying albatrosses began testing small devices that capture and store information about light levels which, when analyzed, can provide an estimate of the location of the device at specific points in time (Bridge et al. 2011, Bridge et al. 2013).

Today, devices that can store a year's data have been engineered to be small enough that a bird as small as a warbler can carry them (DeLuca et al. 2015). Geolocators are affixed to a band or bands in larger birds and onto a back harness in smaller birds. One drawback of the technique is that retrieving the information on the geolocator device requires recapturing the bird. Typically, only a small percentage of banded birds are ever recaptured or relocated, so to increase the chances of recapturing birds carrying geolocators, birds are captured on either breeding or winter territories where they are likely to return and affixed with the geolocator (Bridge et al. 2011, Bridge et al. 2013, McKinnon et al. 2013). Those same territorial locations are searched the following season to recover the units. In recent years, geolocators have been deployed on many birds, revealing many new discoveries that can be applied to bird conservation (Stutchbury et al. 2009, Bridge et al. 2011, Fraser et al. 2012, Johnson et al. 2012, Macdonald et al. 2012, Bridge et al. 2013, Laughlin et al. 2013, McKinnon et al. 2013, McKinnon et al. 2014, DeLuca et al. 2015, Hallworth et al. 2015, Heckscher et al. 2015, Hobson and Kardynal 2015, Rushing et al. 2016, Stutchbury et al. 2016). For example, Wood Thrushes were found to have a relatively narrow spring migration corridor through the Gulf Coast states when it was previously thought that they migrated in a broad front across the southeastern U.S. (Stanley et al. 2012). Geolocator studies of Purple Martins found that their migration timing was not keeping up with extreme weather events (Fraser et al. 2013). Swainson's Thrush populations breeding close together in southern British Columbia were found to use completely different migration routes (Delmore et al. 2012).

An increasing number of bird species breeding in North America's Boreal Forest region are being studied with geolocator technology, providing the first documentation of some remarkable migrations.

A paper published in 2012 describes the results of a project that placed light-level geolocators on Rusty Blackbirds nesting in Alaska. Although only three of the 17 birds with geolocators were recaptured, those three birds yielded valuable information about the timing and route of their migration. All three of the birds crossed over from the southern coast of Alaska to the Canadian prairie provinces and then moved south to winter in the Midwest U.S., with one wintering south to Louisiana. They followed a similar route back north in spring (Johnson et al. 2012).

Another paper published in 2012 used the same technology to track where Golden-crowned Sparrows that winter along the central California coast were spending their summers. Researchers placed geolocators on 33 birds, of which four were recaptured the following year. All four birds had summered along the Gulf Coast of Alaska (Seavy et al. 2012).

One of the most amazing light-level geolocator study results confirmed a migratory pathway that had been the subject of debate for decades. In 2015, scientists tracked the migratory routes of the tiny Blackpoll Warbler, a 12-gram bird slightly smaller than a chickadee. Nineteen individuals were affixed with geolocators on breeding grounds in the high stunted spruce forests of Vermont and 18 more in similar coastal habitat in Nova Scotia. Five birds were recaptured and all had flown directly out over the ocean from their departure points in Maritime Canada or the northeastern U.S. (one from further south near Cape Hatteras). Each then flew thousands of kilometers non-stop over 2-3 days and nights until reaching landfall again in the West Indies, where they rested for several days. From here, each bird eventually departed south again to undertake another leg of its marathon journey, flying another 1,000 kilometers (600 miles) over the southern Caribbean Sea to arrive in northern South America 1-2 days later (DeLuca et al. 2015).

Geolocators

BLACKPOLL WARBLER
MIGRATION ROUTE

A Blackpoll Warbler fitted with a geolocator in Vermont headed to the Atlantic Coast before beginning a long, non-stop flight over the Atlantic Ocean to Hispaniola. After a couple of days of rest, it then finished its journey south to Venezuela, where it spent the winter. The following spring, it flew back north along a more western route. After stopping for a little over a week in the Greater Antilles, it then continued through Florida and stuck close to the Atlantic Coast all the way back up to Vermont, where it was eventually recaptured.

STABLE ISOTOPE ANALYSIS

Isotopes, which are versions of the same element but with different molecular weights, are incorporated in tissue, blood, feathers, and claws when a bird ingests food or water.

Because the distribution of isotope ratios found in nature varies by geographic region, researchers can compare samples of isotopes found in birds with where those ratios occur most commonly to deduce where the bird was during the time the sampled material was grown or developed (Hobson 2007). The technique began to be refined using hydrogen isotopes in the late 1990s and has since developed into a rapidly evolving research field (Hobson 2007, Marra et al. 2011). A benefit is that birds only have to be captured and sampled once, which allows for sample sizes larger than in most studies of individually tracked birds (Hobson 2007, Coiffatt et al. 2009). Isotope analysis can also provide a picture of the generalized migratory pathways of regional populations of birds. Two small drawbacks are that it cannot identify specific movements of birds, only of their probable geographic origin, and that isotope maps for some species are less detailed, making origin determination less conclusive (Hobson 2007, Hobson et al. 2015). Despite these drawbacks, some of the most important applications of migration research are coming from stable isotope studies, sometimes combined with other techniques (Hobson and Wassenaar 1997, Hobson et al. 2001, Hobson 2007, Coiffatt et al. 2009, Hobson et al. 2010, Chabot et al. 2012, Rushing et al. 2014, Hobson et al. 2015, Holberton et al. 2015, Hobson and Kardynal 2016).

A 2005 study of hydrogen isotope ratios of feathers from White-throated Sparrows captured during spring in southern Manitoba showed that the birds were breeding in remote portions of the Boreal Forest, from northern Manitoba westward to southern Northwest Territories, and wintering in the Gulf Coast region of the U.S. (Mazerolle et al. 2005).

A 2010 study of the Rusty Blackbird, a boreal-breeding species that has declined by more than 90 percent over the last 50 years, showed for the first time that eastern Canadian breeding birds winter in the U.S. east of the Appalachians, while those in western Canada winter largely in the Mississippi Valley (Hobson et al. 2010). A recent paper used the technique to examine the biogeography of the Golden Eagle population of eastern North America that nests in Quebec and Labrador. They found that Golden Eagles showed a "leapfrog migration" pattern, with birds from the northernmost parts of the breeding range wintering the farthest south, essentially skipping over (leapfrogging) the wintering range of the birds originating from the southern part of the breeding range (Nelson et al. 2015).

A 2015 study of feathers sampled from Blackpoll Warblers captured at migration banding stations used the technique to demonstrate that populations of the species use different routes during spring and fall migration. Interestingly, adult and young birds from the breeding range in the Boreal Forest region of Alaska and western Canada migrated west to east in the fall. Blackpoll Warblers captured at banding locations in Massachusetts and Pennsylvania were largely from these western populations, while those captured at banding stations in Maine and the Maritimes were more likely to be Blackpoll Warblers that originated from eastern Canada (Holberton et al. 2015).

A remarkable compilation of results from stable isotope analysis of fifteen migrant songbird species from multiple migration monitoring stations across Canada, published in 2015, elucidated, for the first time, the broad geographic origins of migrants monitored at each station (Hobson et al. 2015). Essentially the study provided a breeding distribution origin atlas for the migrant species that they studied. For example, they showed that most American Redstarts captured at banding stations in southern Ontario originated in eastern Ontario and southern Quebec. Yellow-rumped Warblers captured at the same stations came from northwestern Ontario and further north in Quebec and Labrador (Hobson et al. 2015). The analyses also showed that birds captured in fall tended to represent a larger portion of the breeding distribution than those captured in spring (Hobson et al. 2015).

Isotope Analysis

LINKED BREEDING AND WINTERING GROUNDS OF A WHITE-THROATED SPARROW

Isotope analysis can help narrow down and connect the specific breeding and wintering areas used by birds within the species' broader overall range. A White-throated Sparrow captured and sampled in southern Manitoba was found to come from an expanse of Boreal Forest stretching from northern Manitoba to Alberta and the Northwest Territories, while its wintering region correlated with the Gulf Coast region of the United States.

GENETIC MARKERS

One technique that has so far only seen limited application for the study of migratory bird connectivity is the use of genetic markers, which are unique to particular areas of the breeding range of a population, to learn the origins of birds captured during migration or on the wintering range (Coiffat et al. 2009, Robinson et al. 2010, Irwin et al. 2011, Ruegg et al. 2014).

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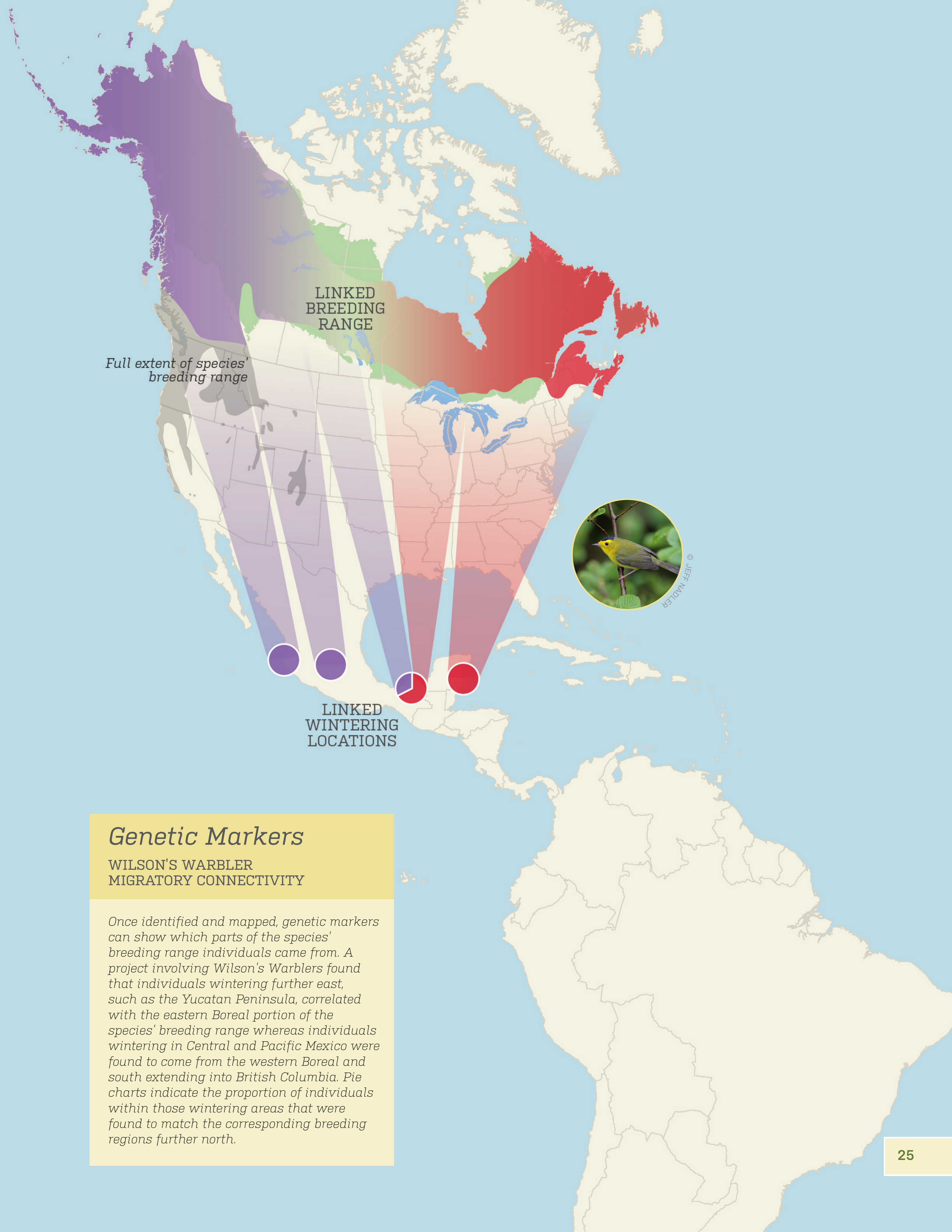
Wilson's Warblers breed throughout much of North America's Boreal Forest and south extending down into southern British Columbia and the northwestern U.S., as well as high-elevation pockets within the Rocky Mountains. They typically winter throughout Mexico and Central America.

The difficulty with this technique is that for each species, the genetic markers must be found and their relationship to the geography of the species' breeding range must be studied and mapped. If unique markers can be found that correspond to different parts of the breeding range, large numbers of birds can then be sampled from migratory stopover locations and wintering locations and their origin can be assigned to them.

The most striking example of the potential power of this methodology was demonstrated in a study published in 2014 that looked at populations of the Wilson's Warbler, a perky bright yellow bird with a black cap that has an extensive Boreal Forest breeding range as well as populations in the western U.S. (Ruegg et al. 2014). The researchers used new rapid DNA sequencing techniques to screen large samples of birds from multiple areas and construct a map showing where birds from different parts of the breeding range were wintering as well as when and where they passed through different areas on migration.

They showed, for example, that Wilson's Warblers wintering in the Yucatan Peninsula of Mexico came almost exclusively from populations nesting in eastern Canada and the northeastern U.S., while those wintering in central Mexico came from western Canada and Alaska (Ruegg et al. 2014). The study provided one of the most detailed accounts of the range-wide connectivity between breeding and wintering grounds for any songbird to date.



Genetic Markers

WILSON'S WARBLER MIGRATORY CONNECTIVITY

Once identified and mapped, genetic markers can show which parts of the species' breeding range individuals came from. A project involving Wilson's Warblers found that individuals wintering further east, such as the Yucatan Peninsula, correlated with the eastern Boreal portion of the species' breeding range whereas individuals wintering in Central and Pacific Mexico were found to come from the western Boreal and south extending into British Columbia. Pie charts indicate the proportion of individuals within those wintering areas that were found to match the corresponding breeding regions further north.

RADAR & AUDIO DETECTION

Radar has been used to study bird migration, particularly nocturnal migration,[4] for many decades (Gauthreaux 1992, Bridge et al. 2011). But recent advances in radar technology and in computational power and analysis algorithms have now vastly increased the application of radar technologies to bird migration research (Gauthreaux and Belser 2003, Gauthreaux et al. 2003).

In the U.S. and parts of Europe, publically available weather radar images from large numbers of radar stations allow many questions related to the timing, volume, and direction of broad scale nocturnal migratory movements to be studied (Bridge et al. 2011, Farnsworth et al. 2015, Van Doren et al. 2015). New statistical modeling techniques are providing estimates of the density of birds and their velocity during nocturnal migration (Bridge et al. 2011). Smaller scale radars have been employed to study the height of migrant birds and how they move in relation to geographic features or human-made obstructions (Fijn et al. 2015).

One particularly promising application of the technology to land conservation planning for birds was a 2014 study that used weather radar from stations across the northeastern U.S. to identify regions with high densities of migrant birds during fall migration (Buler and Dawson 2014). They identified areas at both broad and fine scales across the U.S. where large numbers of birds were stopping during migration. Similar research has identified important stopover areas along the U.S. Gulf Coast (Lafleur et al. 2016). This information can potentially be prioritized for conservation activities that would be beneficial to migrants (Desholm et al. 2014).

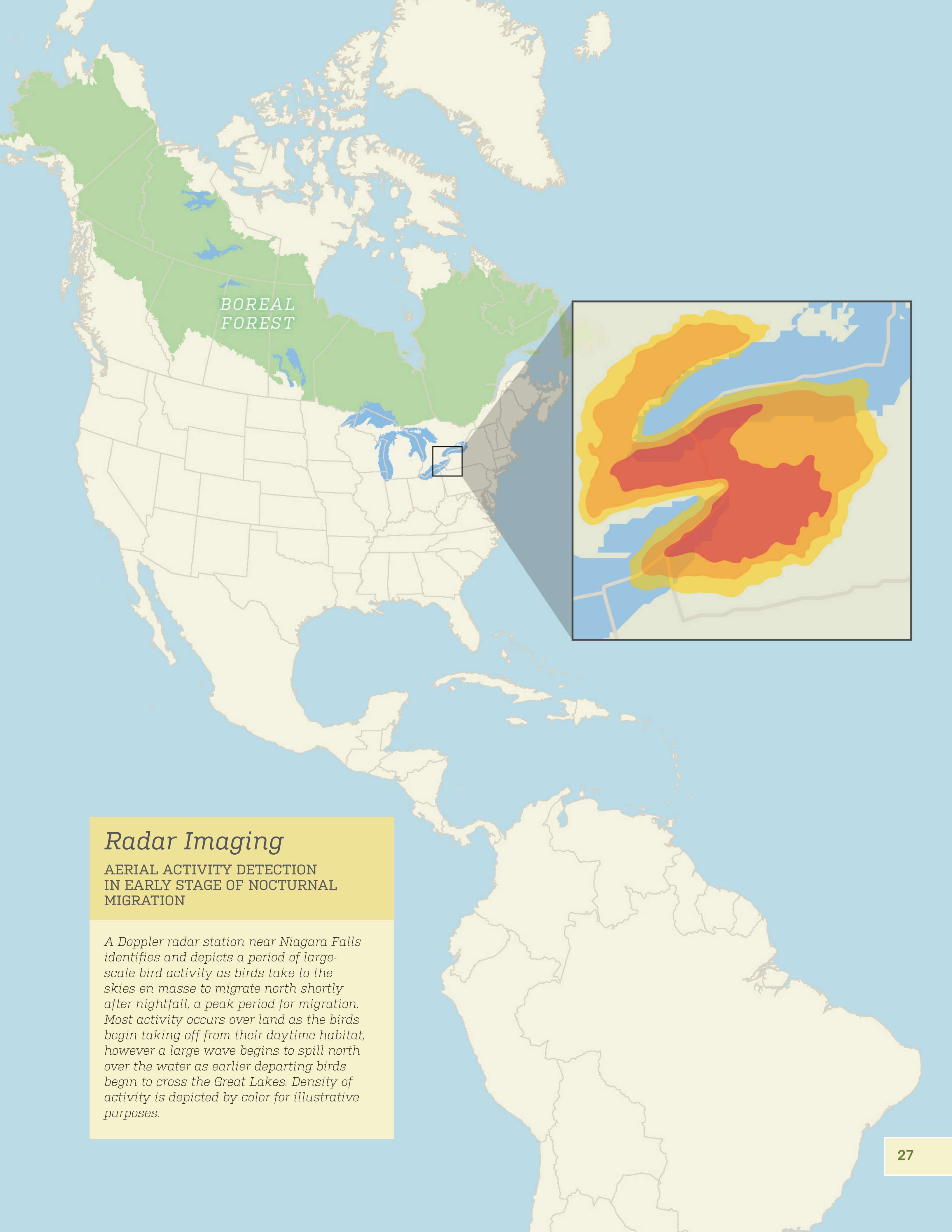
AUDIO DETECTION OF NOCTURNAL MIGRANTS

While radars allow the detection of the overall volume and direction (and sometimes height) of nocturnally migrating birds, they do not allow the specific identify of the birds to be determined (Farnsworth et al. 2004). Many nocturnally migrating birds do, however, emit short flight calls that can be identified to the species level. The identity of some nocturnal calls, notably those of some of the thrushes, has been known for at least a hundred years and some birds give the same calls during the day so that they can be readily determined. But for a large number of species, especially those of warblers and sparrows, the identity of their calls has only been deciphered in the last 10-20 years and many are still being learned (Evans and Rosenberg 2000, Evans and O'Brien 2002).

The use of nocturnal bird call detection in migration research has shown tremendous growth in the last 10 years, as technologies that allow simultaneous use of many automated recording devices and software that helps in sorting and automatically detecting calls have been developed and refined (Farnsworth 2005, Keen et al. 2014, Sanders and Mennill 2014). The development of complex neural network learning algorithms that may permit rapid machine sorting and identification of calls from audio recordings has been even more promising.

Paired with radar studies, audio detection has provided a much more detailed understanding of the species involved in broad-scale migratory movements and of their timing and relative abundance (Farnsworth et al. 2004, Van Doren et al. 2015). One study used a series of automated recorders across upstate New York to document the fall nocturnal migratory movements of Bobolinks (Evans and Mellinger 1999). A study deploying a set of automated recorders in Maine showed for the first time that Pine Siskins, a small finch that has major winter incursions south into eastern Canada and U.S. every two years, sometimes show large-scale night migrations (Watson et al. 2011). They had previously been thought to only migrate during the day.

[4] Most birds, especially songbirds, migrate largely at night. Some larger birds like waterfowl and shorebirds may migrate during either day or night, and birds making multi-day overwater flights must, by necessity, continue their non-stop migratory flights in both daytime and nighttime hours.



Radar Imaging

AERIAL ACTIVITY DETECTION IN EARLY STAGE OF NOCTURNAL MIGRATION

A Doppler radar station near Niagara Falls identifies and depicts a period of large-scale bird activity as birds take to the skies en masse to migrate north shortly after nightfall, a peak period for migration. Most activity occurs over land as the birds begin taking off from their daytime habitat, however a large wave begins to spill north over the water as earlier departing birds begin to cross the Great Lakes. Density of activity is depicted by color for illustrative purposes.

CITIZEN SCIENCE

Citizen science—the use of everyday people to collect data that can then be analyzed by scientists—is not a new concept, especially in the bird world.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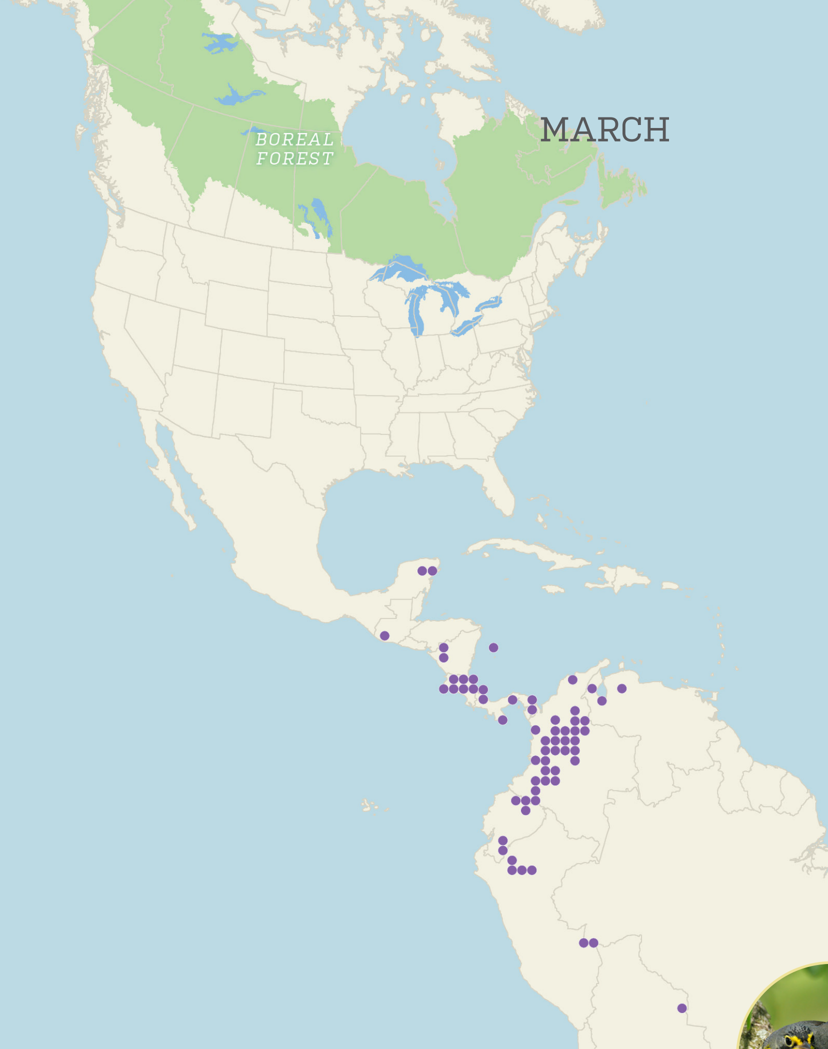
The more than 70% population drop of the Canada Warbler has spurred a cross-boundary effort to preserve the fittingly named migrant, which is organized by the Canada Warbler International Conservation Initiative.

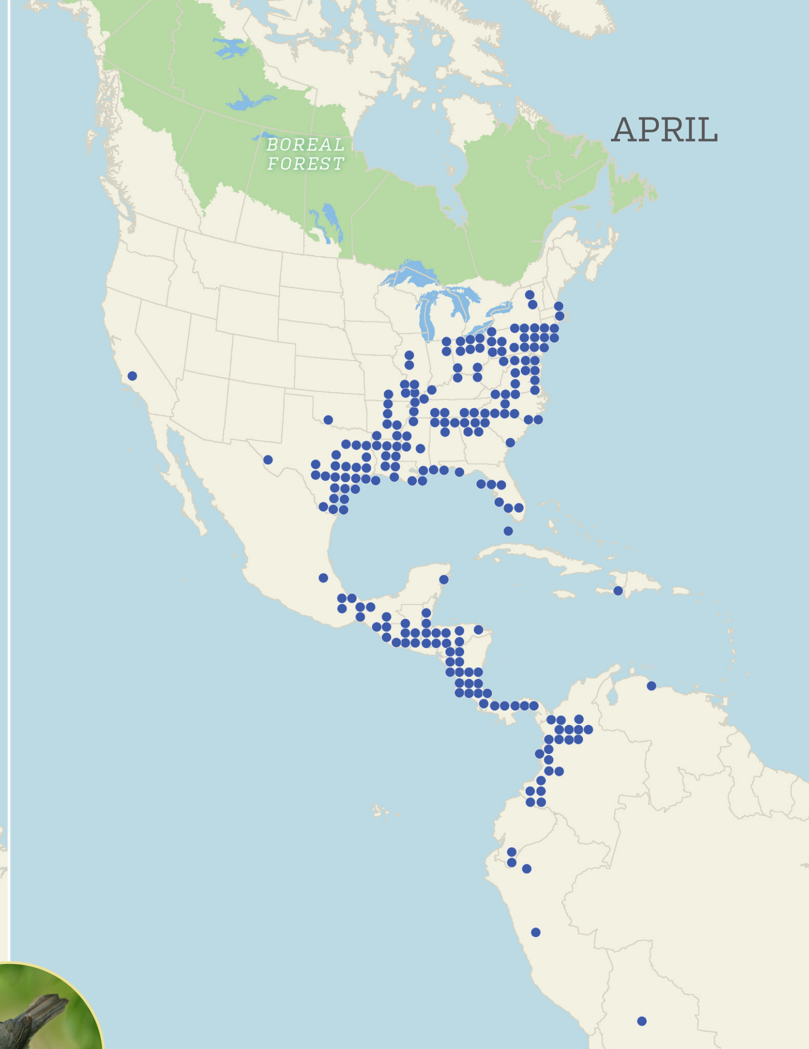
One of the first and longest-running citizen science projects of any kind is the Audubon Christmas Bird Count (coordinated in Canada by Bird Studies Canada). The Christmas Bird Count is now more than 100 years old and annually engages more than 70,000 people who collect bird survey information at more than 2,000 sites around the world.

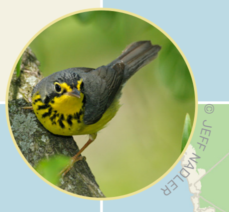
The greatest advances in the use of citizen science to understand the movements and population fluctuations of birds across vast geographic regions have occurred in the last two decades through the application of modern computer and internet technology, as well as more sophisticated statistical modeling techniques (Devictor et al. 2010, Bridge et al. 2011, Supp et al. 2015).

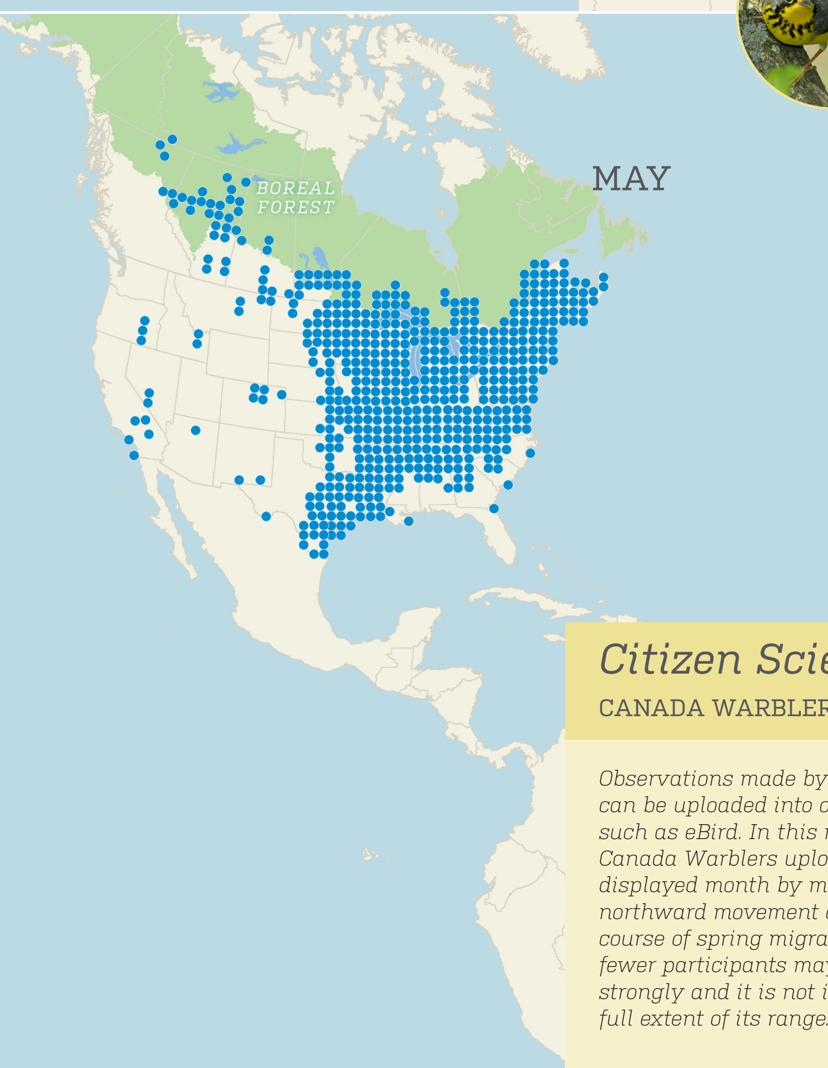
Today, there are hundreds of bird-focused citizen science projects. Some are focused on a particular species or geographic region, and some are designed to collect information that can be used to test a specific hypothesis. One of the most ambitious and innovative citizen science projects is eBird, a joint project of the Cornell Laboratory of Ornithology and the National Audubon Society (Sullivan et al. 2014). The eBird project provides a centralized web portal where anyone can input bird sighting information from anywhere in the world. The eBird database now holds more than six million individual bird checklists, making it one of the largest databases of bird sighting information in the world (Sullivan et al. 2014).

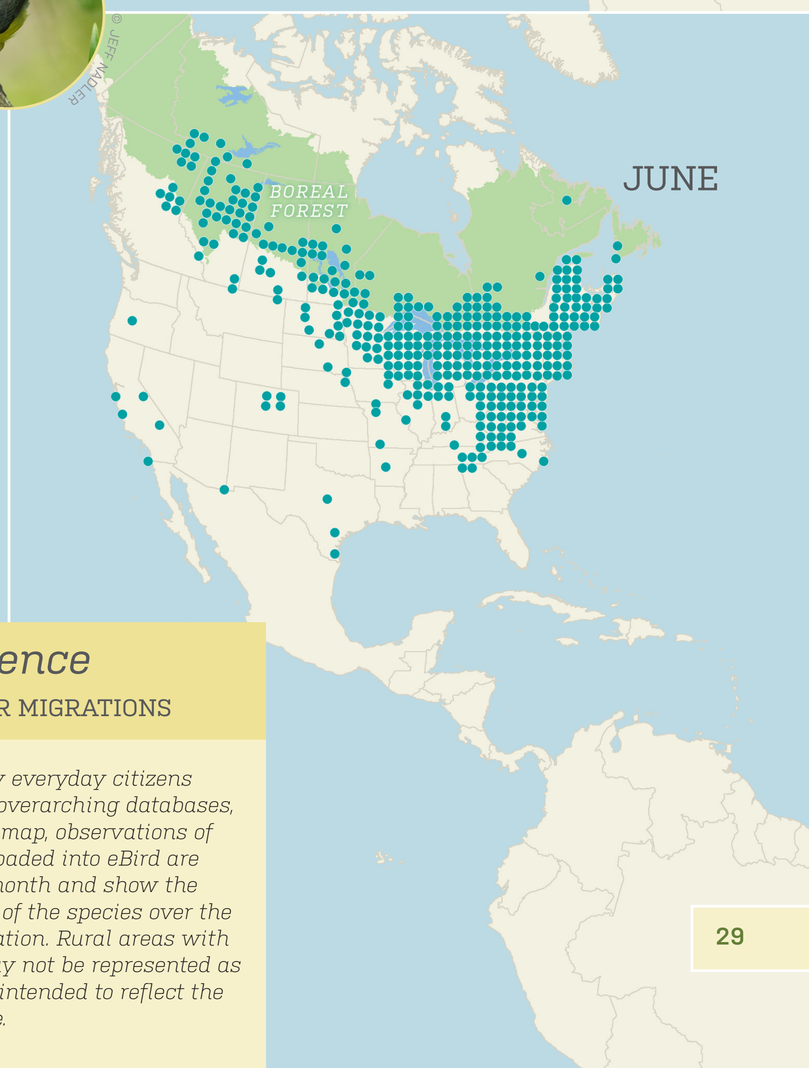
Scientists are finding the data a rich source for investigating many continental-scale questions that could not be readily studied prior to the existence of this massive dataset (La Sorte et al. 2015a, 2015b). A study published in 2016 used novel modeling approaches applied to the millions of eBird checklists across the Americas to, for the first time, track the routes, speed, and distance of migration for entire populations of more than 100 species, most as they moved back and forth between South and Central America and North America (La Sorte et al. 2016).











Citizen Science

CANADA WARBLER MIGRATIONS

Observations made by everyday citizens can be uploaded into overarching databases, such as eBird. In this map, observations of Canada Warblers uploaded into eBird are displayed month by month and show the northward movement of the species over the course of spring migration. Rural areas with fewer participants may not be represented as strongly and it is not intended to reflect the full extent of its range.

Conclusions & Recommendations

Over the last 100 years, since the signing of the Migratory Bird Convention treaty, there has been remarkable progress in collaborative conservation between the U.S. and Canada. As we begin the next century of bird conservation, threats to bird populations are more diverse and require a different and broader set of solutions.

New advances in the technologies available to study birds are exponentially increasing our knowledge about how to protect and manage bird populations and their habitats. We have learned more details about the responsibilities that nations, provinces, states, Indigenous governments and others share in order to ensure the survival of different bird species. Migratory birds need intact habitats across vast scales that encompass all parts of their life cycles from breeding to wintering ranges and the migratory stopover habitats in between. That knowledge affirms that the benchmark for habitat protection must be moved substantially higher than previously acknowledged. In the last remaining largely ecologically intact regions of the Earth, like the Boreal Forest region of Canada and Alaska, it is imperative that a minimum of at least half of the area be placed into conservation areas forever free of large-scale industrial disturbance, while leading-edge sustainability measures are implemented and independently monitored on areas that are subject to industrial-scale natural resource extraction.

Protecting and maintaining bird populations in today's world requires engaging with partners that are applying modern conservation ideas to the intact landscapes where birds thrive. That is why it is equally imperative that Indigenous governments and communities are supported as they take the lead on deciding the future of their lands. Building and maintaining capacity for Indigenous governments and communities to lead in a new and prosperous future that balances conservation and industrial development on lands in the Boreal Forest region of Canada and Alaska must be a priority. Federal, provincial and state governments need to make large-scale investments in providing financial resources for communities to train and hire Indigenous land-use planners, managers, and on-the-land guardians and rangers. This model has been very successful in Australia where Indigenous Ranger programs that now employ over 700 Indigenous people to manage vast areas of vital cultural and ecological importance. It should be implemented in Canada and Alaska as well.

As we celebrate the last 100 years of bird conservation in the Americas, it is also time to look into the new century with new conservation ideas that are informed by the amazing discoveries of migration research and the realization that modern conservation success will require rethinking old paradigms and engaging new and sometimes unfamiliar partners. It is an exciting and hopeful time for bird conservation if we can embrace these new ideas and continue learning and adapting just as birds have done themselves for millions of years.

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RECOMMENDATIONS

PROTECT AT LEAST 50% OF THE BOREAL FOREST REGION

- To maintain migratory bird populations and the full complement of all plant and animal species as well as ecological processes, at least 50 percent of an ecosystem or broad-scale landscape should be incorporated into a network of conservation areas that are free of industrial disturbance, including from forestry, mining and exploration activity, oil and gas extraction and exploration, agriculture and hydropower production.
- The conservation areas network must include very large areas—on the order of at least 10,000-20,000 square kilometers (2.5-5 million acres) in size—to maintain migratory bird populations and large mammal populations as well as the required range of habitat diversity and ecosystem functions and to serve as biodiversity reservoirs in the face of climate change.
- Planning should consider the cumulative impacts of development over meaningful time periods (i.e. decades) to ensure that the full consequences of land use are understood and addressed. Given the unprecedented speed of climate change impacts to ecological systems, especially in northern regions, the viability of wildlife populations is increasingly contingent on managing land use so as to maintain large, intact habitat areas and landscape connectivity.

LAND-USE DECISIONS SHOULD BE LED BY INDIGENOUS GOVERNMENTS AND LOCAL COMMUNITIES

- Land-use decisions across the Boreal Forest region of Canada and Alaska will decide the future of many bird populations. Those decisions must be led by Indigenous governments and communities. They are inseparable from these landscapes. All decisions should follow Free Prior and Informed Consent (FPIC) principles which state that Indigenous peoples have the right to determine and develop priorities and strategies for the development or use of their lands or territories and other resources.
- Conservation of lands must accommodate Indigenous traditional uses of the land and should be managed or co-managed by Indigenous governments. In all cases, there should be protection of traditional values and uses, including hunting, trapping, gathering plants for food, materials, medicines and spiritual and ceremonial practices. Federal and provincial governments should make large-scale investments in providing financial resources for communities to train and hire Indigenous land-use planners, managers, and on-the-land guardians or rangers. Ways of leveraging such programs with Indigenous communities to help fill existing gaps in bird data via training and equipment should be explored as well, particularly in remote northern regions where data are most sparse.

ENCOURAGE AND FUND MIGRATORY BIRD RESEARCH

- Research into the migratory routes, connectivity, timing and other aspects of migration must continue to be encouraged and funded in order to understand the range of factors influencing the future of all bird species on the breeding grounds, wintering grounds and during migration. Cross-cultural and cross-border partnerships and collaborations that work toward full life-cycle conservation of species should continue to be supported and developed. The Sea Duck Joint Venture, Boreal Partners in Flight, the International Rusty Blackbird Technical Working Group, and the Canada Warbler International Conservation Initiative are all models that can be emulated and supported.

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