BOREAL FOREST REFUGE:

Conserving North America's Bird Nursery in the Face of Climate Change

BOREAL SONGBIRD INITIATIVE

Keep the Forest Singing

Contents

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ABOUT THE BOREAL SONGBIRD INITIATIVE

The Boreal Songbird Initiative 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.

SUGGESTED CITATION

Wells, J., D. Stralberg, and D. Childs. 2018. Boreal Forest Refuge: Conserving North America's Bird Nursery in the Face of Climate Change. Boreal Songbird Initiative, Seattle, WA.

ACKNOWLEDGEMENTS

The authors would like to thank Nicole Barker, Valerie Courtois, Emily Cousins, Steve Cumming, Kelly Frawley, Lane Nothman, Fiona Schmiegelow, and Samantha Song for their review and contributions to this report.

This report was made possible by data and analyses from the Boreal Avian Modelling Project (www.borealbirds.ca). Refugia metrics were developed as part of the AdaptWest project (adaptwest.databasin.org), funded by the Wilburforce Foundation.

CREDITS

All graphic design and report layout by Lisa Holmes / Yulan Studio.

All French translation provided by Les services langagiers Marie-Noëlle Caron.

Photo on cover (Canada Warbler) by Jeff Nadler.

Executive summary

The Boreal Forest region of North America contains breeding grounds for billions of birds from over 300 species. As the largest intact forest left on the planet, it has the vast, undisturbed landscapes that allow birds to flourish. Each year, billions migrate to the Boreal Forest to mate and nest, then fly south to parks, backyards and wildlands across the continent until the cycle repeats again the next spring. Conditions in the Boreal Forest sustain this migration, yet climate change is starting to shift the temperature, precipitation, and vegetation patterns in the region. Given the overriding responsibility of the Boreal Forest for maintaining North America's birds, understanding how birds will respond to changing conditions is essential for ensuring their long-term survival. Now recently published niche models and future climate projections are providing a window into how climate change could affect migratory birds and the lands they depend upon.

Analysis of 53 boreal songbird species shows that more than 50 percent of species will experience declines in suitable climate conditions. Such a dramatic decline in suitable area is expected to translate into a major drop in numbers for those species.

The research also shows that certain parts of the Boreal Forest are expected to remain relatively stable into the future and continue to provide essential habitat for birds—including those whose range shifts northward as a result of climate change. It is clear that conserving large landscapes and "climate corridors" offers the best chances for birds to adapt and thrive into the future.

Boreal birds are an indicator of broader changes. The shifts that cause their decline could also endanger other wildlife and interfere with the natural systems that help sustain life in the north. Boreal birds migrate across Canada, to the United States, Central America and as far as South America. Many spend the winter in the tropics where they pollinate plants, consume insects, spread seeds and provide other important services. If some species can no longer find suitable conditions in the Boreal Forest for nesting, their declines will be felt in ecosystems throughout the hemisphere.
These shifts will compound challenges birds are already facing. A third of North America's bird species are threatened with extinction in the absence of efforts to curb climate change and protect their habitat.

Ensuring the long-term health of boreal birds helps maintain the larger web of biodiversity. This benefits wildlife and humans alike, for the landscapes and ecosystems that sustain birds also provide communities with clean air and water, plentiful food and medicine and tools for combatting climate change.

Using the projections of where birds could continue to thrive in the Boreal Forest to inform land use decisions and long-range conservation strategies will help not only the birds, but all who rely on their habitat.

Key findings

Research results highlighted in this report point toward some of the best strategies for ensuring that boreal birds and other animals and plants are not lost as a result of climate change:

- **Climate Refugia Provide Better Chances for Long-term Persistence:** Certain parts of the Boreal Forest are projected to remain relatively stable into the future and will serve as **climate refugia** for many boreal birds and other species. Many of these refugia overlap with important carbon stores, caribou habitat and other high conservation values.
- **Shifting Ranges Will Require Corridors:** Many bird species' distributions will shift northward over time, requiring conservation of large landscapes in order to facilitate their distributional changes through **climate corridors**.
- **Intact Boreal Landscapes Offer the Best Odds for Long-term Survival:** Since most bird species (and other animals and plants) are projected to decrease in abundance and range as a result of climate change, maintaining large intact portions of the Boreal Forest today will provide them their best chances for having robust, healthy populations that allow them to survive and adapt.
- **Most Refugia and Corridors Remain Unprotected:** An overlay of current boreal protected areas with **climate refugia**, **climate corridors**, and **currently intact habitat** shows that there are major gaps in protection.

Recommendations

This report details potential impacts to boreal birds given different climate change scenarios and provides suggestions for ways to mitigate those impacts and ensure boreal bird populations remain a part of our future. Clearly, lowering the rate of continued emission of greenhouse gases would be the first line of defense in mitigating worsening levels of impact to birds. Unfortunately, the levels of greenhouse gases already in the atmosphere and the projected rates of emissions also mean that habitat protections must be rapidly increased in the Boreal Forest as well in order to provide current populations an opportunity to adapt and to provide for climate refugia and climate corridors in the future.

The Boreal Forest region remains the traditional territory of Indigenous Peoples, and many Indigenous Nations and communities are creating innovative models to conserve large landscapes within the forest. Coupled with national and provincial government support, these Indigenous-led efforts offer some of the greatest hope for protecting boreal birds and helping all wildlife become more resilient in the face of a changing climate.

These same conservation efforts will also help Canada honour its international commitments under the UN Convention on Biological Diversity, which calls for protecting at least 17% of its lands and inland waters by 2020. To accelerate toward the Pathway to Target 1 goal, Canada's federal government is investing $1.3 billion (CAD) in nature conservation. Supporting Indigenous-led initiatives and other successful models of boreal conservation will demonstrate global leadership in preserving biodiversity and responding to climate change at the same time.

Given these factors, here's how Canada and the U.S. can help sustain boreal birds into the future:

- **Dramatically decrease greenhouse gas emissions** in order to lessen the future impacts to the environment and all who depend on it for survival. Along with capping industrial emissions, forest conservation efforts can also keep more of the carbon in storage and out of the atmosphere. The Boreal Forest holds the equivalent of up to 36 years' worth of global carbon emissions from burning fossil fuels.
- **Greatly increase land protections** in areas that research indicates are likely to serve as climate refugia for many species, areas that will serve as climate corridors, and areas that currently serve as important reservoirs for healthy and resilient animal and plant populations.
- **Create networks that include very large conserved areas**—on the order of thousands of square kilometres—to adequately maintain migratory bird and mammal populations as well as the range of habitat diversity and ecosystem functions such as natural disturbance.
- **Use projections of where birds – and other wildlife – will thrive in the Boreal Forest to inform which areas are protected as part of the UN Convention on Biodiversity**; many climate refugia and corridors overlap with lands that Indigenous Peoples are already working to protect and investing in these Indigenous-led initiatives will enable Canada to meet the international conservation targets by 2020.

Canada has a special responsibility to conserve the Boreal Forest in the face of climate change. The boreal is the largest intact forest left on the planet and the nursing grounds for billions of birds that migrate throughout the Western Hemisphere. Ensuring birds thrive in the forest will help preserve biodiversity across vast areas. Canada's plan to protect at least 17 percent of lands by 2020 is a welcome first step in sustaining this biodiversity, but it must also look toward bolder goals that protect larger landscapes. By working in partnership with Indigenous Peoples, Canada can be a leader in conservation and help boreal birds and other wildlife adapt to a changing climate and thrive into the future.

Introduction

The dramatic implications of climate change are now being seen and reported on an almost daily basis. During the Northern Hemisphere spring, plants are leafing out and flowering earlier, insects and amphibians are emerging earlier, and migratory birds are arriving earlier (Root et al. 2003). Many plants and animals are shifting their distributions, often northward or upwards in elevation, as their preferred climatic conditions also shift (Virkkala et al. 2018). At the same time, birds across the globe are experiencing major declines from habitat loss and degradation, pollution, and other factors including climate change (Wells 2007). Birdlife International found that one in eight (1,469 species) bird species globally are threatened with extinction (BirdLife International 2017). A 2016 Partners In Flight publication reported that overall songbird abundance in North America had declined by more than a billion birds since 1970 (Rosenberg et al. 2016). A third of all North America's bird species are threatened with extinction in the absence of efforts to curb climate change and protect their habitat and other interventions (NABCI 2016). What do these changes mean for the birds that rely on one of the last, large primary intact forest biomes left on Earth—the Boreal Forest of North America?

The North American Boreal Forest, encompassing 1.5 billion acres (6 million km^2) from Alaska to Newfoundland, is one of the largest ecologically intact regions on Earth. Approximately 1.2 billion (4.8 million km^2) acres of the forest is still intact and nearly pristine, free of industrial development. (Blancher and Wells 2005, Wells 2011, Lee et al. 2006). The vast Boreal Forest includes a surprising variety of habitats and landforms: thick coniferous forests, glacier-capped mountains, sprawling peatlands, and some of the world's largest lakes, rivers, and networks of wetlands (Wells et al. 2013). Because of the size, variety, and intactness of the North American Boreal Forest, it teems with wildlife, including an estimated 1-3 billion nesting birds each summer, earning it the title of "North America's bird nursery" (Blancher and Wells 2005, Wells and Blancher 2011).

More than 300 species of birds breed in the Boreal Forest of Canada and Alaska including waterfowl, shorebirds, thrushes, warblers, sparrows and many others representing at least 47 families. An astonishing 151 bird species have at least 25% of their breeding population within the Boreal Forest. Some 35 bird species are almost completely reliant on the Boreal Forest for breeding habitat with 80% or more of their total population nesting in the region. This includes birds like the Surf Scoter, Red-necked Grebe, Solitary Sandpiper, Great Gray Owl, Boreal Chickadee, Palm Warbler, and Lincoln's Sparrow. Some of the most familiar winter birds across the U.S. and southern Canada are among those that rely on the Boreal Forest including the Bufflehead—a small black and white duck often seen in sheltered coastal bays—and the White-throated Sparrow and the Dark-eyed Junco—two of the most common backyard feeder birds in North America during migration and winter.

The North American Boreal Forest

Each fall, the Boreal Forest region annually "exports" some 3-5 billion birds as new young hatch and begin migrating 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).

Sadly, there are a number of boreal bird species in decline. Boreal-dependent birds like the Rusty Blackbird, the Olive-sided Flycatcher and the Canada Warbler have shown substantial 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 experienced 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).

The many varied habitats of the Boreal Forest region also provide important migratory stop-over locations for both boreal-nesting birds and Arctic-nesting birds migrating through the region. One prominent example is the shores of Hudson and James Bay, which provide some of the most important stop-over habitats for tens of thousands of shorebirds, including species of conservation concern like the Red Knot. Inland deltas like the Saskatchewan River Delta, the Slave River Delta, and the Peace-Athabasca Delta and coastal deltas like the Mackenzie Delta are host to vast numbers of waterfowl, shorebirds and other wetland-dependent birds during migration and during the breeding season. Clearly, the intact forests, wetlands, peatlands and other habitats of the Boreal Forest are responsible for supporting a globally significant abundance and diversity of birds.

Along with birds, the Boreal Forest also harbors many of the world's last healthy populations of large predators, including grizzly bears, wolverine, timber wolves, and polar bears (Bradshaw et al. 2009, Cardillo et al. 2006, Wells et al. 2013). And it is globally recognized as one of the world's last strongholds for migratory mammals, particularly for herds of caribou—collectively numbering in the millions—that travel thousands of miles each year between northern calving grounds and southern wintering areas (Hummel and Ray 2008, Wilcove 2008).

In addition to its value for wildlife, the Boreal Forest provides humankind with globally important ecosystem services. Canada's portion of the North American Boreal Forest (about 85 percent of the total) is one of the world's largest storehouses of carbon (Carlson et al. 2009). It contains 25% of the world's wetlands, and stores more surface freshwater than anywhere else on Earth. These pristine wetlands and waterways also provide nutrient inputs that fuel some of the world's most important marine areas (Wells et al. 2011, Carlson et al. 2009, Bradshaw et al. 2009). Together, these and other forms of natural capital in the Canadian Boreal Forest alone are estimated to be worth $700 billion per year (Anielski and Wilson 2009).

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Lincoln's Sparrow

As we have described, the Boreal Forest has many globally important species and ecosystems that could be lost or degraded as a result of the impacts of unchecked climate change. Birds are a major component of boreal biodiversity, and their populations indicate how changes to the environment may impact other biodiversity and ecosystem features and ultimately human populations themselves. Projecting what could happen to boreal birds under continued warming may encourage stricter limits on industrial carbon emissions but also may help in planning on how to mitigate the impacts of climate change that are already underway.

How is climate change likely to affect boreal bird distributions?

Studies show that a large number of bird species are currently experiencing or are projected to experience declines in numbers as a result of climate change. A recent review of 569 bird species from across the globe showed that at least 23% had already experienced negative impacts from climate change (Pacifici et al. 2017). Studies of North American birds have identified northward shifts in both summer and winter distributions of many species (La Sorte and Thompson 2007, Zuckerberg et al. 2009, Coristine and Kerr 2015). An assessment of projected climate change impacts to 588 North American bird species suggested that more than half would experience a loss of at least half of their current climatically suitable habitat (Langham et al. 2015).

Unfortunately, with an average projected warming of up to 4–5 °C by the end of the twenty-first century (Price et al. 2013), boreal forest species, in general, are expected to experience the loss of cool and wet conditions that maintain their required habitats. In drier western boreal forests, longer and more severe droughts, combined with increased fire and insect pest activity, will likely result in serious tree-killing events that may ultimately transform closed boreal forests into open woodlands (Schneider et al. 2009, Scheffer et al. 2012). In wetter eastern boreal forests, conversion to faster-growing and more temperate forest types with more broad-leaved, deciduous tree species may be expected (Fisichelli et al. 2013, Boulanger et al. 2016). Over the long term, based on end-of-century global climate model projections, the North American Boreal biome could shift northward and shrink in size by an astonishing 25% (Rehfeldt et al. 2012). Additional losses may occur for species and ecosystems that fail to keep pace with the changing climate.

These unprecedented climate change impacts on the trees and other plants and animals that birds depend upon will obviously cause many changes in the numbers and distribution of bird species of the Boreal Forest biome. But each bird species will show a different set of responses. Some species that prefer broadleaf forests may increase in numbers and occupy more of the current Boreal Forest region. Some may be able to capitalize on increased food resources and a longer breeding season. However, most cold-adapted boreal specialist species, both resident and migratory, will face a variety of direct and indirect threats from climate change. From drought- and disturbance-based loss of conifer forest, to changes in food availability, to increased competition pressure from southern species, boreal birds will face a variety of threats at their southern range limits, while rates of northward expansion will be constrained by factors like permafrost dynamics and slow rates of tree dispersal and succession.

Given the overriding responsibility of the Boreal Forest region for maintaining billions of birds of more than 300 species, understanding how these birds will respond to climate change is necessary to inform conservation action. Individual species' expected responses to climate change are informed by climate-based models of bird distribution called bioclimatic niche models. These models can then be projected forward using results from climate simulations based on different scenarios of greenhouse gas emissions.

Although the complexity of mechanisms affecting individual species' responses to climate change are difficult to anticipate, bioclimatic niche models provide important information about the geographic changes in species' climate niches, and the potential for spatial shifts in distribution and abundance.

Niche models constructed for the U.S. and Canada have projected major climate-related shifts in bird species' breeding and wintering ranges (Langham et al. 2015). However, spatial predictions for remote northern regions, including the Boreal region, have been limited by data availability. The compilation of a North American boreal bird dataset by the Boreal Avian Modelling Project (Cumming et al. 2010, Barker et al. 2015), has enabled the development of spatial density models by Stralberg and colleagues (2015b), which can be used to evaluate potential effects of climate change on boreal bird abundance and distribution. The Boreal Avian Modelling Project models were based on current associations between species abundance and climate conditions (aka "niches"), which were projected forward onto future climate scenarios. Despite variability in Global Climate Model projections and gaps in bird data, uncertainties are swamped by the large magnitude of change projected for most species. That is, the climate-change signal was shown to exceed the "noise" of models and data (Stralberg et al. 2015b).

What are the model-projected changes in boreal bird distributions due to climate change?

In this report we summarize the results from a recent series of bioclimatic niche model projections for boreal birds, discuss the potential implications of these results, and provide recommendations for present day conservation efforts. Niche models and future climate projections were developed for 53 species which were identified as primarily associated with forested habitats in the Boreal region of North America. Details of the methodology used to develop these bioclimatic niche model projections can be found in Stralberg et al. (2015b).

Of these 53 forest-associated boreal songbird species, 21 were projected to experience unequivocal declines in the amount of area that provides suitable climate across the Boreal and southern Arctic regions by 2040; 24 species by 2070; and 29 species by 2100 (Appendix A). Importantly, these projections don't account for declines in abundance of bird species as a result of lags in vegetation change that will limit northward range expansion and delay southern-edge range contractions of many bird species. Although generalist and early-successional habitat bird species may keep pace with climatically-driven changes in forest vegetation, species that are associated closely with older age forest are likely to face higher levels of short-term habitat loss, especially if existing old forest habitats are lost to natural disturbance (especially

Evening Grosbeak

fire) and/or human industrial disturbance before new habitats have time to develop (Stralberg et al. 2015a).

Most species are expected to exhibit a northward (or upslope in the case of mountainous areas) shift in their distribution in response to climate change (Appendix B). Areas with high boreal bird abundance will likely shift northward but total abundance across all 53 species is projected to decline within the Boreal region. Projected decreases in the number of boreal species and individual species abundance are most apparent in the interior west, where increasingly dry conditions may exclude many boreal species. Future increases in the number of species are projected to be concentrated in interior Alaska and northern Quebec. The Alaskan boreal interior is unique in that many Canadian boreal species are not currently present there, despite suitable habitat. This is likely due to a current lack of suitable connecting habitat across the mountain ranges of the western parts of the Northwest Territories and Yukon that has historically been a barrier to their dispersal into Alaska (Stralberg et al. 2017). As climate change increases the amount of suitable habitat in the western Northwestern Territories and Yukon, the interior of Alaska is expected to experience an influx of new species, a phenomenon which is already documented to be occurring (Gibson and Withrow 2015).


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Purple Finch

What are the individualistic species responses to climate change?

The climatic niches of boreal birds, despite the fact that they all breed in the Boreal Forest region, show a wide range of variability. This variability means that boreal bird species are expected to show different distributional responses to climate change that encompass many of the general responses described earlier. Take, for example, two mature coniferous-forest associated boreal specialists, the Bay-breasted and Cape May warblers. Today, both species occupy a wide swath of the southern Boreal Forest and adjoining regions with the range extending from northern New England and Quebec west to southwestern Northwest Territories. Both species' ranges are predicted to shift significantly northward and become bisected by Hudson Bay in the future, with potential long-term population consequences. However, the Bay-breasted Warbler is projected to be concentrated in the wetter east (Northern Québec), while the Cape May Warbler will likely be concentrated in the drier Northwest Territories, eventually with little future overlap (Fig. 1). Both of these species currently have stable populations, according to Breeding Bird Survey data, but are climatically vulnerable based on their boreal-restricted niches. Identification and protection of stable climate refugia will be important for such species.

Meanwhile, northern boreal peatland-associated species, such as the Blackpoll Warbler and Rusty Blackbird, are projected to experience some of the largest climate-change associated losses (Fig. 2). These species are already among the fastest declining birds, according to Breeding Bird Survey data, with one billion fewer Blackpoll Warblers now as compared to the 1970s (Rosenberg et al. 2016). The Rusty Blackbird is thought to have declined by more than 90% over the last century and has been placed on the IUCN Redlist as Near Threatened and on the Partners in Flight watch list (Rosenberg et al. 2016, Wells 2007). Unfortunately, the species most at-risk from climate change are also generally the ones with sparse distribution and population data, due to their northern habitat preferences. These and other similar species will require intensive monitoring and management to address expected declines.

Many southerly-distributed species that are associated with broadleaf trees or shrubs and/or mixed conifer-broadleaf forests are expected to gain climatically suitable habitat within the current Boreal Forest biome in the future, as the growing season becomes longer and plant growth increases. However, the sustainability of mixed conifer-broadleaf forests depends on a delicate moisture balance that threatens to be lost in the western boreal region, where increases in precipitation likely won't be enough to overcome the enormous increase

Projected range shifts of two iconic boreal warblers

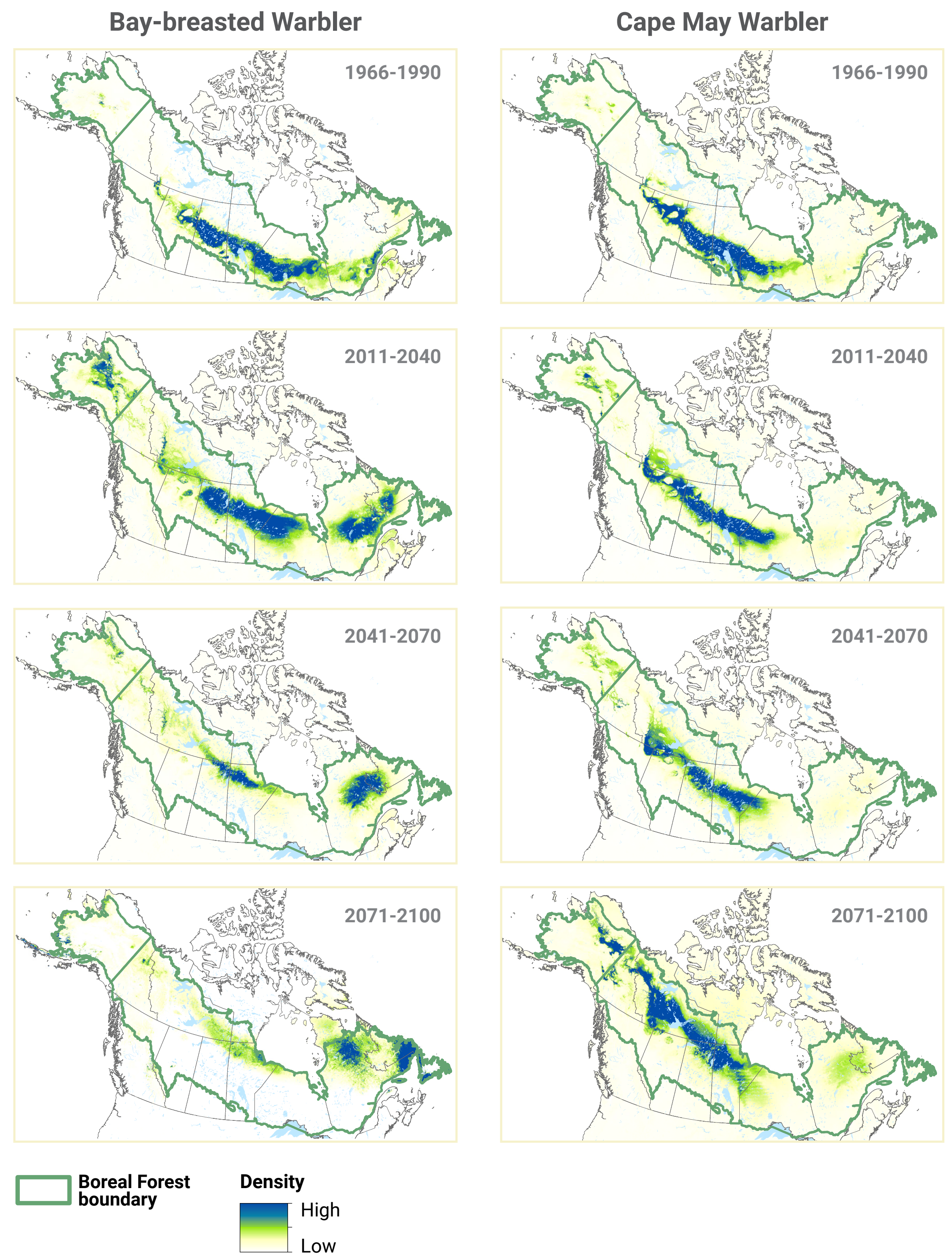


Figure 1. Examples of projected shifts in the density and distributions of coniferous-associated boreal specialist species with ranges projected to contract and shift northward: Bay-breasted Warbler (left) and Cape May Warbler (right). Current distribution is shown in the map at the top and projected climatic suitability by the period 2071-2100 is shown at the bottom with intermediate time periods in-between. Projections are based on a business-as-usual (high-end) emissions scenario, averaged across four global climate models (details provided in Stralberg et al. 2015b).

Projected range shifts of two boreal bird species already in decline

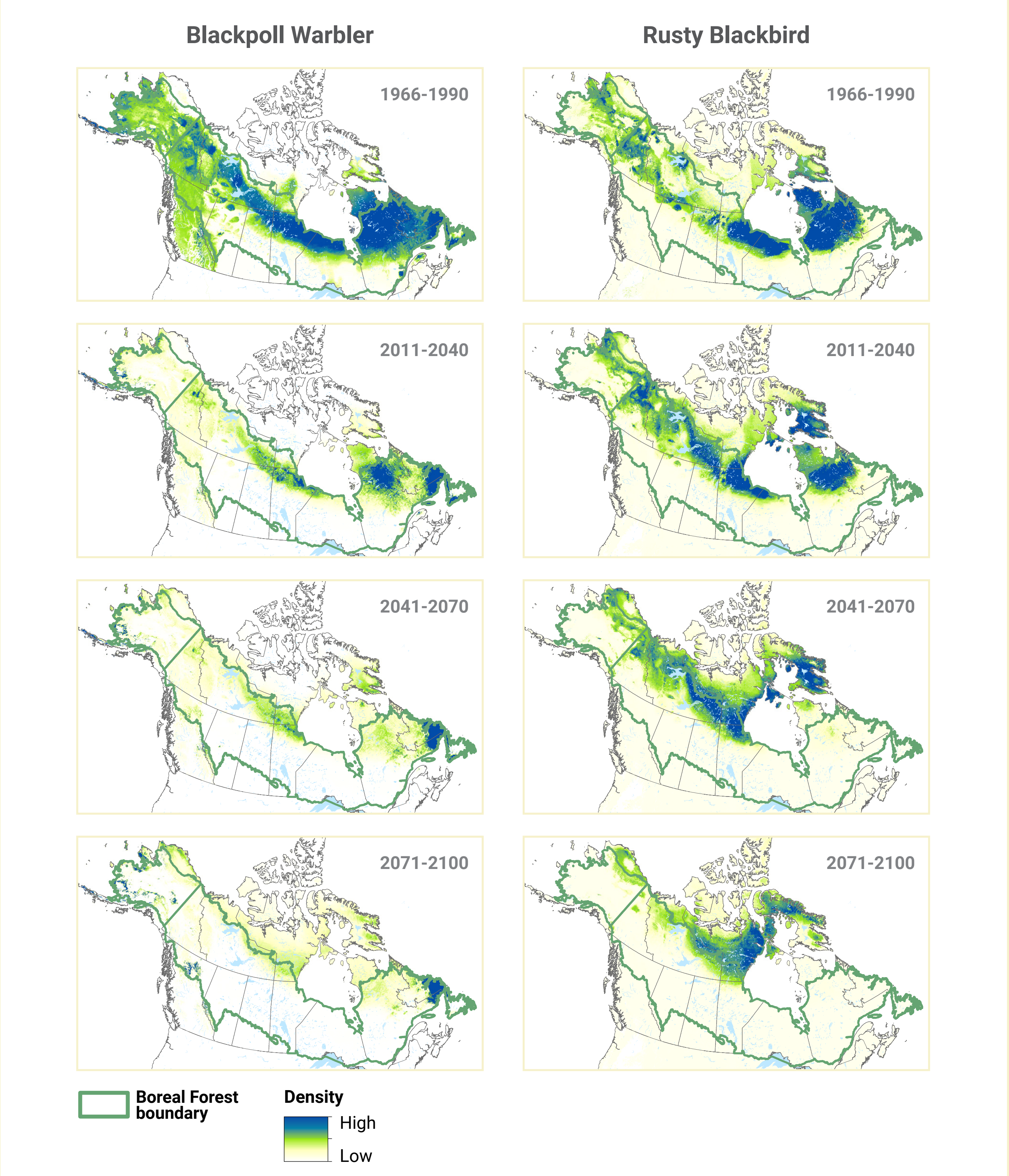


Figure 2. Examples of projected shifts in the density and distributions of declining northerly species expected to contract their boreal distributions: Blackpoll Warbler (left), and Rusty Blackbird (right). Current distribution is shown in the map at the top and projected climatic suitability by the period 2071-2100 is shown at the bottom with intermediate time periods in-between. Projections are based on a business-as-usual (high-end) emissions scenario, averaged across four global climate models (details provided in Stralberg et al. 2015b).

Projected shifts for two species that have extensive ranges in both the US and Canada

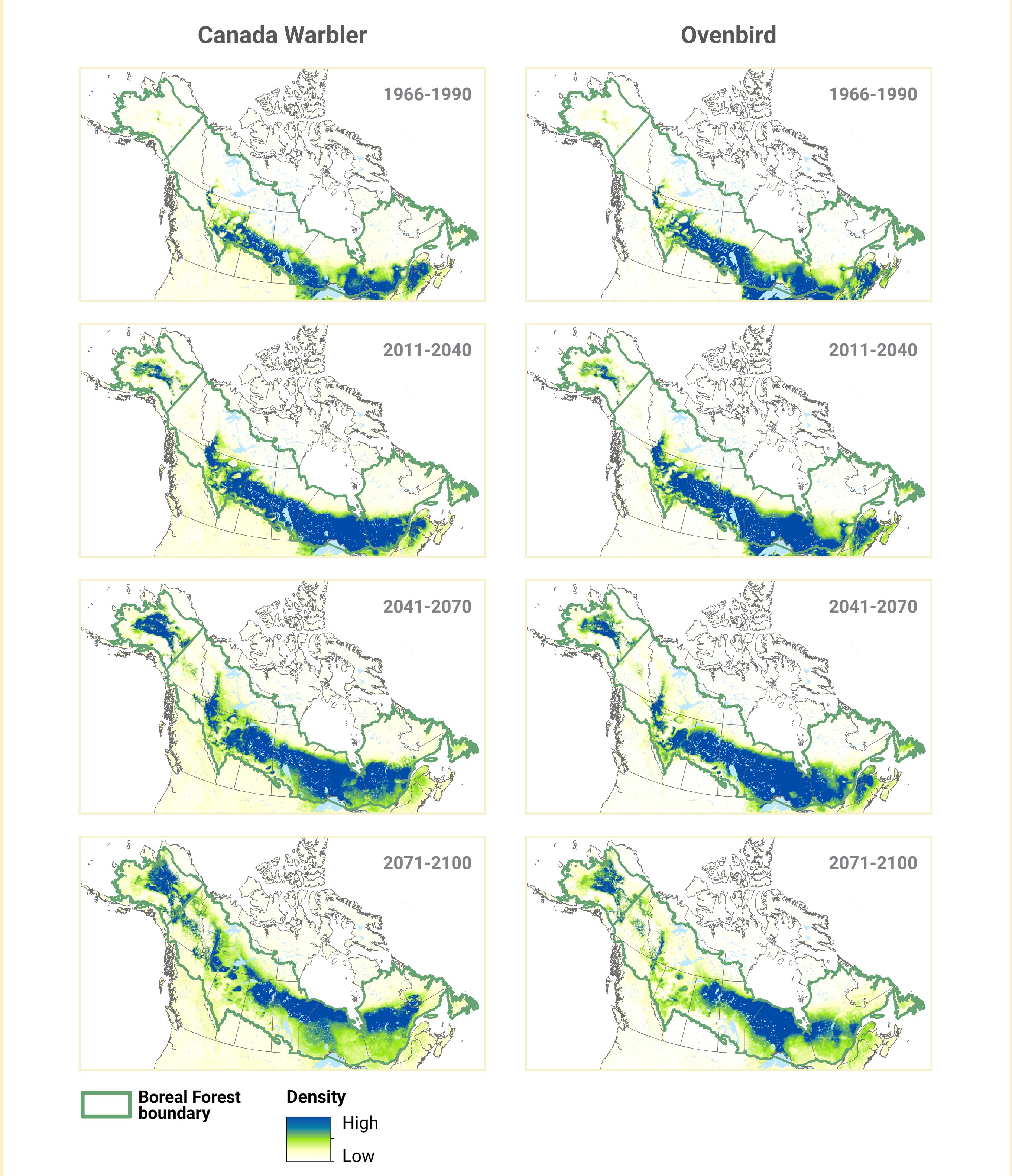


Figure 3. Examples of projected shifts in the density and distributions of broadleaf forest-associated species expected to shift their boreal distributions northward, but with significant uncertainty about the magnitude and direction of expected change: Canada Warbler (left), and Ovenbird (right). Current distribution is shown in the map at the top and projected climatic suitability by the period 2071-2100 is shown at the bottom with intermediate time periods in-between. Projections are based on a business-as-usual (high-end) emissions scenario, averaged across four global climate models (details provided in Stralberg et al. 2015b).

in moisture loss through evapotranspiration (Hogg and Bernier 2005). As a result, several species, including Ovenbird and Canada Warbler, have uncertain boreal-wide future projections (Fig. 3). Furthermore, actual shifts in occupied habitat may be delayed due to lags in vegetation response to climate change, especially for species that depend on mature forests that take time to develop. Conservation of declining species in particular will involve protection of current intact habitat, with an emphasis on in situ ("in place") refugia.

Finally, increasing temperatures will facilitate the northward expansion of many new species into the Boreal Forest, due to increasing habitat suitability. This is particularly true for winter residents that are currently energetically constrained to lower latitudes (Root 1988), and habitat generalists that are relatively well-equipped to take advantage of transitional and emerging vegetation types. Two of the species projected by niche models to expand their suitable climate space into the Boreal region in the future are the Blue Jay, a documented nest predator, and the Brown-headed Cowbird, a nest parasite. These particular species are already expanding due to urban and agricultural development, and are likely to be further facilitated by climate change. Thus, as species respond to climate change at different rates, resulting changes in community composition may have detrimental impacts on native species and should be closely monitored.

Bay-breasted Warbler

For wetland habitats and species, future projections are complicated by the relative stability of peat bog and fen wetlands in particular, which retain moisture like sponges and may be fairly resistant to climate warming (Waddington et al. 2015). These boreal wetlands may serve as population refugia for waterfowl, as prairie pothole wetlands—the other type of habitat most commonly used for breeding by North American waterfowl—are under increasing drought pressure. Although scaup and scoters have experienced major declines, most boreal waterfowl have stable long-term trends, but species that breed late in the season may be particularly sensitive to the negative effects of temperature increases on the insect prey that are crucial for chick rearing (Drever et al. 2012). Additionally, many shorebirds species that nest in the Boreal region are showing population declines, and those species that migrate the longest distances are thought to be most sensitive (Thomas et al. 2006). Clearly large landscape peat and fen systems should be considered for conservation.

What are boreal climate refugia and where are they located?

Most species are projected to have some areas within their current geographic distributions that retain the bioclimatic conditions that they prefer well into the future. These areas of relative niche stability can be termed "climate refugia" for that species (Stralberg et al. 2018). In many cases, the same regions (or portions of them) are projected to be climate refugia for many species. Identifying such places that are likely to be important climate refugia for a broad set of bird species as well as for other animals and plants, could highlight areas particularly important for conservation efforts.

Such an approach was used to identify potential climate refugia hotspots in the Boreal Forest region of Canada and Alaska (Fig. 4). Generally speaking, these can be characterized as areas of relatively moderate climates—e.g., marine and lacustrine coastal areas, and mountain areas that are projected to remain relatively cool and wet in a rapidly warming climate. Individual species refugia may also be found along the latitudinal and elevational ecotones that currently represent northern range limits (e.g., the Boreal-Taiga transition zone). Conservation planning efforts should consider these shared refugia, as well as species-specific refugia, especially for current species at risk and climate-vulnerable species.

Climate refugia for boreal birds

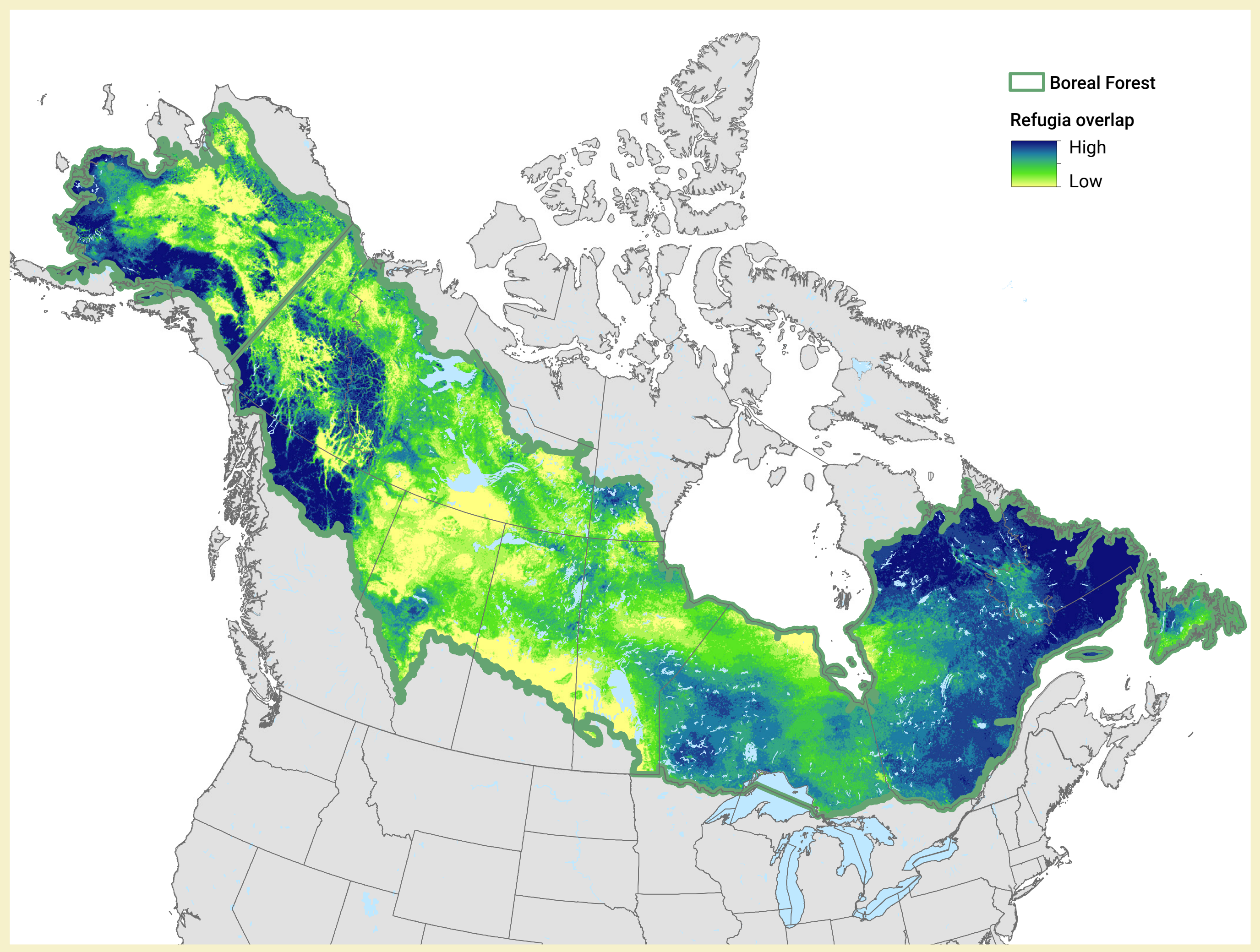


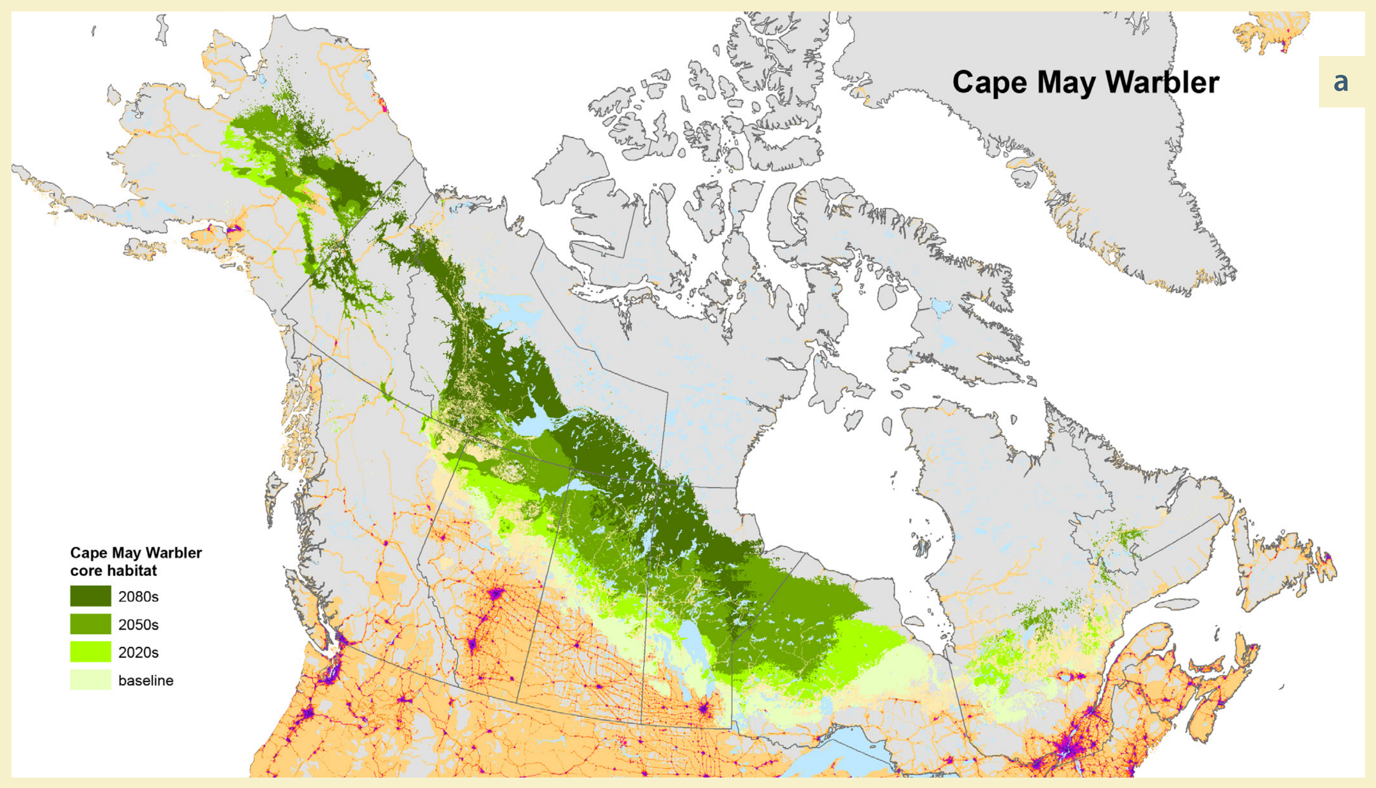
Figure 4. Distribution of climate refugia: regions that are predicted to maintain climatic conditions favorable to multiple Boreal forest-associated species over the next 80 years. Dark blue represents areas with the greatest overlap of single species climate refugia, yellow the least overlap, and green represents areas with an intermediate level of overlap. End-of-century refugia are based on a business-as-usual (high-end) emissions scenario, averaged across four global climate models (Stralberg 2018).

How can we facilitate range shifts of boreal birds?

Some species are projected to see most or all of their geographic distribution shift so that very little of the currently occupied distribution will be occupied in the future. For these species it is particularly important to identify the regions that will serve as the "climate corridors" across which populations will shift as they respond to shifting bioclimatic conditions. Conservation strategies for these regions will require protecting large landscapes of suitable habitat that will allow these distributional shifts of bird populations.

In response to climate change, many boreal species are projected to lose suitable habitat at the southern edges of their distributions while expanding their ranges northward. Although most documented distributional responses to climate change have been range expansions at northern range limits (Parmesan and Yohe 2003, but see Freeman et al. 2018), range contractions along southern limits have also been documented for birds (Zuckerberg et al. 2009) and are particularly likely where anthropogenic or natural disturbance factors (such as drought and wildfire) exacerbate risk and accelerate eco-system transitions. In North America, the drier western Boreal region is extremely vulnerable to drought, insect pest outbreaks, and wildfire (Hogg 1994). The western

Climate corridors for boreal birds over time



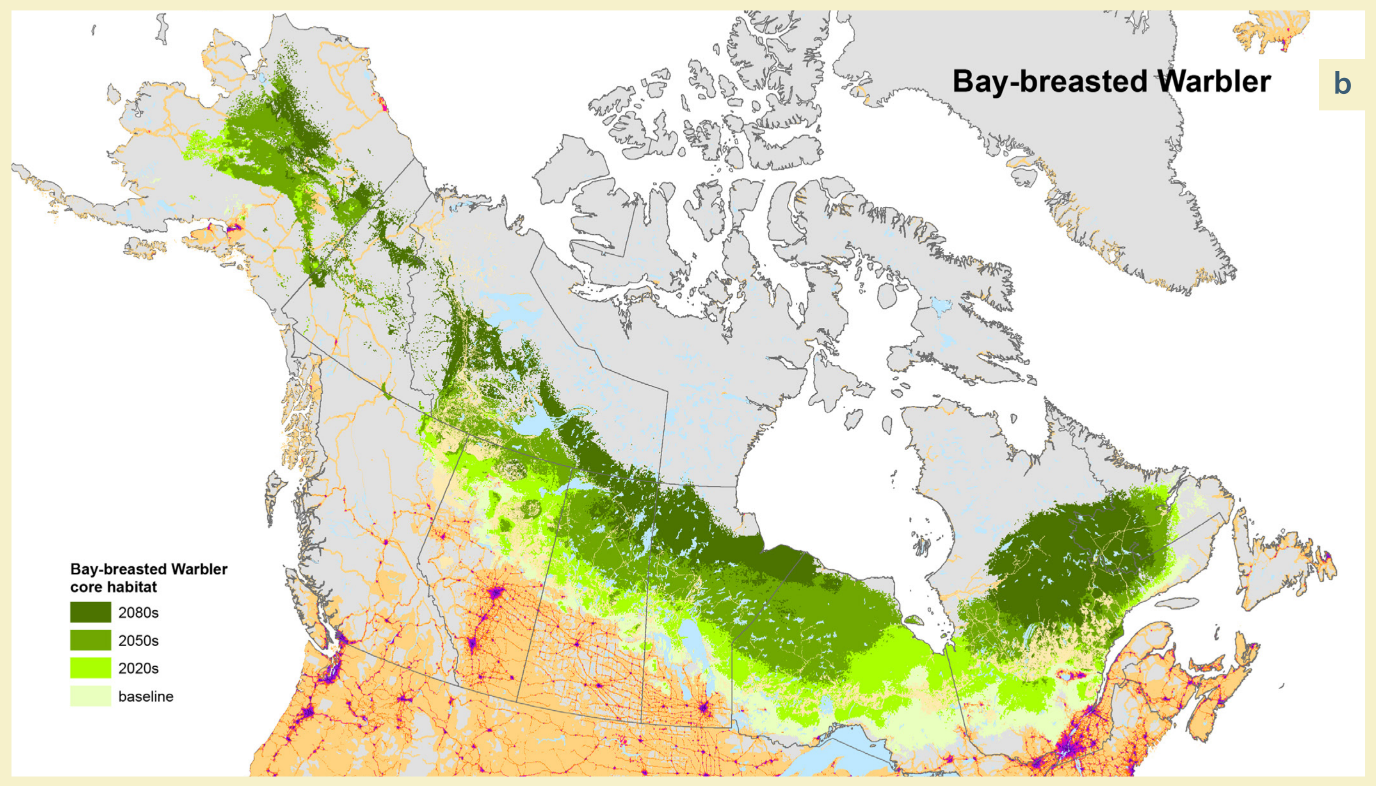


Figure 5. Projected shifts in climatically suitable habitat for Cape May Warbler (a) and Bay-breasted Warbler (b) over time, illustrating potential "climate corridors"—regions through which populations of the species will likely shift through over decades under current climate change scenarios. Regions in lightest green represent current ranges for the species and darkest green the regions predicted to have climatic conditions suitable for the species in 2080. Each shade of green between the two regions represents areas that are part of the climate corridor through which species populations will be forced to move in order to adapt to the changing climate. Species core areas taken from Stralberg et al. (2015a).

Boreal is also experiencing rapid industrial development relative to other regions, due to the cumulative effects of timber harvest and oil and gas development, resulting in a highly fragmented landscape (Schneider et al. 2003, Lee et al. 2006). Such fragmentation may ultimately affect species' abilities to shift distributions, due to declines in population viability, or even via direct impediments to dispersal in highly modified landscapes.

To facilitate long-term range shifts, it is important to maintain habitat connectivity along northern climatic gradients where range expansion is projected to occur. Species for which a predominantly northwestward shift is projected, e.g., Cape May Warbler, may be particularly vulnerable to fragmentation in northwestern Canada (Fig. 5a); whereas species with primarily northeastern climate refugia, e.g., Bay-breasted Warbler, may require additional protections in the east (Fig. 5b). The northwestern cordillera region, from British Columbia, spanning the Yukon to Alaska, will be a particularly important corridor for the many Canadian boreal species projected to extend their ranges into Alaska (Stralberg et al. 2017). However, all species will be particularly vulnerable at the southern margins of their distributions, which also tend to be the most heavily impacted by industrial and agricultural development. Thus, a multi-stage land conservation approach based on "climate corridors," aka "temporal corridors" (Rose and Burton 2009), starting in the south and expanding northward and upslope over time (Appendix B), will help improve viability of the most vulnerable bird populations, leading to an increased likelihood of future distributional shifts in conjunction with changing climate.

How well are potential climate refugia and climate corridors protected now?

To better understand the needs for current and future conservation efforts, we overlaid maps of boreal bird climate refugia and current and projected future bird densities with maps of current protected areas in Canada and current intact forest landscapes in Canada (Appendix C). Taken together, areas of high projected bird density for different time periods may be considered multi-species climate corridors. Across Canada's Boreal Forest region, there are large gaps in the protected areas network with respect to both refugia and high-density areas across all time periods (Appendix D, E). Of the highest valued end-of-century refugia (top quartile), only 7.9% of the land area has been permanently protected. Projected future high-density areas have a similar level of protection, ranging from 7.2% protected in the 2011-2040 time period to 4.3% protected in the 2071-2080 time period (compared to 6.7% in the 1961-1990 baseline period).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Cape May Warbler

However, a source of optimism is that a significant portion of both high value refugia (80.3%) and climate corridors (59.8%) is still intact and free from industrial disturbance, meaning that an expansion of protected areas in these regions, combined with sustainable forest management practices, could address current gaps in bird habitat protection.

Many of these gaps could be filled through the adoption of Indigenous-led land-use plans and conservation proposals. Areas deemed of high value to birds as refugia, climate corridors, or current intact habitat are often being considered for future protected areas or have recently been protected by Indigenous governments and communities, from the proposed Thaidene Nene National Park Reserve in the NWT to Tursujuq Park in Quebec. Fortunately, the Canadian federal government's recent commitment of $1.3 billion in new monies for increasing the pace and scale of land and water conservation in partnership with Indigenous communities may allow some of these needs to be filled. But clearly, much work remains to be done, especially to meet the Aichi treaty obligations to protect at least 17% of Canada's land base by 2020.

Key findings

What do these results tell us about some of the best strategies for ensuring that boreal birds and other animals and plants are not lost as a result of climate change?

- **Climate Refugia Provide Better Chances for Long-term Persistence:** Certain parts of the Boreal Forest are projected to remain relatively stable into the future and will serve as **climate refugia** for many boreal birds and other species. Many of these refugia overlap with important carbon stores, caribou habitat and other high conservation values.
- **Shifting Ranges Will Require Corridors:** Many bird species' distributions will shift northward over time, requiring conservation of large landscapes in order to facilitate their distributional changes through **climate corridors**.
- **Intact Boreal Landscapes Offer the Best Odds for Long-term Survival:** Since most bird species (and other animals and plants) are projected to decrease in abundance and range as a result of climate change, maintaining large intact portions of the Boreal Forest today will provide them their best chances for having robust, healthy populations that allow them to survive and adapt.
- **Most Refugia and Corridors Remain Unprotected:** An overlay of current boreal protected areas with **climate refugia**, **climate corridors**, and **currently intact habitat** shows that there are major gaps in protection.

Conclusions

Birds, like all animals and plants, are facing unprecedented changes and challenges now and in coming decades as a result of climate change. 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. The niche modelling research described in this report demonstrates that climate change increases the scale at which biodiversity conservation is needed, given the rapid changes in habitat suitability that are projected, and the consequent increases in land required to accommodate an individual species' range shift over time.

Canada's commitment to fulfilling its international biodiversity treaty obligations (the so-called Aichi treaty) to protect at least 17% of its lands and inland waters by 2020, is a welcome first step. And the February, 2018 announcement of a $1.3 billion (CAD) investment by Canada's federal government to reach that goal shows heartening global leadership in the protection of biodiversity affected by climate change.

However, modern, comprehensive conservation plans typically identify protection targets between 25% to 75% of the landscape (Noss et al. 2012, Schmiegelow et al. 2006). Ambitious, scientifically-grounded approaches to maintaining the full diversity of species and ecosystem functions, rather than politically-motivated targets, have been encouraged (Noss et al. 2012). 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. In the last remaining ecologically intact regions of the Earth, like the Boreal Forest region of Canada, great potential remains to conserve large, intact landscapes, while simultaneously implementing rigorously evaluated sustainability measures in areas subject to resource development.

Protecting and maintaining bird populations in today's world requires engaging with partners that are applying forward-thinking conservation ideas to the intact landscapes where birds thrive. That is why it is equally imperative that Indigenous governments and communities (whose lands encompass much of the Boreal Forest region) 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 must be a priority.

Recommendations

This report details potential impacts to boreal birds given different climate change scenarios and provides suggestions for ways to mitigate those impacts and ensure boreal bird populations remain a part of our future. Clearly, lowering the rate of continued emission of greenhouse gases would be the first line of defense in mitigating worsening levels of impact to birds. Unfortunately, the levels of greenhouse gases already in the atmosphere and the projected rates of emissions also mean that habitat protections must be rapidly increased in the Boreal Forest as well in order to provide current populations an opportunity to adapt and to provide for climate refugia and climate corridors in the future. The Boreal Forest region remains the traditional territory of Indigenous Peoples, and many Indigenous Nations and communities are creating innovative models to conserve large landscapes within the forest. Coupled with national and provincial government support, these Indigenous-led efforts offer some of the greatest hope for protecting Boreal birds and helping all wildlife become more resilient in the face of a changing climate.

Specific recommendations include:

- **Dramatically decrease greenhouse gas emissions** in order to lessen the future impacts to the environment and all who depend on it for survival. Along with capping industrial emissions, forest conservation efforts can also keep more of the carbon in storage and out of the atmosphere. The Boreal Forest holds the equivalent of up to 36 years' worth of global carbon emissions from burning fossil fuels.
- **Greatly increase land protections** in areas that research indicates are likely to serve as climate refugia for many species, areas that will serve as climate corridors, and areas that currently serve as important reservoirs for healthy and resilient animal and plant populations.
- **Create networks that include very large conserved areas**—on the order of thousands of square kilometres—to adequately maintain migratory bird and mammal populations as well as the range of habitat diversity and ecosystem functions such as natural disturbance.
- **Use projections of where birds – and other wildlife – will thrive in the Boreal Forest to inform which areas are protected as part of the UN Convention on Biodiversity**; many climate refugia and corridors overlap with lands that Indigenous Peoples are already working to protect and investing in these Indigenous-led initiatives will enable Canada to meet the international conservation targets by 2020.

Canada has a special responsibility to conserve the Boreal Forest in the face of climate change. The Boreal is the largest intact forest left on the planet and the nursing grounds for billions of birds that migrate throughout the Western Hemisphere. Ensuring birds thrive in the forest will help preserve biodiversity across vast areas. Canada's plan to protect at least 17 percent of lands by 2020 is a welcome first step in sustaining this biodiversity, but it must also look toward bolder goals that protect larger landscapes. By working in partnership with Indigenous Peoples, Canada can be a leader in conservation and help boreal birds and other wildlife adapt to a changing climate and thrive into the future.

Appendix A

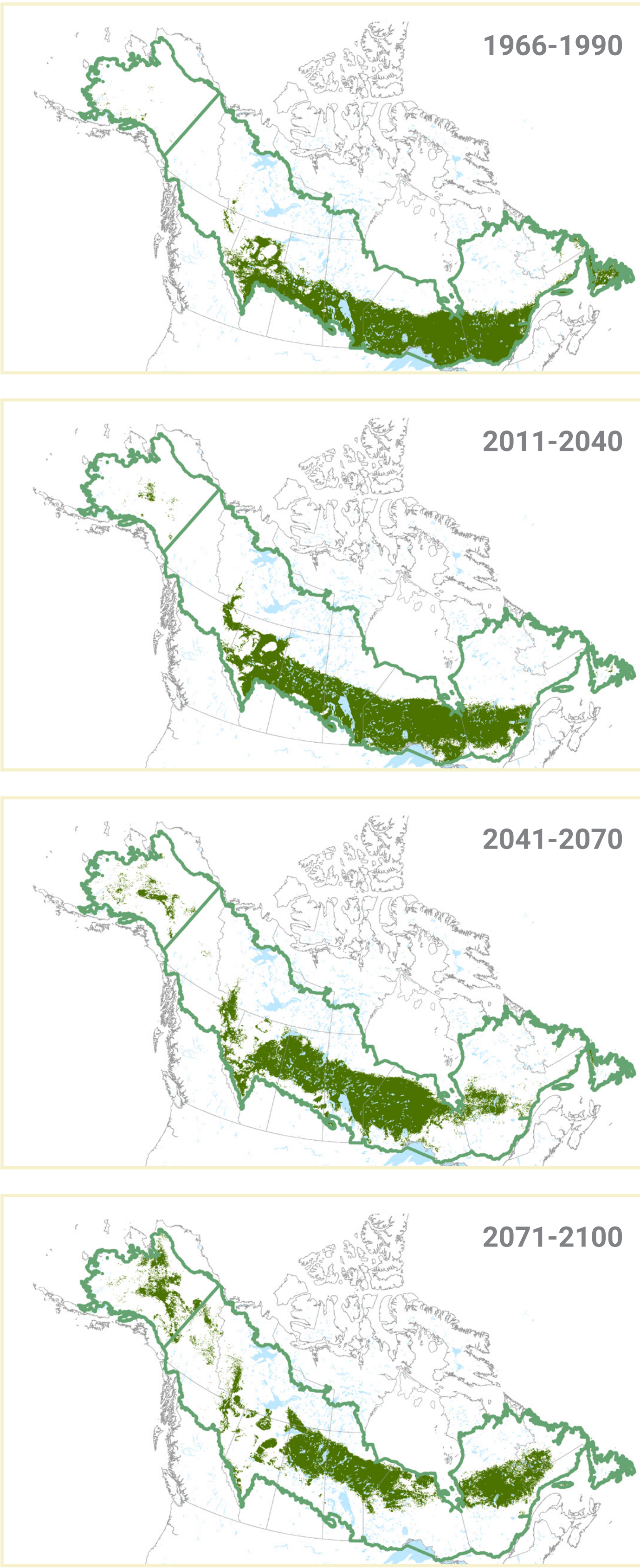
Projected changes in potential abundance of boreal birds over time

		Current period (1961-1990) Singing males x 10⁶		2011-2040 % change		2041-2070 % change		2071-2100 % change	
Species	Code	Mean	(5th, 95th percentiles)	Mean	(5th, 95th percentile)	Mean	(5th, 95th percentile)	Mean	(5th, 95th percentile)
American Redstart	AMRE	36.92	(31.39, 44.59)	42.20%	(20.8%, 84.5%)	76.40%	(53.6%, 126.6%)	110.50%	(70%, 176.1%)
Bay-breasted Warbler	BBWA	13.98	(12.25, 16.54)	34.30%	(14.8%, 57%)	70.80%	(47.3%, 99.9%)	82.90%	(39.5%, 128%)
Black-and-white Warbler	BAWW	31.79	(25.97, 35.29)	4.00%	(-10.2%, 26%)	-9.50%	(-37.3%, 12%)	-37.00%	(-68.8%, -3.8%)
Blackburnian Warbler	BLWA	22.77	(20.03, 25.02)	40.80%	(17.4%, 71.7%)	103.70%	(63.9%, 155.5%)	187.50%	(132.8%, 261.7%)
Black-capped Chickadee	BCCH	12.89	(11.4, 14.51)	23.50%	(6%, 35.9%)	30.30%	(11%, 49.5%)	35.50%	(6%, 66.1%)
Blackpoll Warbler	BLPW	9.24	(6.83, 11.63)	85.40%	(45.5%, 127.4%)	132.00%	(80.5%, 186.2%)	130.80%	(53.1%, 216.8%)
Black-throated Green Warbler	BTNW	2.24	(1.83, 2.62)	59.60%	(36.3%, 90.3%)	207.70%	(142.3%, 287.1%)	347.60%	(231.6%, 511.2%)
Blue Jay	BLJA	123.39	(90.06, 183.34)	-30.00%	(-67.1%, -7.1%)	-43.50%	(-92.8%, -15.5%)	-49.40%	(-102.1%, -13.5%)
Blue-headed Vireo	BHVI	54.49	(44.85, 66)	2.20%	(-3.7%, 8.5%)	-1.60%	(-21.2%, 14.2%)	-26.60%	(-58.1%, -4.5%)
Boreal Chickadee	BOCH	15.1	(11.15, 18.3)	-0.50%	(-9.8%, 7.3%)	-5.10%	(-20.9%, 11.7%)	-20.40%	(-45.2%, -0.2%)
Brown Creeper	BRCR	8.52	(6.57, 10.69)	42.00%	(19.3%, 71.1%)	84.10%	(59.2%, 112.3%)	133.70%	(73%, 178.1%)
Canada Warbler	CAWA	4.77	(3.06, 10.94)	35.60%	(4.2%, 61.1%)	52.90%	(6.8%, 86.5%)	65.10%	(9.8%, 133.5%)
Cape May Warbler	CMWA	43.67	(38.05, 50.89)	22.50%	(10.7%, 37.1%)	54.70%	(36.1%, 77.9%)	96.20%	(62.3%, 137.9%)
Cedar Waxwing	CEDW	20.68	(16.4, 27.6)	-1.90%	(-12.2%, 16.4%)	-10.50%	(-36.3%, 18.7%)	-40.00%	(-67.9%, -15.1%)
Common Raven	CORA	2.05	(1.56, 2.48)	2.10%	(-31.7%, 42.2%)	-16.10%	(-49.6%, 22.2%)	-41.70%	(-88.9%, 5.1%)
Common Redpoll	CORE	10.77	(9.01, 12.39)	1.40%	(-2.7%, 7.4%)	2.90%	(-5%, 10.7%)	-3.20%	(-13.5%, 9.2%)
Connecticut Warbler	CONW	122.75	(74.99, 207.68)	-28.70%	(-59.4%, -12.1%)	-40.10%	(-103.3%, -14.5%)	-60.60%	(-139%, -22.7%)
Dark-eyed Junco	DEJU	104.06	(88.18, 118.76)	-12.00%	(-19.5%, -5.9%)	-22.80%	(-36.7%, -11.9%)	-38.10%	(-55.1%, -24.2%)
Evening Grosbeak	EVGR	5.15	(3.74, 7.07)	28.80%	(11.9%, 55.6%)	55.80%	(27.9%, 96.7%)	93.10%	(50.2%, 163.2%)
Fox Sparrow	FOSP	50.67	(41.09, 64.46)	-20.10%	(-34.6%, -8.5%)	-44.50%	(-63.2%, -30.8%)	-60.10%	(-87.3%, -40%)
Golden-crowned Kinglet	GCKI	58.79	(50.13, 64.92)	15.90%	(5%, 29.8%)	26.70%	(11.2%, 38.9%)	23.30%	(0.3%, 43.2%)
Gray Jay	GRAJ	14.6	(9.97, 20.38)	-38.50%	(-68.4%, -10.1%)	-50.00%	(-95.4%, -22.7%)	-73.40%	(-118%, -43.6%)
Gray-cheeked Thrush	GCTH	83.4	(78.1, 89.86)	-10.20%	(-17.9%, -3%)	-24.50%	(-40.9%, -12%)	-46.50%	(-69.9%, -33.4%)
Hermit Thrush	HETH	40.05	(35.64, 42.82)	-1.50%	(-9.1%, 6%)	-7.00%	(-20.7%, 3%)	-22.00%	(-39.3%, -9.1%)
Least Flycatcher	LEFL	44.39	(40.28, 48.2)	-15.40%	(-22.2%, -7.8%)	-28.60%	(-44.8%, -18%)	-45.10%	(-65.9%, -29.8%)
Magnolia Warbler	MAWA	65.94	(56.52, 74.25)	17.30%	(-7.3%, 36.5%)	25.40%	(10.3%, 39.9%)	9.50%	(-12.4%, 31%)
Mourning Warbler	MOWA	7.53	(6.65, 8.28)	70.20%	(37.9%, 109%)	100.40%	(54.1%, 140.8%)	75.90%	(18.5%, 138%)
Nashville Warbler	NAWA	32.1	(28.35, 35.29)	45.80%	(8.2%, 77%)	71.50%	(17.8%, 103.6%)	20.10%	(-17.4%, 63.9%)
Northern Waterthrush	NOWA	23.78	(19.15, 25.99)	-9.80%	(-21%, 3%)	-18.20%	(-29.4%, -7.1%)	-29.90%	(-47.8%, -13.4%)
Olive-sided Flycatcher	OSFL	56.35	(50.23, 65.52)	-14.20%	(-24.6%, -6%)	-18.70%	(-30.4%, -8.5%)	-26.10%	(-40.3%, -9.7%)
Orange-crowned Warbler	OCWA	4.14	(2.96, 5.52)	-3.10%	(-9.6%, 6.1%)	-10.30%	(-26.6%, 3.7%)	-18.50%	(-39.3%, -1%)
Ovenbird	OVEN	27.87	(25.82, 30.36)	33.80%	(8.3%, 51.1%)	62.30%	(34.6%, 95.5%)	63.50%	(16.6%, 123.7%)
Palm Warbler	PAWA	23.22	(18.72, 28.06)	-35.80%	(-54%, -16.7%)	-51.90%	(-74.3%, -30.9%)	-70.70%	(-96.2%, -49.2%)
Philadelphia Vireo	PHVI	10.28	(8.97, 11.41)	22.90%	(-1.9%, 62.8%)	23.30%	(0.4%, 46.5%)	-10.70%	(-38.5%, 19.5%)
Pine Grosbeak	PIGR	7.96	(3.67, 13.7)	-8.20%	(-33.3%, 4.3%)	-17.10%	(-65%, 5.1%)	-31.00%	(-101.1%, 1.6%)
Pine Siskin	PISI	56.64	(50.07, 66.09)	9.30%	(-11.2%, 30.6%)	27.20%	(8.4%, 51.1%)	61.50%	(21.2%, 120.2%)
Purple Finch	PUFI	7.74	(5.51, 12.42)	25.60%	(10.3%, 43.9%)	54.90%	(31.7%, 78.9%)	101.40%	(65%, 136.2%)
Red-breasted Grosbeak	RBGR	3.25	(2.57, 4.22)	38.60%	(9.5%, 58.6%)	91.20%	(46.8%, 145.9%)	132.50%	(58.6%, 251.3%)
Red-breasted Nuthatch	RBNU	22.07	(21, 23.52)	31.50%	(19.6%, 45.4%)	56.20%	(43.9%, 78.8%)	74.50%	(50.8%, 105.8%)
Red-eyed Vireo	REVI	109.36	(103.74, 13.93)	-4.70%	(-12.3%, 2.4%)	-17.10%	(-31.8%, -5.6%)	-39.40%	(-59.1%, -28.3%)
Ruby-crowned Kinglet	RCKI	34.17	(31.97, 37.14)	49.70%	(24.8%, 77.7%)	95.70%	(73.1%, 122.4%)	109.20%	(60.6%, 152.7%)
Rusty Blackbird	RUBL	9.61	(5.44, 17.38)	-17.60%	(-57%, 1.1%)	-36.70%	(-120.8%, -5.9%)	-55.30%	(-149.7%, -17.9%)
Swainson's Thrush	SWTH	122.2	(114.51, 28.93)	4.70%	(0.5%, 9.7%)	1.50%	(-6.9%, 9.1%)	-11.50%	(-26.2%, -0.2%)
Tennessee Warbler	TEWA	112.07	(104.01, 19.12)	-8.30%	(-23.4%, 12.4%)	-24.60%	(-49.5%, 1.4%)	-55.20%	(-87.2%, -32.9%)
Varied Thrush	VATH	14.22	(11.44, 17.24)	0.70%	(-17.3%, 16%)	8.30%	(-5.7%, 24%)	19.20%	(-8.8%, 63.6%)
Western Tanager	WETA	7.73	(5.96, 9.76)	2.40%	(-13.6%, 18.8%)	5.60%	(-4.2%, 19.3%)	15.40%	(-1.4%, 34.6%)
Western Wood-pewee	WEWP	4.34	(3.29, 5.3)	5.30%	(-10.1%, 24.9%)	11.90%	(-2.8%, 32.8%)	25.90%	(-2.5%, 56.1%)
White-throated Sparrow	WTSP	67.55	(58.73, 76.12)	-3.50%	(-15.1%, 8.1%)	-13.80%	(-30%, 6.1%)	-29.50%	(-53.1%, -0.9%)
White-winged Crossbill	WWCR	15.4	(14.18, 17.87)	12.00%	(-9.4%, 33.9%)	12.30%	(-3%, 23.3%)	-19.50%	(-44%, 3.1%)
Wilson's Warbler	WIWA	82.52	(77.02, 87.53)	11.40%	(-0.8%, 22.3%)	11.60%	(-3.6%, 25.3%)	-6.80%	(-31.3%, 11.7%)
Winter Wren	WIWR	81.39	(68.09, 96.2)	-13.10%	(-24.4%, -2%)	-29.20%	(-46%, -13.9%)	-49.80%	(-71.3%, -34.1%)
Yellow-bellied Flycatcher	YBFL	22.31	(19.62, 24.99)	-4.70%	(-19.8%, 6.9%)	-9.80%	(-36.7%, 5.8%)	-32.40%	(-58.3%, -18%)
Yellow-rumped Warbler	YRWA	173.15	(157.02, 97.43)	-1.70%	(-19.7%, 9.1%)	-6.30%	(-23.2%, 4.6%)	-23.80%	(-43.7%, -9.2%)

Projected end-of-century changes in potential abundance of 53 boreal forest passerine species, as determined by climatic suitability within boreal and southern Arctic ecoregions. Means and confidence intervals are based on 11 data samples, two variable sets, and four climate models (Stralberg et al. 2015b).

Appendix B

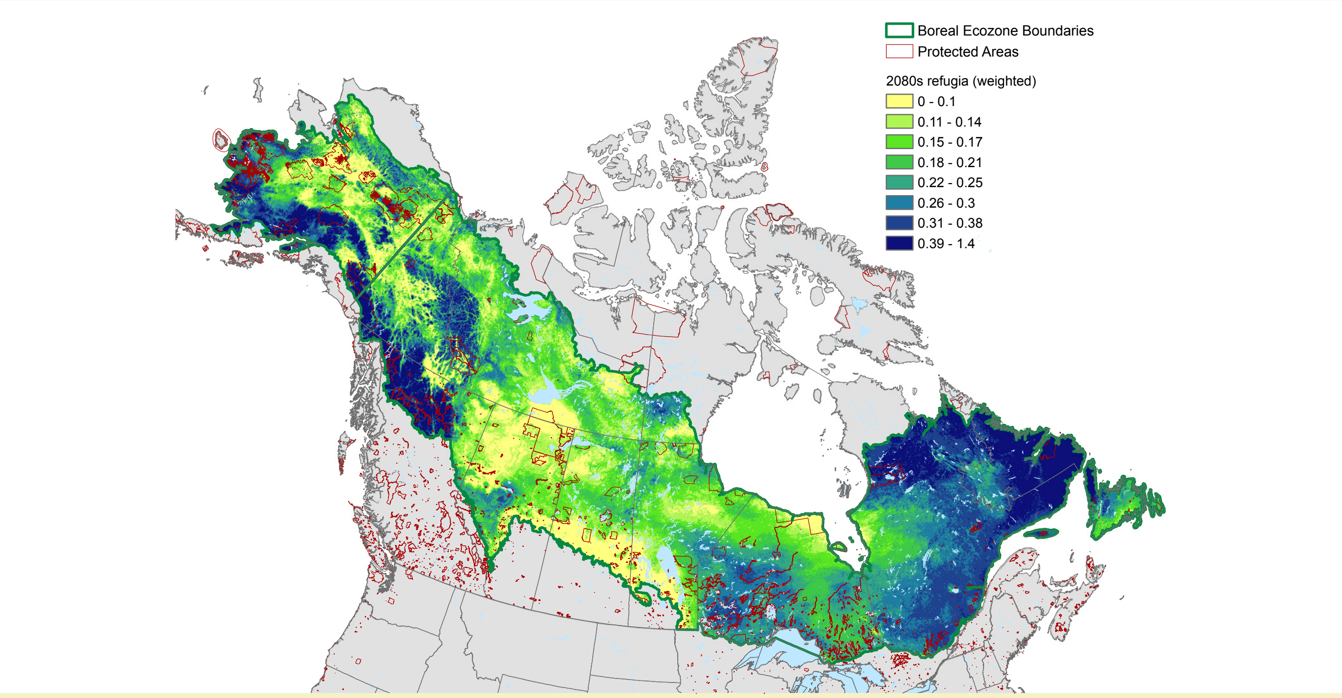
Multi-species climate corridors



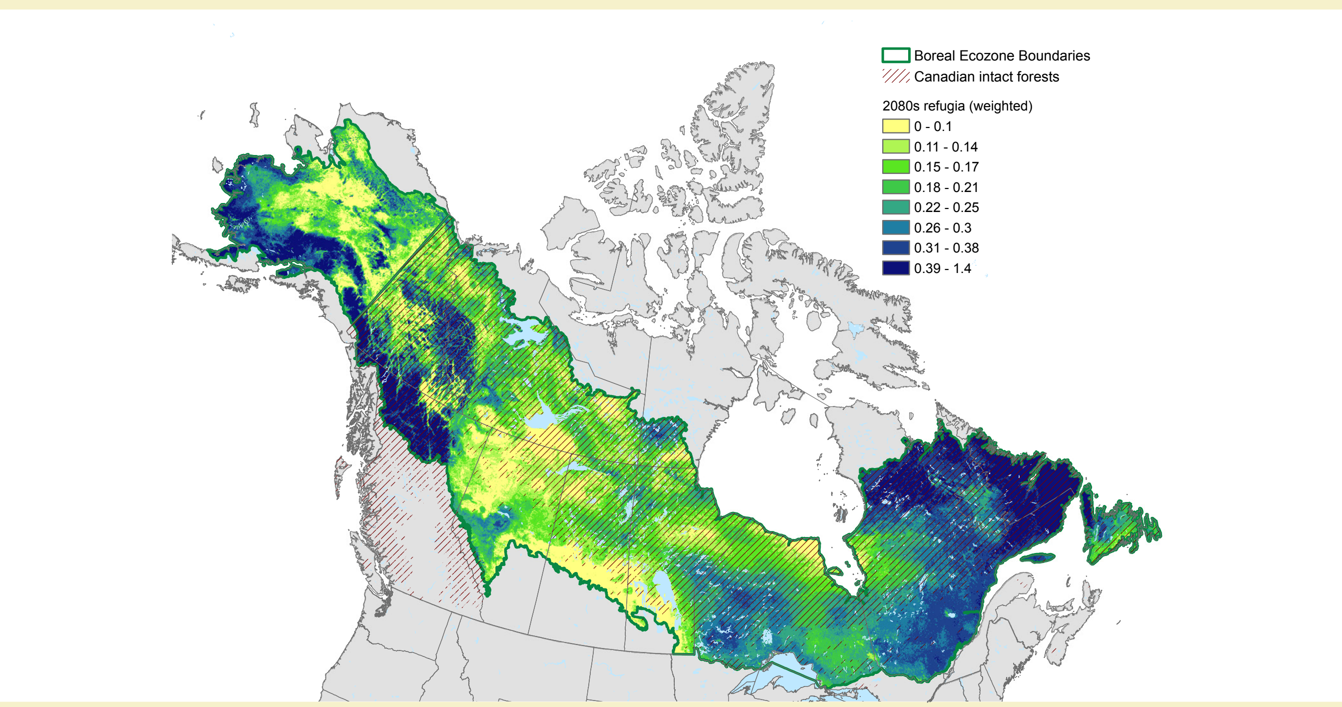
Projected shifts in high-density areas for 53 boreal songbird species over three future time periods. High-density areas are defined as the top 25% of combined predicted bird density for 53 forest-associated species based on abundance models from Stralberg et al. (2015b).

Appendix C

Boreal bird refugia overlaid with current protected areas and intact forest landscapes



Only protected areas that have received full and permanent protection and meet IUCN levels I-IV are included in this dataset. Interim protected areas, land-use plans that have yet to be finalized or approved, and other forms of protected areas were excluded. These types of protected areas would expand the proportion of refugia that is protected if they are finalized or approved as permanently protected places. Sources: CARTS (Conservation Areas Reporting and Tracking) and the office of the Quebec Minister of Sustainable Development, Environment and the Fight against Climate Change.



Intact forest landscapes (IFLs) are unbroken or undivided expanses of forest that are essentially absent of a human industrial footprint and are much better at retaining healthy levels of biodiversity than forests that have been fragmented or degraded. Roads, powerlines, industrial activity, and human structures cannot be present for a region to be deemed as an IFL, nor can areas that are absent of the human footprint but are smaller than 50,000 hectares. Source: Global Forest Watch Canada

Appendix D

Levels of protection and intactness of boreal bird refugia

Province/Territory - Ecozone Type	Total Area (km²)	Intact	Non-Intact	Protected	Unprotected
Alberta - Boreal Plains	2,608	64	2,544	48	2,560
Alberta - Total	2,608	64	2,544	48	2,560
British Columbia - Boreal Cordillera	148,480	144,336	4,144	37,920	110,560
British Columbia - Boreal Plains	2,256	1,360	896	144	2,112
British Columbia - Taiga Plains	16	0	16	0	16
British Columbia - Total	150,752	145,696	5,056	38,064	112,688
Manitoba - Boreal Shield	144	128	16	0	144
Manitoba - Hudson Plains	32	16	16	0	32
Manitoba - Taiga Shield	320	320	0	16	304
Manitoba - Total	496	464	32	16	480
Newfoundland and Labrador - Boreal Shield	60,112	51,056	9,056	3,216	56,896
Newfoundland and Labrador - Southern Arctic	304	304	0	0	304
Newfoundland and Labrador - Taiga Shield	167,824	164,512	3,312	7,664	160,160
Newfoundland and Labrador - Total	228,240	215,872	12,368	10,880	217,360
Northwest Territories - Boreal Cordillera	17,856	17,632	224	7,904	9,952
Northwest Territories - Southern Arctic	96	96	0	0	96
Northwest Territories - Taiga Cordillera	42,160	42,064	96	1,792	40,368
Northwest Territories - Taiga Plains	8,800	6,224	2,576	320	8,480
Northwest Territories - Taiga Shield	1,040	992	48	0	1,040
Northwest Territories - Total	69,952	67,008	2,944	10,016	59,936
Nunavut - Southern Arctic	192	192	0	0	192
Nunavut - Taiga Shield	8,240	8,224	16	0	8,240
Nunavut - Total	8,432	8,416	16	0	8,432
Ontario - Boreal Shield	50,736	30,112	20,624	2,496	48,240
Ontario - Great Lakes	128	0	128	64	64
Ontario - Hudson Plains	640	608	32	0	640
Ontario - Total	51,504	30,720	20,784	2,560	48,944
Quebec - Boreal Shield	380,992	175,440	205,552	6,416	374,576
Quebec - Southern Arctic	70,624	70,592	32	1,168	69,456
Quebec - Taiga Shield	239,120	233,520	5,600	23,184	215,936
Quebec - Total	690,736	479,552	211,184	30,768	659,968
Saskatchewan - Boreal Shield	352	352	0	0	352
Saskatchewan - Taiga Shield	384	384	0	0	384
Saskatchewan - Total	736	736	0	0	736
Yukon Territory - Boreal Cordillera	80,112	77,856	2,256	9,200	70,912
Yukon Territory - Boreal Plains	96	96	0	0	96
Yukon Territory - Taiga Cordillera	21,168	21,040	128	976	20,192
Yukon Territory - Total	101,376	98,992	2,384	10,176	91,200

Area (km2) of multi-species end-of-century refugia (top quartile) that are still part of an intact forest landscape and area currently protected (permanent protection only, IUCN levels I-IV) within Canada.

Appendix E

Levels of protection and intactness for boreal bird climate corridors

Province/Territory - Time Period	Total area (km^2)	Intact	Non-intact	Protected	Unprotected
Alberta - Current	182,784	29,856	152,928	9,040	173,744
Alberta - 2020s	227,280	47,952	179,328	14,992	212,288
Alberta - 2050s	176,400	35,536	140,864	8,848	167,552
Alberta - 2080s	72,112	26,016	46,096	10,592	61,520
Alberta - Average	164,644	34,840	129,804	10,868	153,776
British Columbia - Current	9,440	1,216	8,224	144	9,296
British Columbia - 2020s	32,256	4,912	27,344	384	31,872
British Columbia - 2050s	49,760	5,104	44,656	864	48,896
British Columbia - 2080s	23,728	3,120	20,608	576	23,152
British Columbia - Average	28,796	3,588	25,208	492	28,304
Manitoba - Current	208,112	101,040	107,072	20,064	188,048
Manitoba - 2020s	136,352	136,352	0	19,888	217,888
Manitoba - 2050s	270,448	204,848	65,600	17,056	253,392
Manitoba - 2080s	244,384	223,520	20,864	1,408	242,976
Manitoba - Average	214,824	166,440	48,384	14,604	225,576
Newfoundland and Labrador - Current	78,480	43,664	34,816	2,480	76,000
Newfoundland and Labrador - 2020s	2,912	1,072	1,840	0	2,912
Newfoundland and Labrador - 2050s	12,272	9,712	2,560	1,104	11,168
Newfoundland and Labrador - 2080s	44,608	40,064	4,544	96	44,512
Newfoundland and Labrador - Average	34,568	23,628	10,940	920	33,648
Northwest Territories - Current	2,496	1,424	1,072	16	2,480
Northwest Territories - 2020s	10,064	4,656	5,408	160	9,904
Northwest Territories - 2050s	15,552	8,240	7,312	2,432	13,120
Northwest Territories - 2080s	59,040	48,768	10,272	6,048	52,992
Northwest Territories - Average	21,788	15,772	6,016	2,164	19,624
Nunavut - Current	16	16	0	0	16
Nunavut - 2020s	64	32	32	0	64
Nunavut - 2050s	224	176	48	64	160
Nunavut - 2080s	1,680	1,472	208	864	816
Nunavut - Average	496	424	72	232	264
Ontario - Current	569,632	313,104	256,528	54,656	514,976
Ontario - 2020s	587,456	372,800	214,656	51,232	536,224
Ontario - 2050s	457,792	406,992	50,800	35,936	421,856
Ontario - 2080s	158,320	157,872	448	16,288	142,032
Ontario - Average	443,300	312,692	130,608	39,528	403,772
Quebec - Current	377,184	71,456	305,728	6,736	370,448
Quebec - 2020s	279,072	63,056	216,016	2,960	276,112
Quebec - 2050s	113,504	79,616	33,888	112	113,392
Quebec - 2080s	284,816	247,168	37,648	1,392	283,424
Quebec - Average	263,644	115,324	148,320	2,800	260,844
Saskatchewan - Current	155,808	71,504	84,304	13,376	142,432
Saskatchewan - 2020s	200,800	121,808	78,992	16,944	183,856
Saskatchewan - 2050s	243,568	203,040	40,528	18,048	225,520
Saskatchewan - 2080s	197,536	183,936	13,600	8,304	189,232
Saskatchewan - Average	199,428	145,072	54,356	14,168	185,260
Yukon Territory - Current	48	32	16	16	32
Yukon Territory - 2020s	208	64	144	0	208
Yukon Territory - 2050s	1,664	1,504	160	16	1,648
Yukon Territory - 2080s	31,744	29,232	2,512	2,048	29,696
Yukon Territory - Average	8,416	7,708	708	520	7,896

Area (km2) of projected high-density areas (top quartile) that are still part of an intact forest landscape and area currently protected (permanent protection only, IUCN levels I-IV) within Canada.

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