Understanding and Responding to the Effects of Climate Change on Alberta's Biodiversity

ABMI

BMCCA Biodiversity Management & Climate Change Adaptation

CCEMC Climate Change & Emissions Management Corporation

This report describes the Alberta Biodiversity Monitoring Institute's 3-year Biodiversity Management and Climate Change Adaptation project

Thank you to the BMCCA project team for contributing technical and editorial insight and figures.

Preferred Citation:

Nixon, A., C. Shank, and D. Farr. 2015. Understanding and Responding to the Effects of Climate Change on Alberta's Biodiversity. Alberta Biodiversity Monitoring Institute, Edmonton, Alberta, Canada. Available at: www.biodiversityandclimate.abmi.ca.

Core funding for this project was provided by the Climate Change and Emissions Management Corporation.

Collaborators and other funders:

Several individual projects were jointly funded with the following organizations. Full acknowledgements can be found in individual reports: Government of Canada (Canadian Wildlife Service/Environment Canada, Interdepartmental Recovery Fund, National Sciences and Engineering Research Council of Canada, Agriculture and Agri-food Canada, Department of Defense CFB Suffield), Cenovus, Nexen, Altalink, Suncor, IHS, Petroleum Technology Alliance of Canada, Alberta Environment and Sustainable Resource Development, Alberta Sport, Recreation, Parks and Wildlife Foundation, Saskatchewan Ministry of the Environment, the Foundation for Orchid Research and Conservation, the Alberta Livestock and Meat Agency, and Alberta Innovates Bio-Solutions.

CONTENTS

About the ABMI 4
About the CCEMC 5
Executive Summary 6
Introduction 8
About the Project 9
Climate Change in Alberta 10

Projected Impacts on Alberta's Species and Ecosystems 12
- *Global Climate Models* 13
- *Alberta's Ecosystems* 14
- *Species Distributions* 16
- *Grassland Plant Responses to Climate Change and Grazing* 23
- *Climate Change Vulnerability Assessments* 24
- *Effects of Extreme Weather on Prairie Raptors* 27
- *Invasive Plants* 30

Climate Change Adaptation in Biodiversity Management 32
- *Biodiversity Management and Conservation Planning* 33
- *Species Adaptation Plans* 34
- *Assisted Migration* 37
- *Parks and Protected Areas* 40
- *Adaptations for Ecosystem Services on Alberta's Rangeland* 45
- *Monitoring* 46

Resilience-based Adaptation for Communities 47
- *Climate Change and Southern Alberta Communities* 48
- *Ecosystem-based Adaptation* 49
- *Climate Change and Municipal Planning* 50
- *Adapt-action – a Tool for Communities* 51

Understanding and Addressing Uncertainty 52
Conclusions 54
Building on the Project 57
The Project Team 59
Project Reports and Publications 60
General Terms 63

ABOUT THE ABMI

The Alberta Biodiversity Monitoring Institute (ABMI) is an arm's-length, not-for-profit scientific organization. The business of the ABMI is to monitor and report on the status (current condition) and trends of Alberta's species, habitat, and human footprint. The goal of the ABMI is to provide relevant scientific information on the state of Alberta's biodiversity to support natural resource and land-use decision making in the province.

In the course of monitoring terrestrial and wetland ecosystems across the province over the past twelve years, the ABMI has assembled an extensive biodiversity and human footprint database, developed reliable measurement protocols, and found innovative ways to summarize complex ecological information.

To demonstrate the value and use of the ABMI dataset to address current land and resource management issues, the ABMI recently began undertaking research and development collaborations with partner organizations and researchers. The Biodiversity Management and Climate Change Adaptation (BMCCA) project presented in this report is one such collaborative effort.

Through applications of ABMI capacity (data and knowledge) to specific management challenges, the ABMI has added value to the ABMI's core business of biodiversity monitoring. Notwithstanding, the Institute is not a management agency and does not make management recommendations. In all instances, the ABMI continues to generate value-neutral, independent and publicly accessible data and products. And, all ABMI activities are guided by a core set of principles – we are independent, objective, credible, accessible, transparent, and relevant.

For more on the ABMI, visit www.abmi.ca.

ABOUT THE CCEMC

The Climate Change and Emissions Management (CCEMC) Corporation is an Alberta-based not-for-profit organization with a mandate to establish or participate in funding for initiatives that reduce greenhouse gas emissions or improve Alberta's ability to adapt to climate change.

Adaptation is a critical component of the CCEMC's work.

The CCEMC understands that climate change impacts will result in changes to ecological capacity, productivity and other natural attributes of Alberta's landscape and that economic and social adaptation is required.

The CCEMC works in partnership with the province of Alberta to inform public policy, enhance knowledge and awareness, and build capacity and resilience.

CCEMC ADAPTATION PROGRAM

The CCEMC adaptation program was launched in 2012, funding three initiatives that have produced a wealth of knowledge.

The ABMI Biodiversity Management and Climate Change Adaptation project helps us to understand how climate change will impact Alberta species and ecosystems and the actions we can take to address vulnerabilities.

The Tree Improvement Alberta consortium assesses Alberta forests for adaption with a focus on commercially important tree species that help maintain forest ecosystems. The Tree Species Adaptation Risk Management project replicates climate variation through planting species in new regions of the province (for example, northern species in southern Alberta).

The stakeholder-led Integrated Watershed Management Project for the South Saskatchewan River Basin builds understanding about how to address climate variability throughout the SSRB's river systems. The group developed a comprehensive river system model for the Oldman and South Saskatchewan River Basins and identified opportunities for improvements to water storage, infrastructure and the timing of withdrawls, releases and flows.

To learn more about the CCEMC and its adaptation program see ccemc.ca.

The CCEMC is the core funder of the ABMI Biodiversity Management and Climate Change Adaptation project. The ABMI and its project collaborators are responsible for the design of the project and its delivery, including the language and content of this report.

EXECUTIVE SUMMARY

The Biodiversity Management and Climate Change Adaptation (BMCCA) project, led by the Alberta Biodiversity Monitoring Institute, was initiated in 2012 with the goal of developing essential knowledge and tools to support the effective management of Alberta's biodiversity as climate change impacts the province's species, ecosystems, and human communities.

The project focused on developing predictions of the impacts of climate change on Alberta's biodiversity, reviewing the actions and strategies required to effectively manage biodiversity in a changing climate, developing and evaluating tools and targeted actions to support species management under climate change, and connecting the impacts of climate change on biodiversity to the well-being of Albertans to support climate change adaptation in our communities.

In doing so, the BMCCA project has produced a comprehensive, evidence-based, and original examination of the effects of climate change on Alberta's biodiversity, developed innovative responses to these challenges, and helped frame the discussion around climate change adaptation for biodiversity management in the province.

This report provides a guide to the BMCCA project, summarizing the individual projects, highlighting key outcomes, research advances, and new tools, resources and approaches, and serving as a bridge to more detailed results and outcomes.

INTRODUCTION

Biodiversity is the variety of species and ecosystems on Earth and the ecological processes of which they are a part.[2] This natural diversity is important to the well-being of Albertans because it supports a variety of tangible benefits for our communities, such as clean drinking water and protection from floods, and it is the basis on which our natural resource economies, including agriculture and forestry, are built. In addition, Alberta's biodiversity represents our shared natural heritage; many Albertans identify with aspects of biodiversity - specific plants, animals or natural environments - that represent cultural values.

Climate change is now occurring at a pace faster than at any other time in our experience.[3,4] Alberta's biodiversity has and will continue to respond to changes in climate, including through species' adaptations to new conditions and shifts in their distributions. There will also be consequences for human communities and the livelihoods of individual Albertans through changes to agriculture, forestry, recreation, flood-control and other services provided by native ecosystems.

The potential implications of climate change for biodiversity and human communities are far-reaching. Because even the most effective reductions in global greenhouse gas emissions will not prevent climate change, there is widespread recognition that planning for these changes is critical.[5,6] Climate change adaptation involves anticipating the consequences, both positive and negative, of climate change and responding to reduce identified risks and capitalize on any opportunities.[7]

Understanding and anticipating the potential impacts of climate change on Alberta's biodiversity is necessary to ensure that today's decisions about land use, natural resource management and conservation are relevant and effective over the long term, and to initiate the necessary shifts in policy and practice that will be required to support decision making in the future.

---

[2] *Environment Canada. 1995. Canadian Biodiversity Strategy: Canada's Response to the Convention on Biological Diversity. Hull, Quebec, 86 pp.*

[3] *Government of Alberta. 2008. Alberta's 2008 Climate Change Strategy. Available at: http://esrd.alberta.ca/focus/alberta-and-climate-change/climate-change-strategy/documents/AlbertaClimateChangeStrategy-2008.pdf*

[4] *IPCC. 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, NY, pp. 1-30.*

[5] *Warren, F.J. and D.S. Lemmen, editors. 2014. Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation. Government of Canada, Ottawa, ON, 286 pp.*

[6] *IPCC. 2014. Summary for Policymakers. In: Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, NY, pp. 1-32.*

[7] *Ibid.*

ABOUT THE PROJECT

Through its work monitoring terrestrial and wetland ecosystems across the province over the last twelve years, the Alberta Biodiversity Monitoring Institute (ABMI) has developed an active and collaborative research program that demonstrates the value of the Institute's extensive biodiversity database and applies its research capacity to specific environmental planning and management challenges.

In 2012, the Alberta Biodiversity Monitoring Institute, with collaborators from the University of Alberta, the Miistakis Institute, the University of Saskatchewan, and Alberta Innovates Technology Futures, initiated the three-year Biodiversity Management and Climate Change Adaptation (BMCCA) project. The goal of the project was to develop essential knowledge and tools to support the effective management of Alberta's biodiversity as climate change impacts our species and ecosystems are realized.

From its outset, the project recognized the need for:

- *a better understanding of the predicted impacts of climate change on Alberta's species and ecosystems,*
- *the development and analysis of tools and targeted actions to support climate change adaptation in biodiversity management,*
- *informed discussion on the actions required to effectively manage biodiversity in a changing climate, and*
- *an improved understanding of the connection between the impacts of climate change on biodiversity and the well-being of Albertans to support climate change adaptation in our communities.*

The BMCCA project has addressed these knowledge gaps through review of relevant scientific literature, analysis of existing data, field experiments and observations, and the development of online resources. The project has produced a broad, evidence-based, and original examination of the effects of climate change on Alberta's biodiversity, developed innovative responses to these challenges, and helped frame the discussion around climate change adaptation for biodiversity management in the province.

This report is a guide to the BMCCA project. It highlights key outcomes, research advances, and new tools, resources and approaches, and serves as a bridge to more detailed results and outcomes.

CLIMATE CHANGE IN ALBERTA

Alberta's climate is changing; recent climate trends and future climate projections[8] have been summarized for the province by Richard Schneider (2013). Over the last 100 years, the provincial mean annual temperature has increased by 1.4°C, with much of that increase occurring since the 1970s from increases in winter and spring temperatures.

These observed trends are projected to continue over the course of at least the next hundred years, even if greenhouse gas emissions stabilize (which is unlikely). By the end of this century, Alberta's mean annual temperature is predicted to increase by at least 2°C from the 1961-1990 average. Depending on the global climate model and greenhouse gas emissions scenario used to forecast future climate conditions, this increase could be as high as 4-6 °C (Fig. 1).

In addition to continued warming, most climate models also project an overall increase in provincial annual precipitation, by about 10% on average. Warming temperatures will result in increasing evapotranspiration, which will lead to an overall decline in available moisture, especially in mid-summer, despite the small projected increase in precipitation. Alongside changes in average conditions, extreme weather events, like heavy rainfalls or very dry years, are likely to become more frequent as well.[9]

8 Hamann, A. et al. 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. Bulletin of the American Meteorological Society 94: 1307–1309.

9 e.g., Karl, T. R., G. Meehl, C.D. Miller, S.J. Hassol, A.M. Wapole, and W.L. Murray (eds). 2008. Weather and climate extremes in a changing climate: Regions of focus: North America, Hawaii, Caribbean, and US Pacific Islands. Synthesis and Assessment Product 3.3, Report by the US Climate Change Science Program and the Subcommittee on Global Change Research.

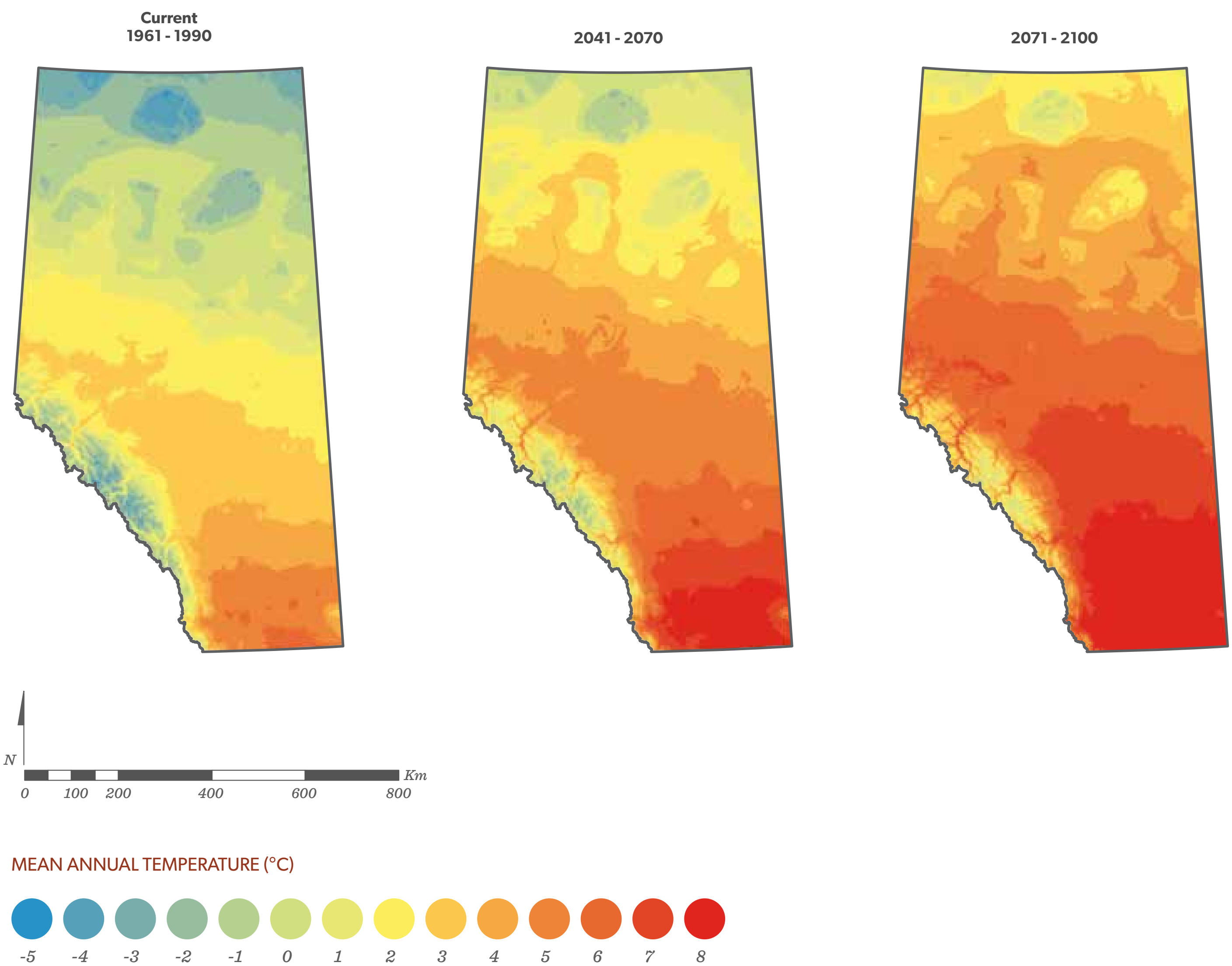


FIGURE 1.

Current and projected future mean annual temperatures in Alberta, indicating an average temperature increase of 4°C by the end of the century. These projections are based on an ensemble, or average, of 19 global climate models, and assume that atmospheric greenhouse gas concentrations will continue to increase (A2 emissions scenario).

PROJECTED IMPACTS ON ALBERTA'S SPECIES AND ECOSYSTEMS

Developing adaptive solutions to the challenges posed to Alberta's biodiversity by a changing climate first requires understanding how climate change might affect species and ecosystem distributions and abundances. The BMCCA project used three main approaches to assess these potential impacts:

- *ecological niche models (see below) to develop spatial predictions of the potential distributions of species and ecosystems under changed future conditions,*
- *species assessments using NatureServe's Climate Change Vulnerability Index (CCVI)[10] to determine the relative climate change vulnerability of Alberta's species, and*
- *field research on the effects of weather on mortality and reproduction of selected species.*

These three different approaches produced mutually insightful results. Ecological niche models predict where a species or ecosystem could potentially exist in the future, but by themselves do not address whether species are actually capable of dispersing into and thriving in new, climatically suitable areas. By contrast, relative vulnerability assessments identify a species' vulnerability within its current range and provide insights into the traits that are most important in determining vulnerability, but do not incorporate potential shifts in range. The combination of these two approaches to evaluate the potential impacts of climate change on species can provide insight that is both ecologically and spatially relevant. Field research provides empirical evidence as to how species react to current weather, allowing enhanced predictions of the population effects of future climate and identification of potential management responses.

ECOLOGICAL NICHE MODELS

Ecological niche modeling is the process of predicting the distribution of species or ecosystems based on correlations between environmental conditions (e.g., climatic variables, soil characteristics, etc.) and species or ecosystem occurrence. This technique is also known as species distribution modeling, or bioclimatic envelope modeling. Models that are developed to describe the current distribution or abundance of species or ecosystems are combined with projections of future climate to project future distributions, and sometimes abundance, under changed climatic conditions.

Scientists make a variety of assumptions when they use ecological niche models to project future species or ecosystem distributions, including assumptions about what aspects of climate are important to the distribution, the quality and quantity of the data used to develop the models (page 22), the current and future availability of suitable habitat, and the ability of species to disperse in response to changed conditions, among others.

[10] *For more information: http://www.natureserve.org/conservation-tools/climate-change-vulnerability-index*

GLOBAL CLIMATE MODELS

A complementary suite of global climate models represents the range of potential future climate conditions in Alberta.

Many BMCCA projects employed global climate models (GCMs) to predict future climatic conditions in Alberta. Global climate models have been developed by internationally renowned research centres across the globe to provide projections of global climate under a suite of greenhouse gas emissions scenarios. These scenarios, based on assumptions about future global economic, technological, and social development, represent future atmospheric greenhouse gas concentrations.[11]

The predictions from these models are variable and there is no consensus on which models are best for particular research questions or regions of interest. Selecting among the various GCMs and emissions scenarios to represent future conditions in Alberta is a complex task. Diana Stralberg (2012) identified a set of five GCMs from the World Climate Research Project (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3)[12] as a complementary suite of models to represent the range of potential future climate outcomes for Alberta, including both wetter and drier climate scenarios (Table 1).

The BMCCA project typically relied on either ensemble data (generated by averaging across a suite of GCMs for a single greenhouse gas scenario), or comparisons among projections from two or more of the identified GCMs and greenhouse gas emissions scenarios to represent the uncertainty associated with projected future conditions. The A2 greenhouse gas emissions scenario, which is characterized by regionally oriented economic development and a continuously increasing population and consequently projects continuously increasing atmospheric greenhouse gas concentrations,[13] was the most commonly used scenario.

TABLE 1.

A complementary suite of global climate models that represent a range of potential end-of-century climate outcomes for Alberta (Stralberg 2012).

Global Climate Model	Future Projection
ECHAM5/MPI-OM, Germany	*Most representative of all models for the Alberta region*
INM-CM3.0, Russia	*Wetter*
CGCM3.1(T47), Canada	*Wetter, less seasonal*
GFDL-CM2.1, USA	*Drier*
UKMO-HadGEM1, UK	*Drier, much warmer*

[11] *IPCC. 2000. Summary for policy makers. In: Special Report on Emissions Scenarios for the Intergovernmental Panel on Climate Change. 27 pp. Available at: https://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf*

[12] *Meehl, G.A. et al. 2007. The WCRP CMIP3 multimodel dataset: A new era in climate change research. Bulletin of the American Meteorological Society 88:1383-1394.*

[13] *See 11.*

ALBERTA'S ECOSYSTEMS

Projections of the future distributions of Alberta's major ecosystems indicate changes in their size and distribution under different climate change scenarios, in particular an expansion of grasslands and a decline in the area of the boreal forest.

The diversity of Alberta's ecosystems can be represented by the provincial system of Natural Regions and Subregions (Fig. 2).[14] These 21 Natural Subregions, nested within six Natural Regions, represent unique combinations of landforms, soils, climate, and vegetation. However, the nature and boundaries of these regions are expected to change as the distribution of vegetation shifts in response to changing climate. Understanding how Alberta's ecosystems will be distributed in the future provides the basic foundation for natural resource planning, including for agriculture, forestry and biodiversity conservation.

Richard Schneider (2013) developed bioclimatic envelope models (page 12) to describe the current distribution of Alberta's Natural Subregions, and applied these models to climate projections for the 2020s (2011-2040), 2050s (2041-2070), and 2080s (2071-2100), evaluating five potential future climate scenarios: Cool, Median, Hot, Dry and Wet.[15]

The most dramatic change projected was the expansion of Alberta's grasslands at the expense of other ecosystems (Fig. 2).[16] Under the Cool Model, the Grassland Natural Region was predicted to expand northward into the Parkland and the Parkland, in turn, replaced the Dry Mixedwood and Central Mixedwood. Under the Hot model, the predicted expansion of grasslands was more rapid until, by the end of the century, that ecosystem covered almost the entire province; the boreal forest was projected to disappear completely except for a remnant at higher elevations in the Caribou Mountains.[17]

Uncertainties remain in the types and rates of ecological transitions that will occur in response to these projected shifts in the climate envelopes of Alberta's Natural Subregions. Richard Schneider and colleagues (submitted) predict substantial lags between changes in climate and subsequent ecosystem transitions, especially in the transition from mixedwood boreal forest to aspen forest, and then to parkland and grassland ecosystems. Further, they predict these transitions are unlikely to occur gradually or steadily and that ecosystem components will respond to climate change at different rates. For example, in upland forests, natural disturbances like fire will be important for initiating ecosystem changes, including the transition of mixedwood boreal forest to parkland or grassland ecosystems. But, Schneider and colleagues argue that the resilience of peatlands to climate change and natural disturbance, and their likely persistence on the landscape through to the end of the century, will play an important role in mitigating future forest loss, especially of aspen. So, the future northern Alberta landscape may be comprised of a mosaic of peatlands and upland aspen forest, a novel ecosystem that is not represented in Alberta today.

---

[14] Natural Regions Committee. 2006. Natural Regions and Subregions of Alberta. Government of Alberta, Edmonton, AB, 264 pp. Available at: www.albertaparks.ca/media/2942026/nrsrcomplete_may_06.pdf

[15] These five future scenarios represent different combinations of global climate models and greenhouse gas emissions scenarios. Refer to Schneider (2013) for detailed descriptions.

[16] Additional maps of projected future ecosystem distribution can be found at: www.biodiversityandclimate.abmi.ca/resources/map-galleries

[17] Learn more about this research by watching a presentation by Dr. Richard Schneider at: www.biodiversityandclimate.abmi.ca/videos

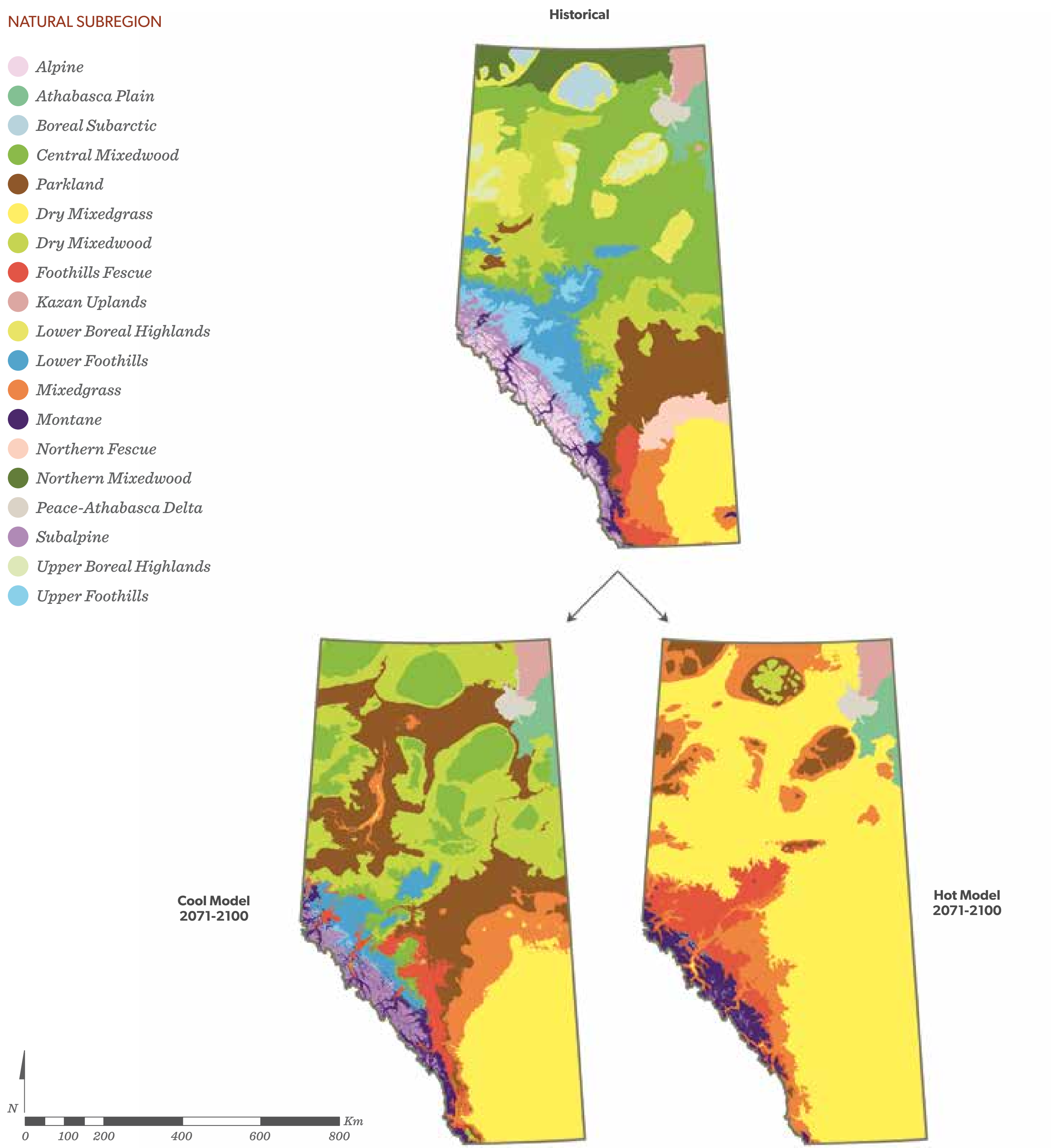


FIGURE 2.

Two end-of-century projections of the distribution of Alberta's Natural Subregions based on different global climate models and greenhouse gas emissions scenarios. Regardless of the global climate model and emissions scenario used, an expansion of southern ecosystems (parkland and grassland) and a decline of boreal ecosystems is projected (Schneider 2013).

SPECIES DISTRIBUTIONS

The BMCCA project made extensive use of species distribution modeling (page 12) to project the future ranges of species, particularly boreal birds and vascular plants, under climate change scenarios. Understanding where species are likely to occur in the future is critical to long-term biodiversity management, including the management of species at risk and conservation planning.

Alberta Birds

North American birds have been the subject of intensive studies, and researchers have generated a rich dataset of many thousands of geographically referenced observations for North America. For example, the Boreal Avian Modelling project has compiled an extensive data set for the North American boreal region.[18] The BMCCA project took advantage of this valuable information in several studies of how climate change is likely to impact the distributions of Alberta's birds.

> ***By the end of the century, most of Alberta's boreal songbirds are projected to decline in potential abundance in response to climate change and their distributions are projected to shift northward and upslope. Grassland songbirds will have the potential to expand their ranges in Alberta as suitable climate becomes more available.***

The boreal forest is the Alberta ecosystem projected to suffer the greatest losses in area from climate change (page 14). Similarly, projections of boreal-breeding songbird abundance by Diana Stralberg and Erin Bayne (2013) indicated declines for 42 boreal-breeding songbird species in Alberta by 2040, 48 species by 2070, and 50 species (60% of the species examined) by 2100. The distributions of most species were projected to shift northward and upslope.

Many species were projected to first increase as suitable climate space expands, and then decrease in Alberta by the end of the century, as the suitable climate space shifts northwards and into the Northwest Territories.[19]

Coniferous boreal forest species such as Bay-breasted and Tennessee Warblers were projected to shift almost entirely out of the province, while deciduous forest-associated species such as Ovenbird and Canada Warbler were generally projected to contract their distributions in the central part of the province and move upslope into the highland regions (Fig. 3).

There is greater uncertainty in the projections for deciduous forest-associated species because the response of these species to and the persistence of their preferred habitat in future climate scenarios are sensitive to variation among GCM projections for moisture in the boreal region. Deciduous forests have the potential to rapidly convert to grassland if soil moisture is sufficiently reduced.

Mountain species such as Varied Thrush and Townsend's Warbler were generally projected to move upslope, experiencing a range contraction, while grassland-associated species like Savannah Sparrow and Clay-colored Sparrow are expected to expand into the current boreal region.

The implications of these range shift projections to conservation planning are further explored on page 41.

---

[18] *The Boreal Avian Modelling Project: http://www.borealbirds.ca/*

[19] *Maps of boreal-wide songbird abundance projections are available at: www.biodiversityandclimate.abmi.ca/resources/map-galleries*

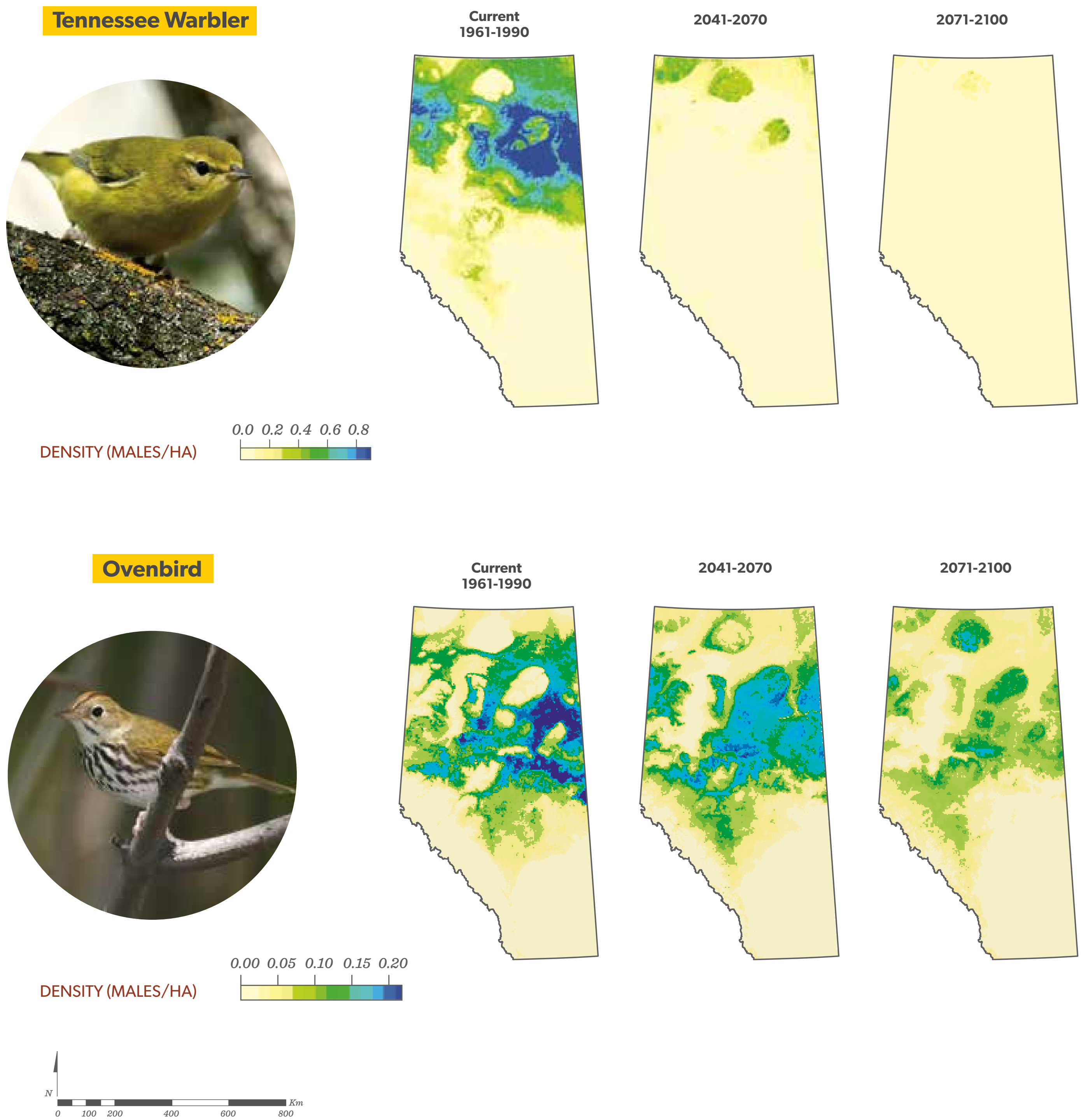


FIGURE 3.

Current and projected future provincial distribution and density (males/ha) of two boreal songbirds: the Tennessee Warbler and Ovenbird. These projections are the average result of projections from four global climate models using the A2 emissions scenario (Stralberg and Bayne 2013).

Models of 15 grassland songbirds across their continental ranges developed by Amy Nixon and colleagues (2015) confirmed that there is the potential for a majority of these species to expand their ranges in Alberta. The northern edge of suitable climate for grassland birds in Alberta was generally projected to shift northward while, in most cases, the southern limit was projected to remain more or less intact, extending south into the United States (e.g., Western Meadowlark, Fig. 4). However, this pattern was not consistent among all the species modeled. For example, Sprague's Pipit was projected to lose 87% of its Alberta range as a result of a lack of suitable grassland habitat becoming available in the north, coupled with northward movement of its southern range edge.

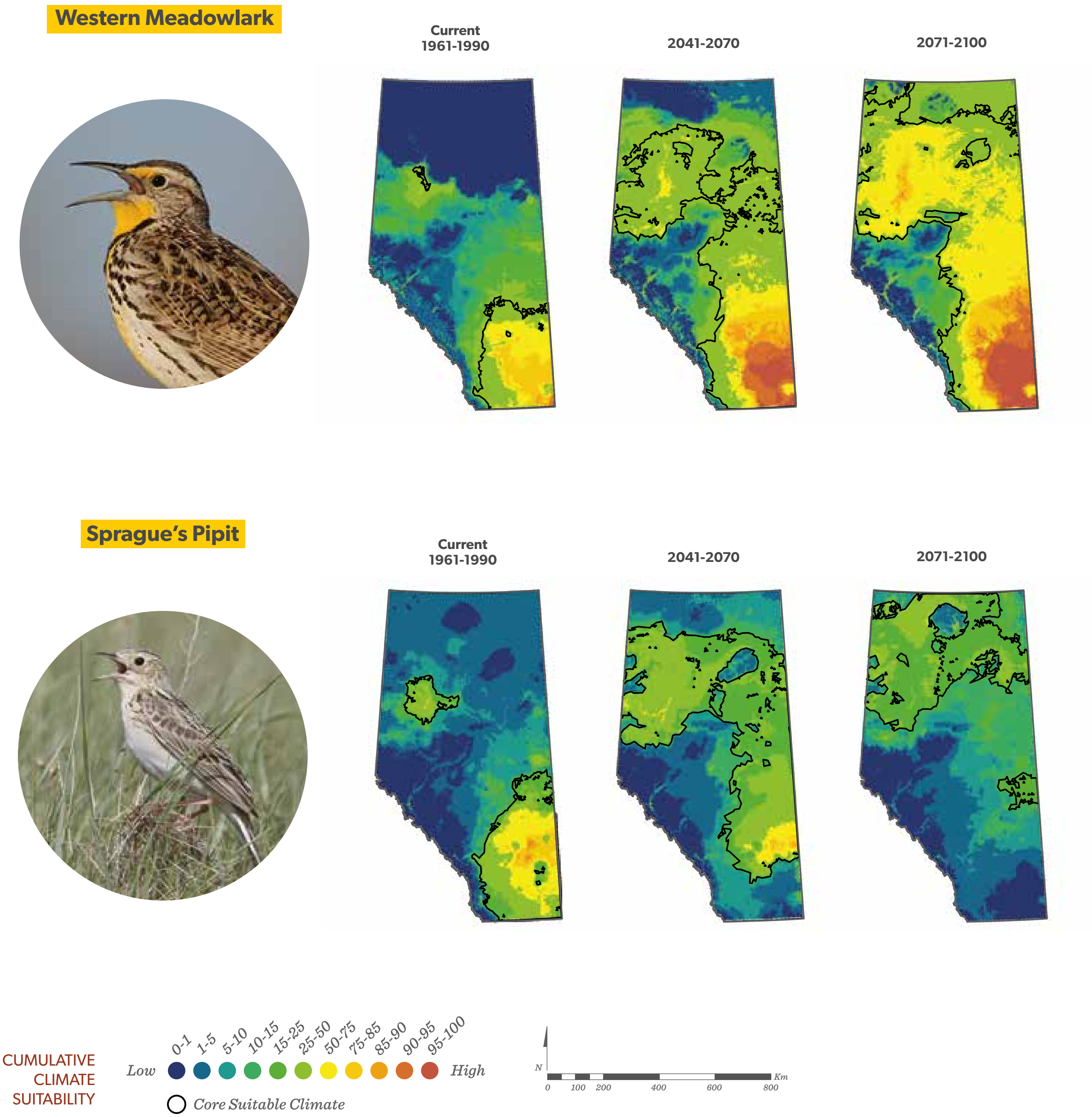


FIGURE 4.

Current and projected future suitable habitat for the Western Meadowlark and Sprague's Pipit in Alberta. These projections are based on an ensemble of 19 global climate models and the A2 emissions scenario (Nixon et al. 2015).

Plant Species Diversity

As for birds, there is a wealth of geographically-referenced observations of Alberta plants that can be used to understand future distributions of these species under a changing climate.

> ***Future projections of the ranges of over 1500 Alberta plants indicate changes in provincial plant diversity, including increases in the number of species present and their genetic diversity for many areas, but decreases in the Rocky Mountains.***

As individual species shift their distributions in response to changing climatic conditions, there will be consequences for different aspects of biodiversity, not just species diversity, but also phylogenetic diversity, or the degree of evolutionary relatedness among those species.

Understanding the potential changes in these measures of diversity in response to climate change provides a more complete picture of the impacts of climate change on biodiversity in the province. If related groups of species are affected by climate change in a similar way, there could be a disproportionate loss in phylogenetic diversity representing a greater overall loss in the evolutionary history of Alberta's plant species.

Identifying potential changes in these patterns can inform land use planning and conservation priorities by highlighting differential threats within the province. For example, it might be beneficial to identify areas of high species richness and high phylogenetic diversity in current and future time periods to prioritize conservation actions.

Jian Zhang and colleagues (in review) developed ecological niche models for 1541 Alberta plant species, almost 90% of the species found in the province. Of these, nearly one quarter were projected to lose >80% of their current provincial distribution of suitable habitat, while a third were projected to more than double their suitable habitat. [20] For nearly half of the species examined, suitable climate space was projected to shift northward by at least 10 km/decade.

As a result of these projected shifts in species' distributions, both plant species richness and phylogenetic diversity were expected to increase for most regions by the end of the century (Fig. 5). In the Rocky Mountains, which have the highest phylogenetic diversity of plant species in the province today, overall declines in diversity were projected.[21]

---

[20] *Maps for many species are available in the rare plant map gallery at: www.biodiversityandclimate.abmi.ca/resources/map-galleries*

[21] *Learn more about this research by watching a presentation by Dr. Scott Nielsen at: www.biodiversityandclimate.abmi.ca/videos*

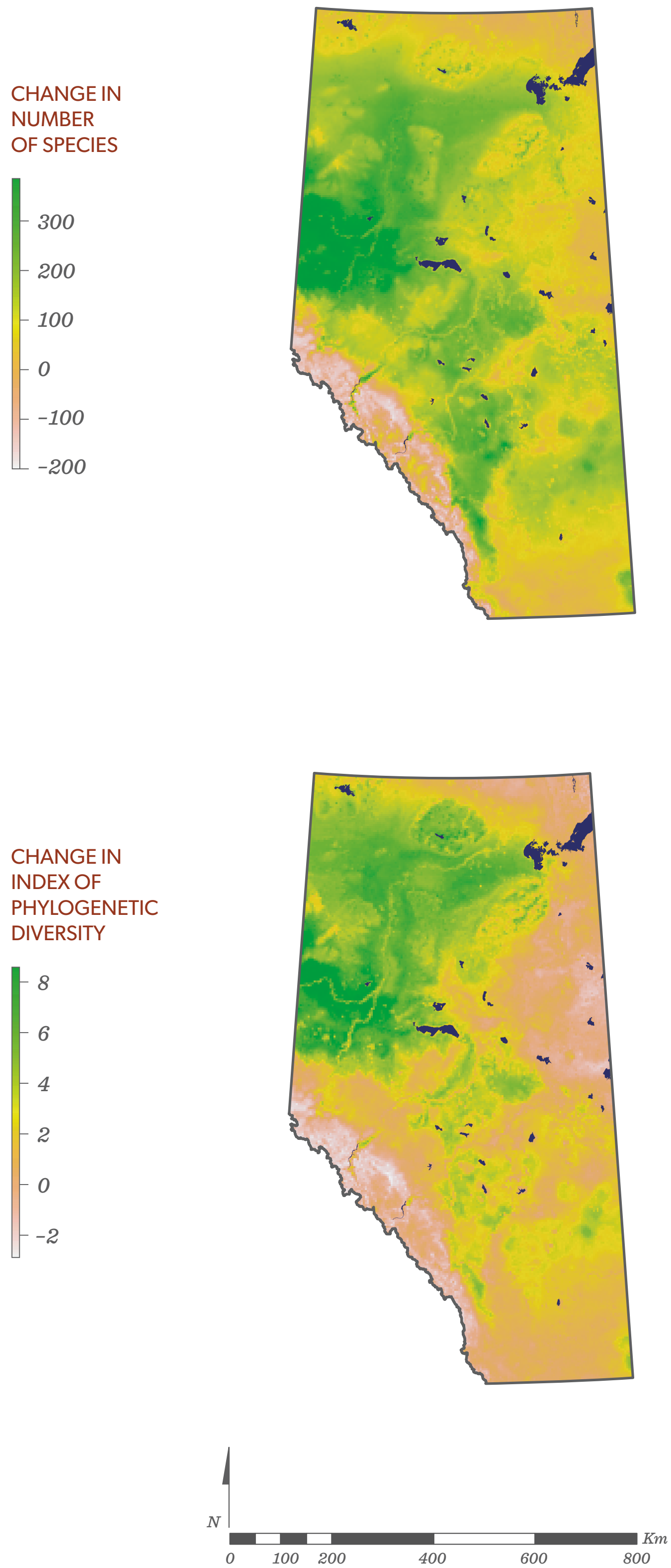


FIGURE 5.

Projected changes in plant species richness (top) and phylogenetic diversity (bottom) in Alberta from the current period (1961-1990) to the end of the century (2071-2100). Water bodies are indicated in blue. These projections are based on the CGCM3 global climate model, assuming the A1B emissions scenario (Zhang et al. in review).

An Improved Method for Species Distribution Models

A new statistical method addresses spatial biases in widely-available "presence-only" species observations, leading to more accurate species distribution models.

Species distribution modeling (page 12) requires reliable species location information as a starting point. These data are often in the form of "presence-only" data obtained from databases of museum records or field sightings, including Alberta databases like ACIMS.[22] These records tend to be concentrated in areas that are more easily sampled; because they may not be representative of all species locations, these records may produce unreliable predictions. Jessica Stolar and Scott Nielsen (2015) demonstrated a method of accounting for this "effort bias" in species distribution models of rare vascular plants, bryophytes and butterflies in Alberta. By relating existing species records to the density of roads, location of experts, resource extraction sites, population density, terrain ruggedness and protected status, they created an estimation of "collection effort" that can be used to weight species observations in the distribution models. This flexible approach is widely applicable due to the increasing availability of online biodiversity databases and will lead to more robust spatial predictions.

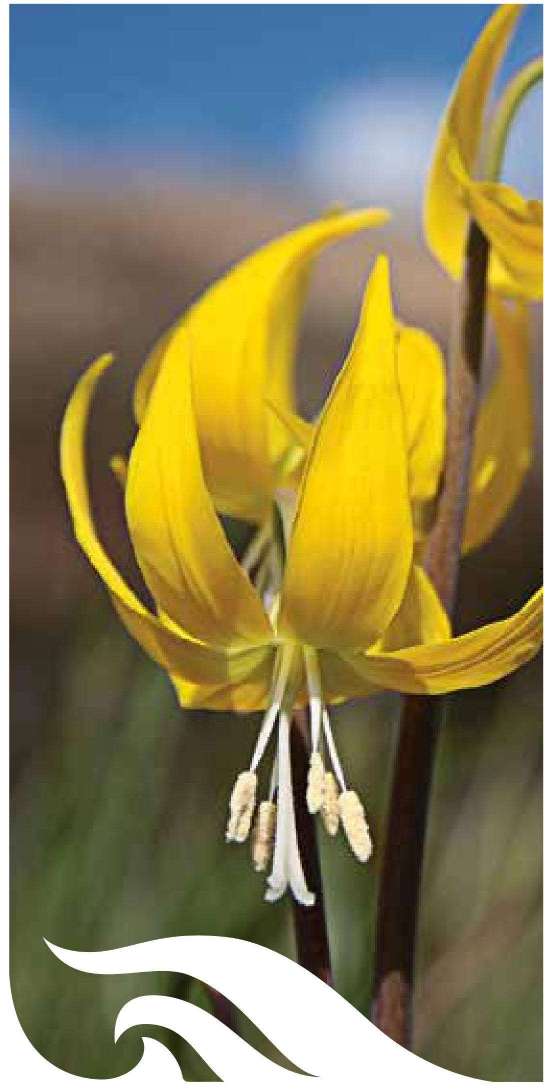


Photo:

The Yellow Glacier Lily grows in moist areas with rich soil in the alpine and subalpine. Because of the rugged terrain and challenging access, these high elevation habitats are relatively under-sampled compared to other regions of the province.

[22] *ACIMS: Alberta Conservation Information Management System. For more information: http://www.albertaparks.ca/albertaparksca/management-land-use/alberta-conservation-information-management-system-(acims).aspx*

GRASSLAND PLANT RESPONSES TO CLIMATE CHANGE AND GRAZING

Simulated grazing magnifies the shift in grassland plant communities towards arid-adapted species in response to climate change.

Species responses, especially the responses of plant species, to climate change can be predicted from detailed, localized information about the species' environmental and climatic preferences, in addition to using broad geographic associations between the species' distribution and climatic conditions (ecological niche models). Shannon White and colleagues (in prep) examined the response of grassland plant species adapted to warm/dry or cool/moist conditions to experimental manipulation of rainfall, temperature and grazing across the Canadian prairies.

The strength of the response in the abundance of these groups of species to the climate treatments increased along a gradient, with the weakest response at the driest, warmest site and the greatest response at the wettest, coolest site. This suggests that grassland plant communities in regions that are already relatively warm and dry already possess adaptations to aridity and are less likely to respond to warmer and drier conditions.

When climate treatments were combined with simulated grazing, there was a strong increase in the abundance of arid-adapted species. This suggests that heavy grazing will magnify any effects from climate change on grassland plant communities, and highlights the potential role of grazing management in responding to climate change impacts on vegetation communities in the grasslands region.

CLIMATE CHANGE VULNERABILITY ASSESSMENTS

Vulnerability assessments for a wide variety of Alberta species and taxonomic groups provide an overview of the relative risk to species from climate change and the factors influencing their capacity to respond to future conditions.

Climate change vulnerability is the integration of the expected exposure of a species to climate change, its inherent sensitivity to altered climate, and its capacity to adapt to possible change.

Not all species will be equally vulnerable to climate change; understanding which species are most vulnerable, and what factors contribute to climate vulnerability is necessary to prioritize potential responses. Chris Shank and Amy Nixon (2014) used NatureServe's Climate Change Vulnerability Index (CCVI) [23] to calculate a relative measure of vulnerability for 173 species of amphibians, birds, insects, mammals, and vascular plants to climate change over the next 40 years.

Reptiles and amphibians were among the most climate vulnerable species, largely because of their specific habitat requirements and inability to disperse through human-modified landscapes. In contrast, birds were typically ranked as less vulnerable because of their excellent dispersal capabilities. Wide-ranging and common species, like the Coyote, were also ranked as lower vulnerability. Species-at-risk tended to be scored as being more vulnerable largely because of their restricted ranges and already small populations (Fig. 6).

This broad survey of climate vulnerability, supported by relevant literature,[24] highlights key considerations for species management in a changing climate, including: the importance of introducing the effects of climate change into the assessment and management of species at risk;[25] addressing barriers to dispersal so species may be better able to move in response to the changing climate; and the need for more detailed research into the potential responses of species to climate change, including prediction of potential future habitat, for species of particular interest or high vulnerability.

---

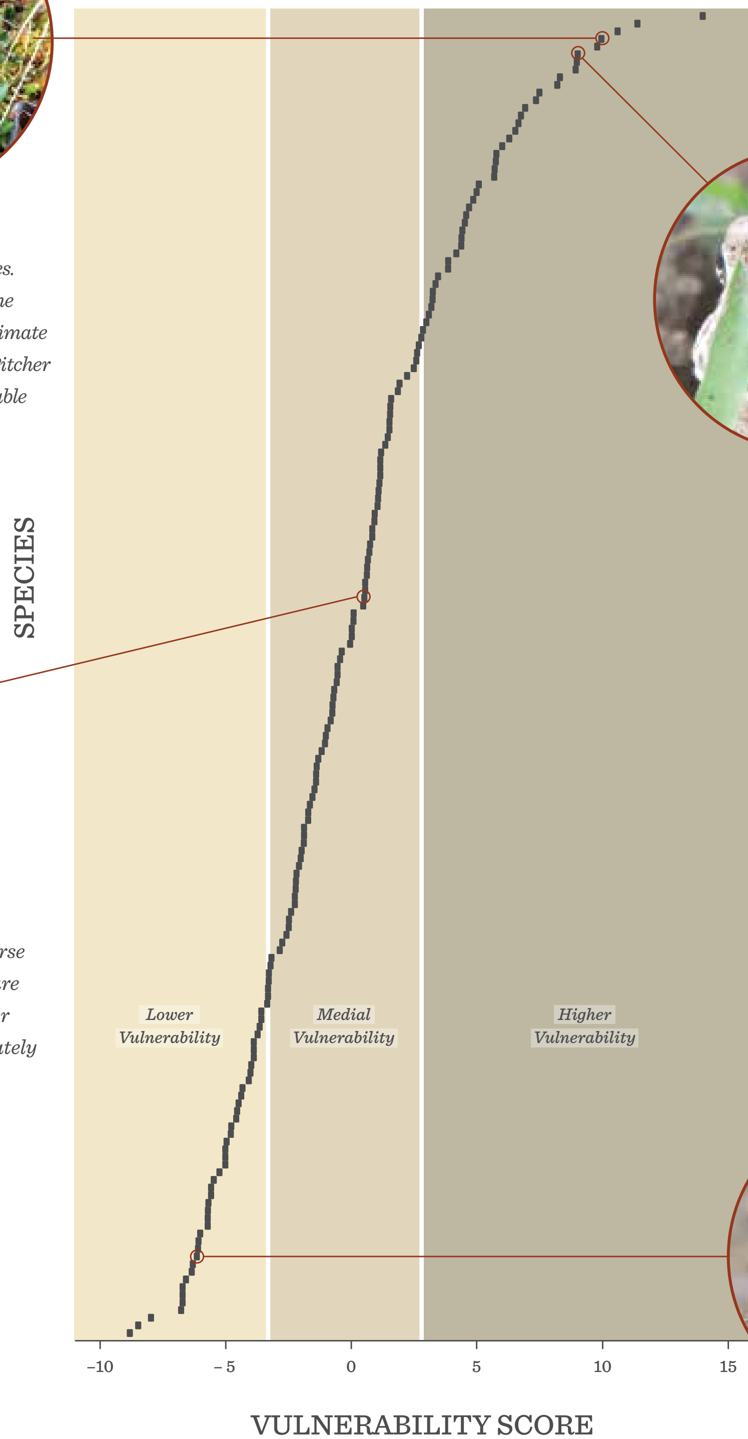
23 NatureServe Climate Change Vulnerability Index, available at: http://www.natureserve.org/conservation-tools/climate-change-vulnerability-index

24 For each species assessed, detailed information is available at: http://www.biodiversityandclimate.abmi.ca/resources

25 Fish and Wildlife Division. 2008. Alberta's Strategy for the Management of Species at Risk (2009-2014). Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton AB, 30pp. Available at: http://esrd.alberta.ca/fish-wildlife/species-at-risk/documents/StrategyManagementSpeciesRisk2009-14.pdf

Purple Pitcher Plants, like many Alberta plants, have very limited dispersal abilities. As a result, their populations might become stranded in unfavourable conditions as climate change occurs around them. The Purple Pitcher Plant was one of the most climate-vulnerable plant species assessed.

Although migratory species, like the Harlequin Duck, are able to easily disperse to areas where the habitat and climate are suitable, the preference of this species for cool mountain streams makes it moderately vulnerable to climate change in Alberta.



In part because of their reliance on ephemeral wetlands for breeding, grassland amphibians like this Great Plains Toad are highly vulnerable to climate change. Of the ten amphibians assessed, six ranked in the top 25% most vulnerable species to climate change in Alberta.

The Coyote is a wide ranging and adaptable species that has relatively low vulnerability to climate change.

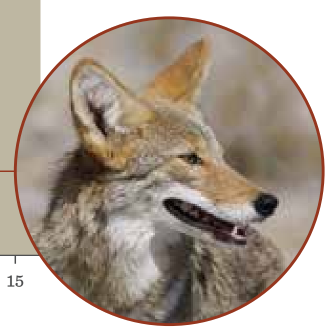


FIGURE 6.

Vulnerability scores for 173 Alberta species. This ranking highlights species that are most and least vulnerable to the expected changes in climate and can support prioritization of species for further research or management action (Shank and Nixon 2014). For each species assessed, detailed information is available at: http://www.biodiversityandclimate.abmi.ca/resources

American Pika—A Detailed Examination of Climate Change Vulnerability

Of the 37 species of mammals assessed for climate change vulnerability using the CCVI, the American Pika ranked second only to Ord's Kangaroo Rat in vulnerability. The CCVI score was largely based on species traits cited in the literature from research done in the US where temperatures are typically warmer, snowfall shallower, and mountain blocks more isolated than in Alberta's Rocky Mountains.

Using climate data specific to Pika locations in Alberta, Chris Shank (in press) examined whether future climatic conditions are likely to put Alberta Pikas at risk. Future mean summer temperatures at almost all current Pika locations are not expected to exceed the threshold for endangerment set by the US Fish and Wildlife Service and most will remain cooler than the current warmest site in Alberta.

Most current sites have sufficient elevation within 5 km to allow pika populations to migrate vertically to maintain mean summer temperatures below that of the currently warmest Alberta site. Climate change seems unlikely to place American Pikas at risk in Alberta by the end of this century. However, this conclusion assumes sufficient future snow cover, meadow habitat, and talus availability, and should be consistently assessed through a well-designed monitoring program.

This more detailed analysis points to limitations in using research results from areas outside the species range of concern and suggests that the generality of the CCVI approach can result in uncertain outcomes for some species.

Photo:

The solitary American Pika lives on rocky talus slopes near alpine meadows.

EFFECTS OF EXTREME WEATHER ON PRAIRIE RAPTORS

The effects of extreme weather events are particularly pronounced for species inhabiting the grasslands where suitable cover is generally lacking. Detailed field research shows that heavy precipitation reduces Burrowing Owl nest success by flooding nests and limiting prey deliveries to owlets, while strong and prolonged windstorms often destroy Ferruginous Hawk nests.

Severe weather events are likely to have the largest consequences for wildlife on the prairies where there are few opportunities to find cover. Burrowing Owls and Ferruginous Hawks are of particular interest because both are designated as Endangered in the *Alberta Wildlife Regulation,*[26] and listed as Endangered and Threatened,[27] respectively, under the federal *Species at Risk Act.*[28]

Incidences of extreme heat, rain, and wind are expected to increase dramatically over the coming decades. This could have severe consequences: Alberta populations are already so small that they could potentially be driven to extinction by a random series of severe weather events. An improved understanding of the factors contributing to climate change vulnerability for these species can support climate change adaptation planning (page 34).

[26] *Alberta Wildlife Regulation. Alberta Regulation 143/1997. Available at: http://www.qp.alberta.ca/documents/Regs/1997_143.pdf*

[27] *Endangered species face imminent extirpation or extinction. Threatened species are likely to become Endangered if nothing is done to address the factors leading to its decline. Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2014. Assessment Process Categories and Guidelines. Available at: http://www.cosewic.gc.ca/eng/sct0/assessment_process_e.cfm*

[28] *Canada Species at Risk Act. S.C.2002, c.29. Available at: http://laws-lois.justice.gc.ca/eng/acts/S-15.3/*

Burrowing Owls

The Burrowing Owl is listed as an Endangered species nation-wide, at least partly because of the impacts of extreme weather, including heavy rainfall and storms. Through their long-term field research, Ryan Fisher and colleagues (in review) have found that extreme one-day rainfalls result in nest flooding. Consequently, productivity (i.e. owlet survival rate) is negatively impacted by precipitation anomalies. However, if owlets were provided with supplemental food (by the researchers), almost all survived periods of heavy rainfall.

Considering the expected increase in extreme rainfall events within its breeding range as climate change progresses, the long-term persistence of the Burrowing Owl is uncertain, but could be alleviated by managing Burrowing Owl habitat to enhance the supply of food. Supplemental feeding, while costly and time-consuming, could be used as a short-term measure to improve owlet survival in emergency situations.

Because Burrowing Owls, like many prairie birds, are migratory, climate change impacts on both wintering grounds and migration routes could be as important to their persistence in Canada and Alberta as the conditions on their breeding grounds. Troy Wellicome and colleagues (2014), including Ryan Fisher and Erin Bayne from the BMCCA project, found that storms during fall migration and above average precipitation on the wintering and breeding grounds were associated with reduced survival of Burrowing Owl populations. Stochastic events, such as large storms during migration, could pose a serious risk to the Canadian population because it is already so small.

Photo:

The Burrowing Owl is a small owl that nests in burrows in the flat, treeless landscapes of Alberta's Grassland Natural Region.

Photo:

The Ferruginous Hawk, North America's largest hawk, breeds on Alberta's prairies.

Ferruginous Hawks

Ferruginous Hawk populations in Alberta have declined precipitously since the early 1990s for reasons that are still not well-understood. Ryan Fisher and Erin Bayne (2013) initiated a project in 2012 to better understand the species' vulnerability to extreme weather with respect to behaviour, reproductive output and nest reoccupancy patterns.[29] Over the course of the study, nest success was estimated for nearly 900 nesting attempts, and video footage and hourly weather data from portable weather stations were collected at nineteen Ferruginous Hawk nests. Using satellite transmitters attached to twenty adult hawks, the study also monitored the effects of weather on hawk migration.

The data collected through this intensive field research is providing unique insights into the responses of Ferruginous Hawks to extreme weather events. For example, Chelsey Laux and colleagues (in review) discovered that Ferruginous Hawks are able to detect impending storms through changes in barometric pressure and mitigate the risk of nest damage by increasing nest maintenance behaviours prior to the storm's arrival. The project is on-going with three graduate students continuing the research.

[29] *Learn more by watching "Weathering the Storm: Alberta's Ferruginous Hawks in a Changing Climate" at: http://www.biodiversityand-climate.abmi.ca/resources/videos*

INVASIVE PLANTS

Incorporating species distribution models into invasive species risk assessments identifies Giant Knotweed, Salt Cedar, and Alkali Swainsonpea as three high-risk invasive plants for Alberta under future climate conditions, and highlights several areas in southern Alberta at greatest risk of new invasions.

Climate change will alter conditions suitable for plant growth in Alberta, inevitably resulting in the introduction and establishment of species not currently found in the province. Some of these species will be invasive, with negative ecological or economic impacts. To evaluate invasion risk for 16 plant species not currently present in Alberta, Shauna-Lee Chai and colleagues (2014) combined invasiveness assessments based on species characteristics with the potential for each species to establish in Alberta under current and future climatic conditions.

The degree of invasiveness for each species was evaluated based on four traits: ecological impact, biological characteristics, dispersal ability, and feasibility of control, using standardized ranking criteria.[30] The suitability of current and future Alberta climates for each species was assessed through a combination of climate matching and species distribution modeling.

Of the 16 terrestrial species assessed, the three most problematic invasive plants were Giant Knotweed (*Fallopia sachalinensis*), Salt Cedar (*Tamarix chinensis*) and Alkali Swainsonpea (*Sphaerophysa salsula*); these species were determined to have both the highest invasiveness scores and greatest potential increase in suitable habitat in Alberta. This analysis could support climate change risk assessments for invasive plants under the Weed Control Act.[31]

The Grasslands Natural Region was evaluated as the most at-risk region to new invasive species in both current and future climates, and the Municipal Districts of Pincher Creek, Cardston and County of Forty Mile were the municipalities/counties with habitat predicted to be suitable for the greatest number of new invasive species by the 2050s (Fig. 7).

Because early detection and rapid response is critical to successful management of invasive plants, identification of new potential invasive plant threats can support ongoing management initiatives across Alberta.

Photo:

Climate change will make Alberta's climate more favourable for Salt Cedar. This aggressive invasive species has very high water demands, and impacts native ecosystems by lowering water tables and increasing the salt content of the soil.

[30] *Invasiveness assessments for all 16 species can be found at: http://www.biodiversityandclimate.abmi.ca/our-work/climate-change-impacts/*

[31] *Alberta Weed Control Act.SA 2008 cW-5.1. Available at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/acts6156*

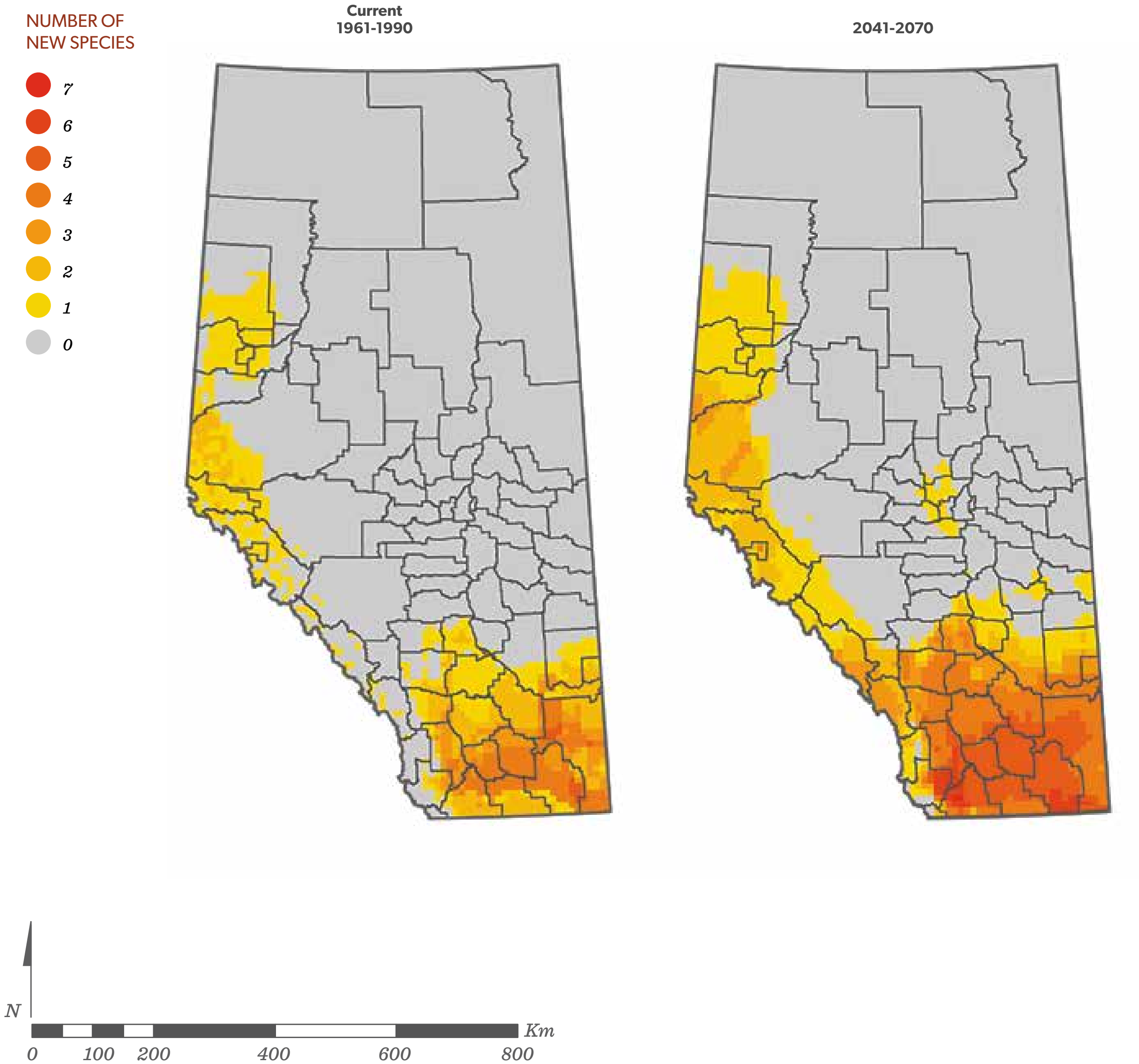


FIGURE 7.

Current and projected future suitable habitat for potential new invasive plant species. Climate change will increase the risk of new invasive plant species for Alberta, especially in the south, by improving the suitability of the climate for species not currently present in the province (Chai et al. 2014).

CLIMATE CHANGE ADAPTATION IN BIODIVERSITY MANAGEMENT

Changes to Alberta's biodiversity are an inevitable result of climate change. The challenge is to apply our understanding of these impacts to the identification and development of policies and management strategies that have the best chance of maintaining a diversity of species adapted to the new conditions.

The BCCMA project explored a variety of potential strategies designed to accommodate climate change in the planning and management of Alberta's biodiversity, for both individual species and across landscapes. These strategies include:

- *setting biodiversity objectives that accommodate changing climate conditions,*
- *identifying and protecting future biodiversity hotspots and climate refugia,*
- *assessing strategies for mitigating climate risk in key species, and*
- *effectively monitoring the effects of climate change on biodiversity.*

BIODIVERSITY MANAGEMENT AND CONSERVATION PLANNING

> *Climate change should factor into the choice of biodiversity objectives and the approaches used to achieve them. Management actions can support species' responses to climate change through already well-understood approaches, and conservation planning can incorporate climate change scenarios to effectively achieve biodiversity objectives across a range of potential futures.*

The goal of biodiversity conservation is to maintain ecosystems, species and genetic diversity along with the processes that shape them. Richard Schneider (2014) explored how climate change impacts could be considered when defining specific biodiversity objectives and how these objectives can be most effectively achieved through conservation planning and management.

Effective biodiversity management requires operationally defining the ecological state that is to be achieved. Frequently, these objectives identify human development and land-use change as the primary sources of ecological changes. However, climate change is also a potent driver of ecological change that will challenge many efforts to achieve biodiversity objectives if it is not explicitly considered when the objectives are defined. Biodiversity objectives will need to be adjusted to reflect biodiversity responses to ever-changing climatic conditions.

Protected areas are widely recognized as a critical tool for biodiversity conservation in a changing climate.[32] Alberta's network of protected areas is based largely on the goal of representing current ecosystem diversity by representing the provincial Natural Regions and Subregions.[33] With climate change, ecosystem distributions will shift over time, so it may be appropriate to link representation to regional landscape characteristics, like soil types or geological features, that are likely to remain stable over time. See page 40 for further explorations of this approach for Alberta. Climate refugia (page 42) for high priority species or species groups could be considered for protection as a species-level complement to landscape-level priorities.

Both inside and outside of protected areas, active management for some species and ecosystems will be required to meet biodiversity objectives, not to resist the potential impacts of climate change, but to support species whose ranges may be shifting in response to a changing climate. The tools to do so are well-known, and some are already being implemented by practitioners, including reduction of human disturbance, removal of dispersal barriers, assisted migration (page 37), and exclusion of non-native competitors.

Uncertainty about the scale and effects of climate change will necessitate novel approaches to planning for biodiversity management and conservation. Alternative planning methods that can accommodate this additional uncertainty are the identification of "no-regrets" strategies that minimize the overall risk of catastrophic outcomes or the application of multiple "bet-hedging" strategies simultaneously in different regions that in concert lower the risk of widespread failure in achieving biodiversity objectives.

---

[32] *Canadian Parks Council Climate Change Working Group. 2013. Canadian Parks and Protected Areas: Helping Canada Weather Climate Change. Parks Canada Agency on behalf of the Canadian Parks Council. 52 pp.*

[33] *Scientific Framework for Alberta Parks. Available at: http://www.albertaparks.ca/albertaparksca/management-land-use/building-the-parks-system/scientific-framework.aspx*

SPECIES ADAPTATION PLANS

Climate change adaptation plans for two Endangered grassland raptors provide practical management considerations and actions to enhance the abilities of these species to adapt to climate change. These options include siting artificial nest burrows for Burrowing Owls in well-drained locations and securing Ferruginous Hawk nests from blow down.

Recovery plans for species at risk often mention climate change as a risk factor, yet they rarely provide practical approaches for identifying specific climate change risks or potential management solutions. Doing so requires a detailed understanding of a species' biology and the species' response to current conditions and to potential future climates.

By combining the outcomes from detailed field research (page 27) with literature review, the BMCCA project has highlighted management approaches for both Burrowing Owls and Ferruginous Hawks that could be considered for incorporation into species-at-risk recovery plans.

Burrowing Owls

Burrowing Owls will be affected by climate change in Alberta both through projected changes in the frequency and intensity of extreme weather events, and through changes in habitat availability in response to projected average climate conditions. Potential management responses highlighted by Ryan Fisher and Erin Bayne (2014) in their Burrowing Owl climate change adaptation plan include habitat management to ensure availability of prey, construction of artificial burrows in areas with good drainage and, as a last resort when populations are low, supplemental feeding of owlets during inclement weather. Because Burrowing Owls had a historical range extending further north, reintroduction is a potential option but is not recommended until the factors currently limiting populations are better understood and effectively addressed.

Ferruginous Hawks

Field research (page 29) has demonstrated that collapse of Ferruginous Hawk nests from extreme wind and rain events is a significant source of reproductive failure and one that is likely to increase in the future as extreme weather increases in frequency and intensity. In their climate change adaptation plan for Ferruginous Hawks, Chris Shank and Erin Bayne (2015) also concluded that the effects of weather on the hawks' primary prey item, Richardson's ground squirrels, is significant to the long-term persistence of Ferruginous Hawk populations because of the tight link between ground squirrel populations and hawk reproductive success.

The primary management response proposed in the adaptation plan to address expected increases in extreme weather events is to create artificial and natural nest substrates that are resistant to blowout. Additional suggested actions, including addressing other impacts of extreme weather events, like nestling survival, and the potential impacts of long-term change in average climate conditions, will require considerably more research on, and monitoring of, both Ferruginous Hawks and Richardson's ground squirrels.

Photo Opposite Top:

The underground nests of Burrowing Owls are vulnerable to flooding during heavy rain.

Photo Opposite Bottom:

Ferruginous Hawk nests constructed on artificial nest platforms are nearly twice as likely to withstand heavy winds as those in trees.

ASSISTED MIGRATION

Wild populations have two primary ways of responding to environmental change: adapting behaviourally or genetically to new conditions, or moving to track suitable conditions through range shifts. Species with limited dispersal abilities, in fragmented habitats, or with high habitat specificity may not have the capacity to move to where conditions are more suitable, and this could increase their risk of extirpation or extinction.

Assisted migration, the intentional translocation of a species beyond its current distribution to areas where climate is predicted to be more favourable in the future, has been proposed as a potential proactive conservation tool to address this risk.

The BMCCA project supported two translocation experiments to assess the feasibility and some of the potential risks and benefits of assisted migration as a climate change adaptation strategy. These experiments have included assessments of the climate-related risks to existing populations, of the potential for successful establishment of populations in new areas, and of translocation methods that could be implemented in conservation programs.

Montane Mammals

> ***Columbian Ground Squirrels adjust their hibernation timing in response to environmental conditions even though this timing is partly genetically controlled, indicating the potential for this species to respond relatively quickly to changing climatic conditions.***

In recent years, Columbian Ground Squirrels have been emerging from hibernation later in the spring as a result of late spring snowstorms, resulting in reduced fitness and population viability. In 2008, Jeffrey Lane (2014) initiated a series of translocation experiments in the Alberta Foothills demonstrating that both genetic variation and individual responses to the environment contribute to variation in hibernation timing. In addition, translocation was validated as a research and potential management tool, with many individuals surviving more than a year post-translocation. The results of this long-term research, supported by the BMCCA project, have implications for the effectiveness of using assisted migration as a management tool to address potential population declines in montane mammals resulting from a changing climate.

Photo:

Columbian Ground Squirrels, mid-sized rodents of Alberta's Rocky Mountains, hibernate in underground burrows for typically 250 days of every year.

Rare, Range-restricted Plants

Experimental translocations demonstrate that suitable climatic conditions for the Northern Blazing Star, a rare plant in Alberta, already occur much further north than the species' current distribution, providing support for assisted migration as a potentially effective management response to climate change.

Jennine Pedersen and colleagues (2014) have been undertaking transplantation experiments with the Northern Blazing Star, a rare plant occurring in central Alberta, to determine the species' vulnerability to climate change and whether assisted migration could be a feasible conservation response.[34]

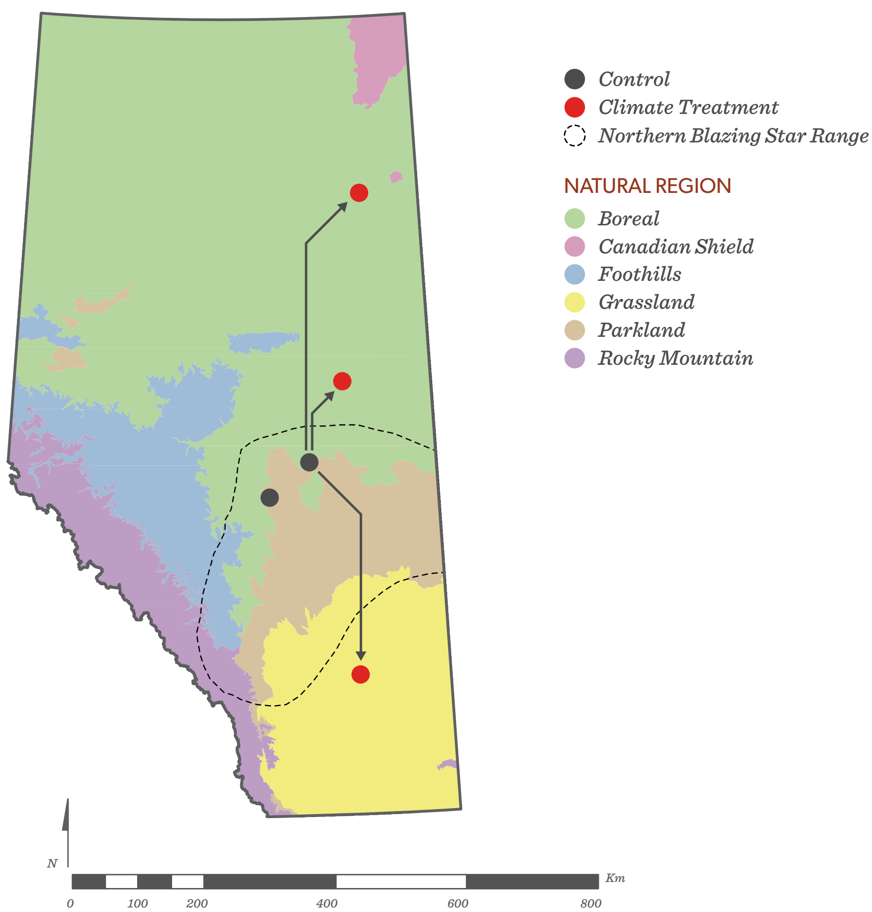
Northern Blazing Star has been transplanted to two areas north and one location south of its current range in central Alberta (Fig. 8).

In addition, plants were transplanted to two control locations within the species' current range. In summer 2014, seeds planted at the more northern locations showed significantly better seed emergence rates than at the control and southern locations, suggesting that the optimal climatic conditions for the species may already have shifted northwards.

The survival of adult plants and emergence of seedlings outside the current range of Northern Blazing Star also suggests that assisted migration would be a viable conservation tool for this species, provided that adult plants are able to reproduce successfully at the northern sites. Initial experiments are now underway with a second rare plant, Long-leaved Bluets.

FIGURE 8.

To test the effectiveness of assisted migration, adult plants and seeds of the Northern Blazing Star were moved north to areas projected to have suitable future climates. Translocations to the south were used to test the sensitivity of the species to the hotter and drier conditions expected to occur in the future at currently occupied locations. (Pedersen et al. 2014).



[34] *Learn more by watching "Blazing Ahead of Climate Change" at: http://www.biodiversityandclimate.abmi.ca/resources/videos*

Photo:

The Northern Blazing Star occupies open habitats with sandy soils in the central region of Alberta.

PARKS AND PROTECTED AREAS

Protected areas contribute to species' resilience to climate change by limiting the added pressures of human disturbance, such as land use change or habitat fragmentation. However, Alberta's current network of protected areas was not created in consideration of the impacts of climate change on provincial biodiversity.

Building on the projections of future ecosystem and species distributions developed through ecological niche modelling (pages 14-22), the BMCCA project has examined how climate change could be incorporated into protected areas planning, considering the consequences of climate change for the protection of landscape diversity (ecosystems), and particular species groups.

Alberta's Protected Areas Network

> ***Alberta Parks aims to preserve a network of areas that represents the natural diversity of the province by including all major ecosystems. As the size and distribution of these ecosystems is modified by climate change, the proportion of each ecosystem protected will remain largely unchanged, indicating that the current approach to parks planning will continue to meet conservation goals.***

Alberta Parks' landscape-level conservation strategy is based on achieving representation of the province's ecosystems, described by 6 Natural Regions and 21 Subregions, as a coarse-filter approach to protecting species and ecological processes.[35] However, as the climate changes, the structure and location of ecosystems will change and protected areas may no longer be representative.

Richard Schneider and Erin Bayne (2015) tested the extent to which targets based on proportional representation of ecosystems would continue to be met under a changing climate. By developing hypothetical systems of representative reserves for Alberta to achieve ecosystem representation targets (i.e., % of the area of each ecosystem protected) and applying these protected area networks to altered ecosystem distributions projected by bioclimatic envelope models (page 14), they found that ecosystem representation would be generally maintained or increased under conditions of climate change.

One potential explanation for this result is that Alberta's ecosystems serve as proxies for more stable and enduring features of the landscape, such as topography and latitude. These features, termed "land facets," provide the arenas to accommodate the full range of biodiversity's dynamic responses to climate change.

The current ecosystem-representation approach to planning parks and protected areas in Alberta is therefore a viable approach to developing a climate-ready protected areas system. However, it is important to recognize that with this approach the absolute area of an ecosystem that is protected will decline if the absolute area of the ecosystem is reduced. For example, a significant proportion of the remaining boreal forest could be protected, meeting a proportional target, but the absolute area might be small.

[35] *Scientific Framework for Alberta Parks. Available at: http://www.albertaparks.ca/albertaparksca/management-land-use/building-the-parks-system/scientific-framework.aspx*

Priority Areas for Conservation of Rare Species

> *Ecological niche models identifying areas of high current and future diversity of rare Alberta plant and butterfly species indicate that the Foothills Natural Region will be increasingly important for plant and butterfly diversity as climate change progresses.*

Using ecological niche modeling (page 12), Jessica Stolar and Scott Nielsen (in review) examined the current and future distribution of Alberta's rare (NatureServe ranks S1 – S3)[36] vascular plant and butterfly species[37] and determined the locations of current and potential future conservation gaps in Alberta's protected areas. Vascular plants and butterflies are two groups of species with relatively rich Alberta location datasets that support modeling of rare species.

Rare vascular plant species are currently concentrated in the Rocky Mountain and Foothills Natural Regions and in the Cypress Hills; the Foothills will likely become an increasingly important region for rare plant diversity by the 2080s (Fig. 9). Although Alberta's protected area network overlaps significantly with current and future hotspots of rare plant species richness, gaps still remain. Depending upon the time period and the target set for species protection, gaps in the current protected areas network were observed for 16 - 43% of the rare species considered.

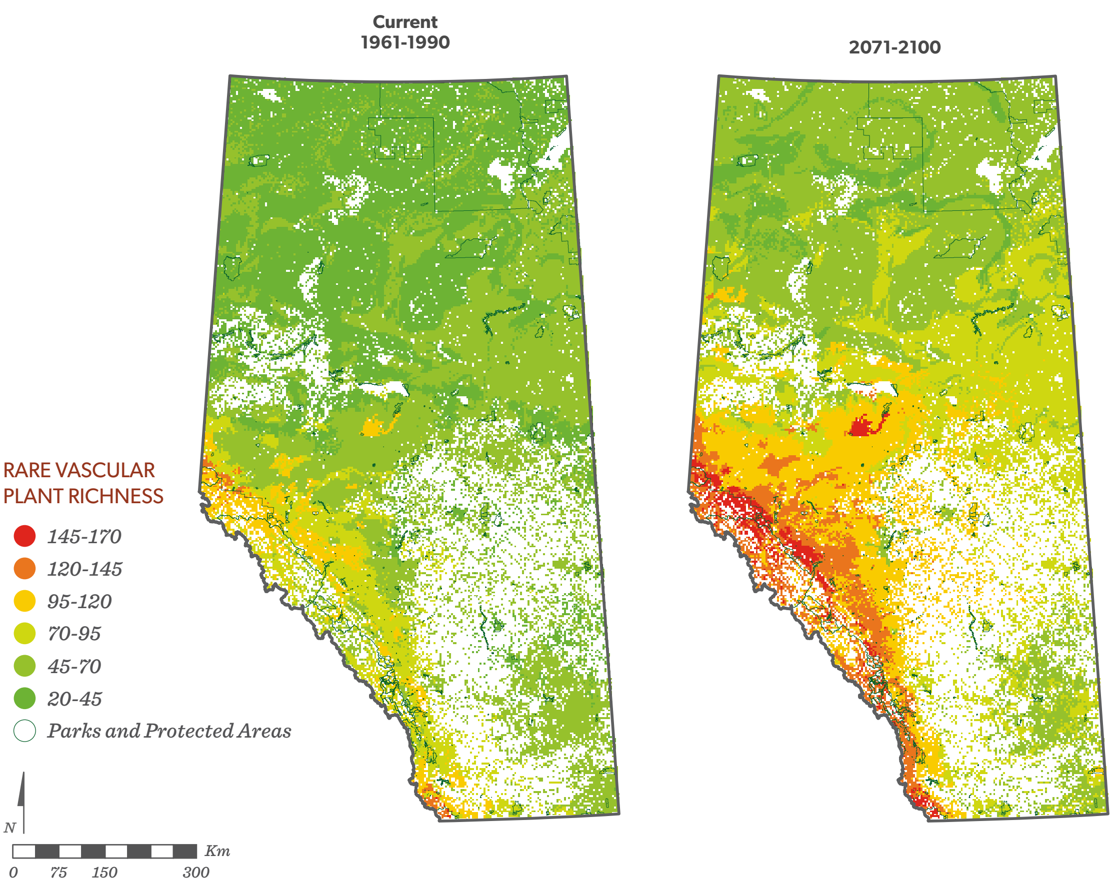


FIGURE 9.

Current and projected future rare plant richness in Alberta. Species richness is projected to increase in the Foothills Natural Region in particular by the end of the century. This future projection is based on a suite of 273 rare species, an ensemble of 15 global climate models and the A2 emissions scenario. Areas of non-habitat, including rock, water, and agriculture (in white) were omitted (Stolar and Nielsen in review).

[36] *S-rankings by NatureServe reflect the conservation status of a species in the province. They range from S1 (critically imperilled) to S5 (demonstrably secure). For more information: http://explorer.natureserve.org/ranking.htm*

[37] *Maps for many species available in the rare plant map gallery at: www.biodiversityandclimate.abmi.ca/resources/map-galleries*

Identifying Climate Refugia

Climate refugia are areas with a climate currently suitable for a species and expected to retain suitability in the future. Species distribution modeling for boreal songbirds suggests that the Marten, Pelican and Swann Hills are likely to be important climate refugia for a large number of species.

Climate refugia are those areas of current species distribution that are expected to retain climatic habitat suitable for the species in the future. Such areas can be important for species conservation since they mitigate the need for adaptation and dispersal, and can provide species with additional time to respond to environmental changes.

Of the 84 Alberta songbird species modeled by Diana Stralberg and Erin Bayne (2013), 42% were expected to see a decline in area of refugia by the end of the century and nine species were expected to retain less than 1% of their original range in refugia.

Boreal songbirds rely on more than suitable climate, however; limitations to forest growth and succession will also impact the potential future distributions of suitable habitat for these species. Diana Stralberg and colleagues (in revision) extended the refugia concept to evaluate "modified refugia" or those that track both suitable climate and forest age over time.

Boreal forest stands are expected to become younger as natural disturbances such as fire increase in frequency and intensity and forestry activity continues. Considerable young forest will become available and bird species that depend on that forest type, like Mourning Warbler, can be expected to change distributions rapidly as the climate changes. However, sufficient suitable habitat to maintain large populations of old forest specialists, like Black-throated Green Warbler, will become available only after a lag time of many decades as the forest matures.

Conservation planning for boreal songbirds must therefore consider maintaining both stable habitat for those species that are unable to easily shift their distributions, and newly suitable habitat for species that are able to occupy new areas. Taking into account constraints placed by forest age, conservation areas expected to protect the greatest proportion of boreal birds over time are concentrated at higher elevations.

By including habitat considerations into the interpretation of species distribution models, this "modified refugia" approach represents a significant refinement in predicting areas that will be of the greatest conservation significance in a changing climate.

Boreal-wide results have been summarized for Alberta by Diana Stralberg and colleagues (2014) to suggest that the province's hill and mountain systems are conservation priorities (Fig. 10). The Marten, Pelican and Swan Hills in central Alberta are particularly important because they are expected to retain their current upland mixedwood and white spruce forests until the end of the century, in the absence of land use change or natural disturbances like fire.

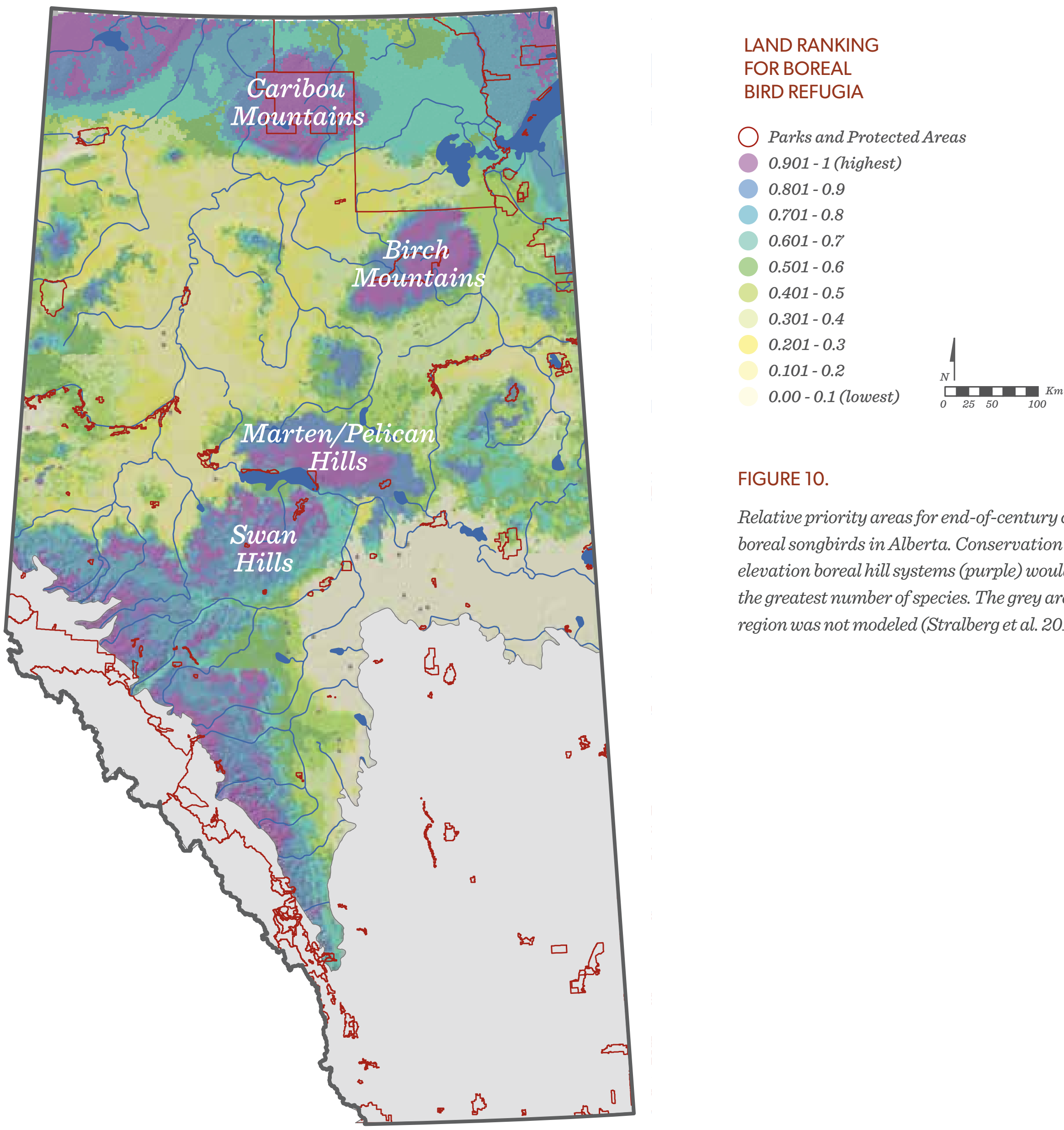


FIGURE 10.

Relative priority areas for end-of-century conservation of boreal songbirds in Alberta. Conservation of the higher-elevation boreal hill systems (purple) would offer protection to the greatest number of species. The grey area outside the boreal region was not modeled (Stralberg et al. 2014).

Current Biodiversity in Potential Climate Refugia

> *Species distribution modeling suggests that Alberta's hill systems will be important refugia for boreal plants and animals as the climate changes. Field research is describing current climate and biodiversity patterns in several hills systems and evaluating the potential of these regions as climatic refugia for boreal biodiversity.*

Higher elevation areas of Alberta are likely to provide climate refugia for boreal birds and plants in the coming decades (pages 41-43). In 2014, Diana Stralberg and colleagues (2014) initiated a project to evaluate the potential for Alberta hill systems to act as refugia by collecting field data on how landforms, elevation, latitude and exposure influence weather conditions and biotic communities. Current gradients in elevation and latitude can be treated as proxies for changes in climate through time, allowing more precise prediction of the potential value of the hill systems as climatic refugia.

Four study areas across the province, from Cypress Hills in the south to the Buffalo Head Hills in the north, with similar forest types (upland mixedwood forests) but differing mean annual temperatures, were chosen for study. In each area at least three elevations were sampled in as many as four aspect/landform classes. Sampling consisted of deploying automated audio recording units for detecting birds, mammals and amphibians, installing temperature sensors, and conducting vascular plant and plant structure surveys.

Preliminary analysis by Erin Bayne and Diana Stralberg (2015) indicated that the richness of songbird communities was greatest at lower elevations and in the south part of the province. Species richness was higher at southern locations because the songbird communities included species adapted to grassland, agricultural and urban environments, but the cause(s) of the elevational gradient in species richness are still unclear. These data highlight the complexities of understanding topographic and climate controls on species distributions, and the need for enhanced monitoring of Alberta's hill systems.

ADAPTATIONS FOR ECOSYSTEM SERVICES ON ALBERTA'S RANGELAND

Carbon modeling for Alberta's rangeland suggests that climate change will result in long-term declines in aboveground biomass production and belowground carbon storage. Both processes are sensitive to grazing intensity, however, suggesting that grazing management has the potential to be a useful adaptation measure to maintain these ecosystem services on rangelands over the long-term.

Ecosystem services are the benefits people receive from nature that contribute to our health and well-being. Climate change is anticipated to have numerous and wide-ranging effects on the provision of many ecosystem services, which will impact people, communities, and industries that rely on those services. Understanding these impacts, as well as the costs and benefits of potential adaptation strategies is therefore critical for long-term social, environmental, and economic planning.

In collaboration with ABMI's Ecosystem Services Assessment (ESA) project[38] Amy Nixon and colleagues (2015) used a carbon dynamics model to examine the impacts of recent and future climate change on two ecosystem services in Alberta's native grasslands: soil carbon storage for climate change mitigation and aboveground biomass production (i.e. forage) for livestock grazing. They further investigated the potential of grazing management (low-, moderate-, or high-intensity grazing) as a climate change adaptation strategy to maintain these processes over the long term.

In a preliminary analysis of model results, aboveground biomass and soil carbon storage increased or remained stable in response to recent climate change, depending on the grazing regime. In response to projected future climate change to the mid-century (2050s), modelled aboveground biomass increased, but subsequently decreased in response to climate change by the end of the century (2080s). Low-intensity grazing typically resulted in higher modelled values of aboveground biomass and soil carbon, compared to higher-intensity grazing. This suggests that adjusting grazing intensity is one potential adaptation measure to maintain or improve aboveground biomass production and carbon storage in rangeland soils as climate change progresses. This work is continuing under the ESA project.

[38] *For more information, visit: www.ecosystemservices.abmi.ca*

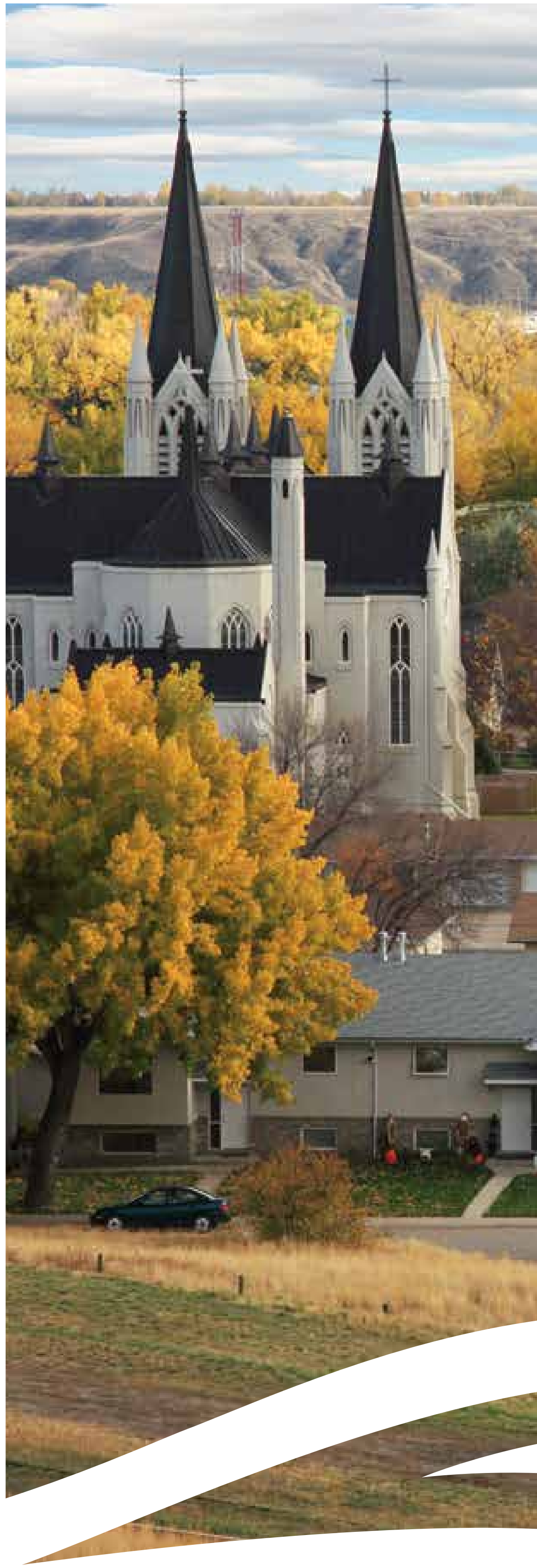
MONITORING

Biodiversity monitoring is essential to support climate change adaptation. Richard Schneider (2014) highlighted several of the roles of biodiversity monitoring in climate change adaptation. These include: the construction and validation of future projections of species and ecosystem distributions, the development and measurement of ecological indicators, and evaluation of adaptive management actions. High-quality, long-term monitoring data can also provide an early warning system for detecting the effects of climate change on species and ecosystems.

The Alberta Biodiversity Monitoring Institute monitors over 2500 species in terrestrial and wetland habitats in Alberta through field data collection and remote sensing, providing the most comprehensive biodiversity monitoring data for the province. Erin Bayne (in prep) discussed how relative abundance data from the ABMI's monitoring program can be used to detect changes in species distributions, even if their range edges do not occur in Alberta. Further, he identified how new technology and remote sensing can improve monitoring of species phenology, or the timing of biological events like migration or spring green-up, which will be impacted by climate change.

However, both Richard Schneider (2014) and Erin Bayne (in prep) have identified new monitoring approaches that would improve the quality of biodiversity data for predicting and detecting the impacts of climate change on Alberta's biodiversity. To complement existing monitoring efforts, surveys could be intensified in areas where the response of biodiversity to climate change is likely to be most easily detected, such as along ecotones like the boundary between the Parkland and Boreal Natural Regions, and along elevation gradients. In addition, more intense monitoring in protected areas would better enable detection of ecological change in the absence of human disturbance; this information can be used in establishing and measuring ecological benchmarks.

RESILIENCE-BASED ADAPTATION FOR COMMUNITIES



As climate change progresses, Alberta's communities – and their local governments – will need to make decisions that encourage adaptation and promote resiliency to their new climate and environmental conditions. Resilient communities are able to respond positively to the consequences of climate change in their municipalies. But, developing adaptation approaches requires understandable, geographically relevant (i.e., local) climate change projections, an assessment of the implications of future climates on community well-being, and access to the existing body of knowledge on effective adaptation measures.

Recognizing this need and the necessity of a decision-support tool that makes a connection between biodiversity conservation and municipal climate resilience, the Miistakis Institute has developed Adapt-action: an online tool that will help Alberta municipalities incorporate climate change adaptation in their planning. The tool is currently targeted towards small to medium municipalities in the Grasslands Natural Region of Alberta, but is relevant for municipalities across the province.

To ensure that Adapt-action meets a significant need and can be broadly used, the Miistakis Institute reviewed the implications of climate change for rural Alberta communities in the grasslands region, the connections between Alberta municipal policy and climate change adaptation action planning, and the potential roles for ecosystem-based adaptation in building community climate resilience.

CLIMATE CHANGE AND SOUTHERN ALBERTA COMMUNITIES

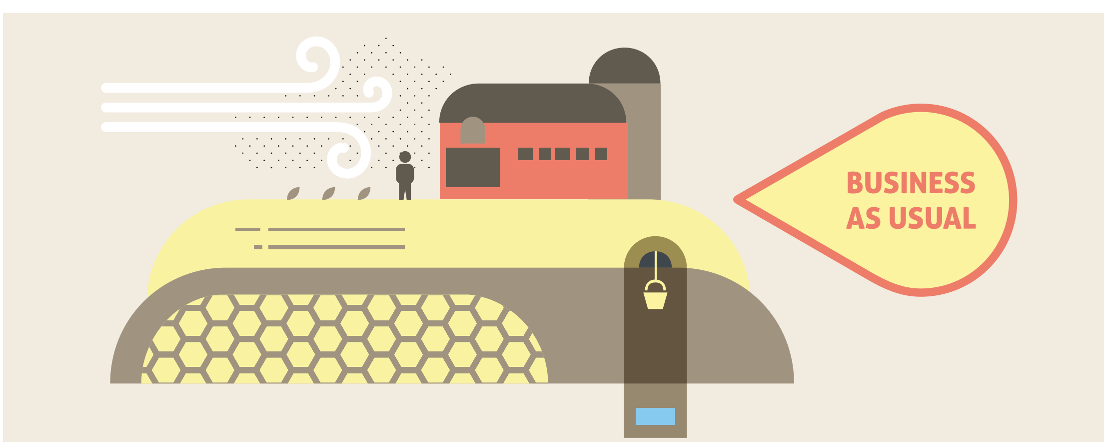
Climate change is expected to impact Alberta's rural municipalities economically, socially, and environmentally. Understanding these potential impacts is necessary to plan adaptive approaches to future climate conditions.

The projected changes in Alberta's climate, both in terms of changes in average conditions and changes in climate extremes and extreme events, have significant implications for the well-being of rural municipalities in the grasslands region. Tracy Lee and colleagues (2014) reviewed and summarized the climate change implications for agriculture, infrastructure, emergency response, recreation, and human health; they found that all are vulnerable to the impacts of climate change and that the implications for municipalities are widespread, overlapping and interconnected.

For example:

- *Increased temperatures and reduced moisture availability in summer could result in changes in grassland productivity or species composition that affect forage quantity or quality and therefore impact stocking rates for livestock production.*
- *Streamflow reductions, combined with projected reductions in available moisture, may impact production of irrigated crops and the demand for irrigation infrastructure.*
- *Changes in streamflow and the timing and intensity of rainfall could also impact water quality through runoff and nutrient loading, with consequences for water treatment infrastructure and human health.*

Alberta's rural municipalities have a long history of adapting to environmental change, and in many cases have already integrated resilience to climate variability into their municipal operations. This experience provides a strong foundation for continuing to build climate resiliency in preparation for projected future changes in climate that will likely be outside the norm of historical variability, even in light of the uncertainty associated with these projected changes.



Climate change will have significant implications for the well-being of Alberta's rural municipalities. Communities will need to incorporate climate change into their planning.

Ecosystem-based adaptation strategies can help build climate resiliency for rural municipalities.

ECOSYSTEM-BASED ADAPTATION

> ***Ecosystem-based adaptation strategies, a complement to adaptation through infrastructure, are proactive and can achieve multiple community benefits in addition to building climate resiliency.***

There are a variety of ways that municipalities can approach climate change adaptation. *'Ecosystem-based'* approaches, reviewed by Tracy Lee and Ken Sanderson (2014), focus on building climate resilience by protecting or restoring the healthy ecosystems that support human well-being – through food production or water purification, for example.

Ecosystem-based adaptation complements other climate change adaptation strategies, such as those that rely on the development of new infrastructure like storm sewers or stream channels, but it also has several advantages. Approaches that focus on building ecosystem resilience to climate change have the potential to achieve multiple community objectives through a single action. For example, a protected wetland upstream of a community maintains the resilience of the community's water supply, while also continuing to provide critical habitat for aquatic plants and wildlife, store carbon and filter water.

Because they have multiple benefits, these strategies are lower-risk (often termed "no-regrets") in light of the uncertainty associated with predicting the exact impacts of climate change on a community. Though the benefits and costs of each adaptation strategy will depend on the specific nature of the risks identified by individual communities, ecosystem-based approaches are often cost-effective, in particular because a single action can support multiple community objectives and address multiple climate change risks.

CLIMATE CHANGE AND MUNICIPAL PLANNING

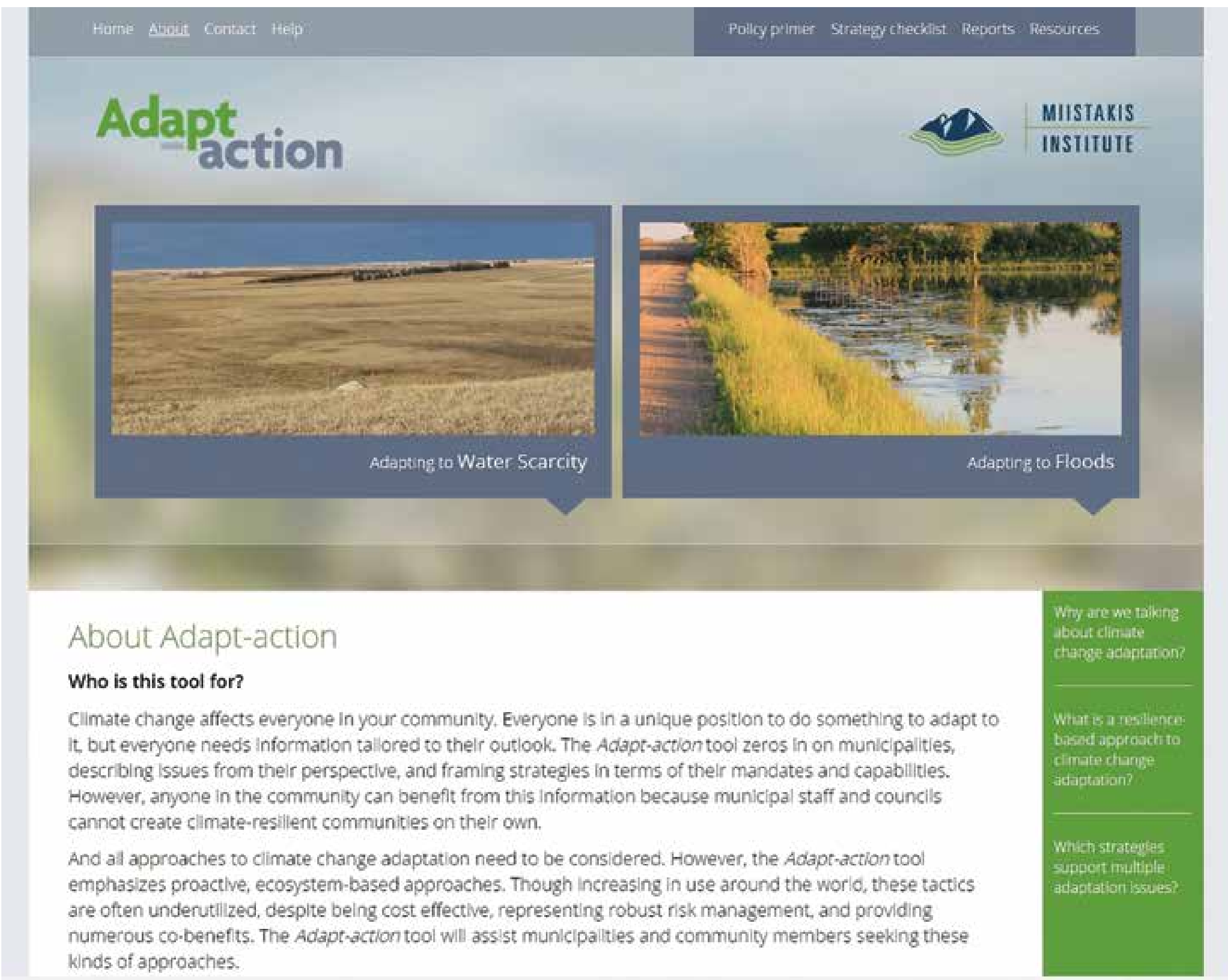
Municipal governments in southern Alberta have a variety of options for incorporating climate change adaptation into their policies and planning processes.

As the level of government closest to residents, municipalities are well-positioned to implement plans and strategies that can benefit the health, security and liveability of Alberta's communities in a changing climate. A variety of opportunities, reviewed by Guy Greenaway and colleagues (2014), exist for municipal governments in southern Alberta to incorporate climate change adaptation into existing policies and plans. For example:

- *Broad-scale planning and development strategies, like Municipal Development Plans, that outline a vision for the entire municipality and therefore have pervasive influence, can yield potentially large gains in climate resilience through relatively small changes, such as changes in plans for future land use in the municipality.*
- *Non-statutory plans like sustainability plans and growth management strategies will play an increasing role in providing specific opportunities to incorporate climate change into municipal planning.*
- *Agricultural Services Boards and Agricultural Fieldmen in rural municipalities represent a vital link for implementing climate change adaptation strategies because of their responsibility and concern for agricultural viability and ecological resource sustainability.*

ADAPT-ACTION – A TOOL FOR COMMUNITIES

Adapt-action is a free, web-based support tool for Alberta municipalities, uniquely designed to help them include climate resiliency in their planning.[39] Adapt-action provides practical and credible information on the implications of climate change for municipalities, the causal environmental changes, and potential adaptation strategies. Adapt-action's focus on ecosystem-based strategies complements resources that emphasize infrastructure approaches to building climate resiliency. The Adapt-action website is a hub for practical information on climate change adaptation planning for municipalities.



---

[39] *Available at: www.adaptaction.ca*

UNDERSTANDING AND ADDRESSING UNCERTAINTY

There is considerable uncertainty in predicting future climatic conditions and their effects on Alberta's biodiversity. Better understanding the sources of this uncertainty allows for more effective planning and decision-making.

Predictions about future events or outcomes will always be uncertain. This is particularly true in projecting future conditions that result from the complex interactions between climate change and biodiversity. Importantly, incorporation of predictions about future conditions into effective management planning requires an understanding of the sources of uncertainty and the level of confidence associated with those predictions.

What contributes to uncertainty in climate change projections for biodiversity?

Uncertainty in projections for Alberta's future biodiversity can arise from several sources including uncertainty in the accuracy of climatic conditions predicted by the global climate models (GCMs), differences in the modeling algorithms, quality of the data used to parameterize the models, and the often unpredictable ecological responses of species and communities to novel environments.

The accuracy of GCMs will be influenced by the natural variability in climate systems, by the amount of greenhouse gas emissions and by differences between the algorithms employed by different modeling groups. Uncertainty in the projections of future climate conditions increases through projected time; the largest component of uncertainty about the far future is whether and how society limits emissions.

Projections from global climate models were employed by much of the research on the BMCCA project, and in most cases, uncertainties in model projections were bounded by reporting results from several different models under one or more greenhouse gas emissions scenario.

What are we most confident about?

While outcomes from individual projects should be viewed with caution, careful analysis suggests some robust generalities that emerge across studies. Higher levels of certainty are associated with good data and with agreement among differing analyses. Confidence is highest when there are multiple and consistent sources of high-quality evidence.

For example, Richard Schneider (2013) investigated changes in Alberta's ecosystems under several climate change scenarios and concluded that the projected direction of change in the climates for each Subregion, and the potential subsequent transformation of ecosystems, were consistent for most of Alberta's Natural Subregions and for the majority of climate models. Projections from different GCMs differed primarily in the speed with which the changes will occur.

To examine the reliability of ecological niche models for predicting the future distribution of boreal birds, Diana Stralberg and colleagues (2015) evaluated the magnitude of projected changes in species' abundances relative to the uncertainty associated with those projections. They found that, despite increasing uncertainty towards the end of the century, the magnitude of the projected directional change in species abundance generally exceeded the uncertainty.

Contrary to expectations, uncertainty about the state of Alberta's avifauna declines with longer time horizons because of the large magnitude of the projected change. More detailed analysis suggested that greater uncertainty was associated with species of deciduous forests because they are strongly dependent on moisture conditions and therefore more sensitive to the climate model employed. For the majority of species, GCM uncertainty was much larger than model or data uncertainty, highlighting the need for scenario planning, as well as adaptive monitoring and management as more data are collected. For several subarctic species, however, high uncertainty was related to data gaps that should be addressed.

In some cases, consistent outcomes have emerged from individual studies in which uncertainty was not explicitly addressed. For example, multiple (independent) analyses suggest the wetter Foothills Natural Region and higher elevation hill systems are likely to remain climatically suitable for a large diversity of boreal species in the future (Stolar and Nielsen in revision, Stralberg in revision, Stralberg et al. 2014), while grassland species are likely to expand into the drier boreal plains region (Nixon et al. 2015, Schneider 2013, Stralberg and Bayne 2013,).

How can uncertainty be incorporated into planning and decision-making?

Uncertainty about the way climate change will affect biodiversity does not necessarily mean that we cannot make effective management decisions. Natural resource planning usually uses a deterministic approach in which the management approach chosen is the one most likely to achieve the desired result based on the assumption that future conditions can be predicted. For example, maintaining forest inventory dictates harvest levels based on growth and yield estimates. However, if forest productivity changes with the changing climate, current harvest levels may no longer meet stated goals.

Richard Schneider (2014) explored several options for advancing biodiversity-related planning in the face of climate change uncertainty. One approach is a "no regrets" strategy designed to produce acceptable, if not ideal, management outcomes across a wide range of potential futures. Another approach is "bet hedging" in which a variety of strategies is applied simultaneously across the landscape with the expectation that some will be more effective than others. This approach can be evolved into a classic "adaptive management" approach in which the better alternatives are identified and adopted more broadly. A "triage" approach is contentious in that it entails shifting from trying to save all species to making a conscious decision to invest resources into saving certain species while accepting losses of others.

From a community adaptation perspective, ecosystem-based adaptation helps to address the uncertainty associated with planning for climate change. Because they have multiple benefits, these strategies are lower-risk in light of the uncertainty associated with predicting the exact impacts of climate change on a community.

CONCLUSIONS

Through its coordinated research efforts, the BMCCA project has created a large body of knowledge that contributes to a better understanding of the future of Alberta's biodiversity and of the approaches that might be employed to manage the province's living resources in the face of a changing climate.

Alberta's species and ecosystems will continue to shift and change.

Projections for the distributions of Alberta's regional ecosystems indicate the potential for dramatic ecological change, especially in the boreal region of northern Alberta. Similarly, projections for a variety of Alberta's species demonstrate that the climate niches of boreal species in Alberta are highly vulnerable to climate change, and it is likely that many boreal species will shift their distributions out of the province.

In contrast, grassland species and ecosystems in the province have the potential to expand, but these opportunities may be limited by current and potential future land-use. Differences in the transition rates among species and ecosystem components will likely result in novel combinations and new ecosystems.

Not all Alberta species are equally vulnerable to climate change.

Both broad and detailed assessments of species' climate vulnerability highlight vulnerable groups or species that may require special attention. These include species already vulnerable because of land use change or other factors, as well as some that are not currently at risk. Increasing incidence of extreme weather events exacerbates risk for many species, particularly rare or at-risk species with small population sizes. However, many other species, especially those that are wide-ranging and adaptable, will likely thrive as the climate changes.

Incorporating climate change vulnerabilities into general and detailed species assessments and recovery plans will guide management actions necessary to conserve these species over the long term and respond to potential opportunities to recover species at risk. Many of these actions, like habitat management and conservation, are already being implemented to address non-climate risks, but some novel approaches, such as assisted migration, may become necessary for some species.

Climate change will increase risk from invasive species.

Climate change will alter conditions for plant growth in Alberta, inevitably resulting in an increase in the rate at which non-native species are introduced and become established in the province. Many of these species have traits expected to have negative ecological or economic consequences in Alberta. Incorporating climate change into current invasive species risk assessments can identify new priority species for early detection and rapid response, and highlight priority regions for increased monitoring.

Landscape-level planning should consider climate change.

Expected changes in species and ecosystem distributions have consequences for current and future land use in Alberta. The stable, enduring landscape features, like topography and latitude, characterized by Alberta's Natural Subregions, will continue to represent much of the province's biodiversity at the ecosystem scale, even as climate change progresses. We have further identified likely climate refugia for species and species groups. In particular, the higher elevation areas of Alberta are likely to provide climate refugia for boreal birds and plants in the coming decades.

Conservation planning approaches that combine these elements will have considerable current and future conservation benefit. The provincial regional planning process under the Land Use Framework[40] provides an opportunity for the identification and establishment of climate-ready protected areas. Outside of protected areas, expanding human land use will have major consequences for biodiversity. Land use planning should incorporate climate change projections for a more accurate picture of the future of species and ecosystems in the province.

[40] *https://landuse.alberta.ca/REGIONALPLANS/Pages/default.aspx*

Ecosystem-based adaptation can increase climate resiliency for local communities

Although most climate change adaptation planning at the local level emphasizes engineered infrastructure that addresses specific climate risks, ecosystem-based adaptation approaches may provide opportunities to increase climate resiliency of local communities. These approaches, which increase climate resiliency by identifying and managing natural infrastructure like wetlands, are well-suited to municipal needs and mandates.

The benefits of ecosystem-based adaptation for local governments include: 1) the co-benefits, including their additional support of agriculture, biodiversity conservation, human health protection, recreation planning, and economic sustainability objectives, 2) cost-effectiveness through harnessing existing natural infrastructure, and 3) improved risk management through a proactive, systems-based approach that addresses a broader range of potential impacts. Ecosystem-based adaptation approaches could complement, rather than replace, municipalities' hard infrastructure approaches.

Uncertainty in prediction and planning can be accommodated.

Multiple lines of evidence, detailed statistical analysis and new modeling tools allow a better assessment of the level of uncertainty associated with changes in biodiversity in response to climatic changes. Despite some lack of precision in predicting the future state of Alberta's biodiversity, we are now in a much better position to forecast broad patterns of future change. A variety of practical approaches, such as "no-regrets" or "bet-hedging" approaches, can be employed to address future uncertainties in planning for landscape and species conservation and to incorporate uncertainty into management decision-making.

For municipalities wanting to address climate-related risks to their social, economic, or environmental well-being, ecosystem-based adaptation strategies, such as wetland conservation and restoration, are lower-risk than many other adaptation strategies in light of the uncertainty associated with climate change. This lower implementation risk is a result of the potential of these strategies to achieve multiple community objectives and address more than one climate risk through a single action.

Continued and expanded biodiversity monitoring is required.

High-quality, spatially explicit observational data obtained through monitoring, including species presence, species abundance and ecosystem data, underpin the majority of research developed through the BMCCA project. Biodiversity data can provide an early warning system for detecting the effects of climate change on species and ecosystems. These data also contribute to construction and validation of future projections of species and ecosystem distributions, development of biodiversity indicators to support decision-making, and evaluation of adaptive management actions.

Several BMCCA projects were based on species observation data collected by citizen scientists and contributed to long-term datasets, such as the Breeding Bird Survey[41] and ACIMS.[42] With the current and improving ability to accurately and easily geo-reference observations, the growth of these datasets will become an increasingly valuable source of information for scientists investigating the impacts of climate change on biodiversity.

---

[41] *Breeding Bird Survey: https://www.pwrc.usgs.gov/bbs/*

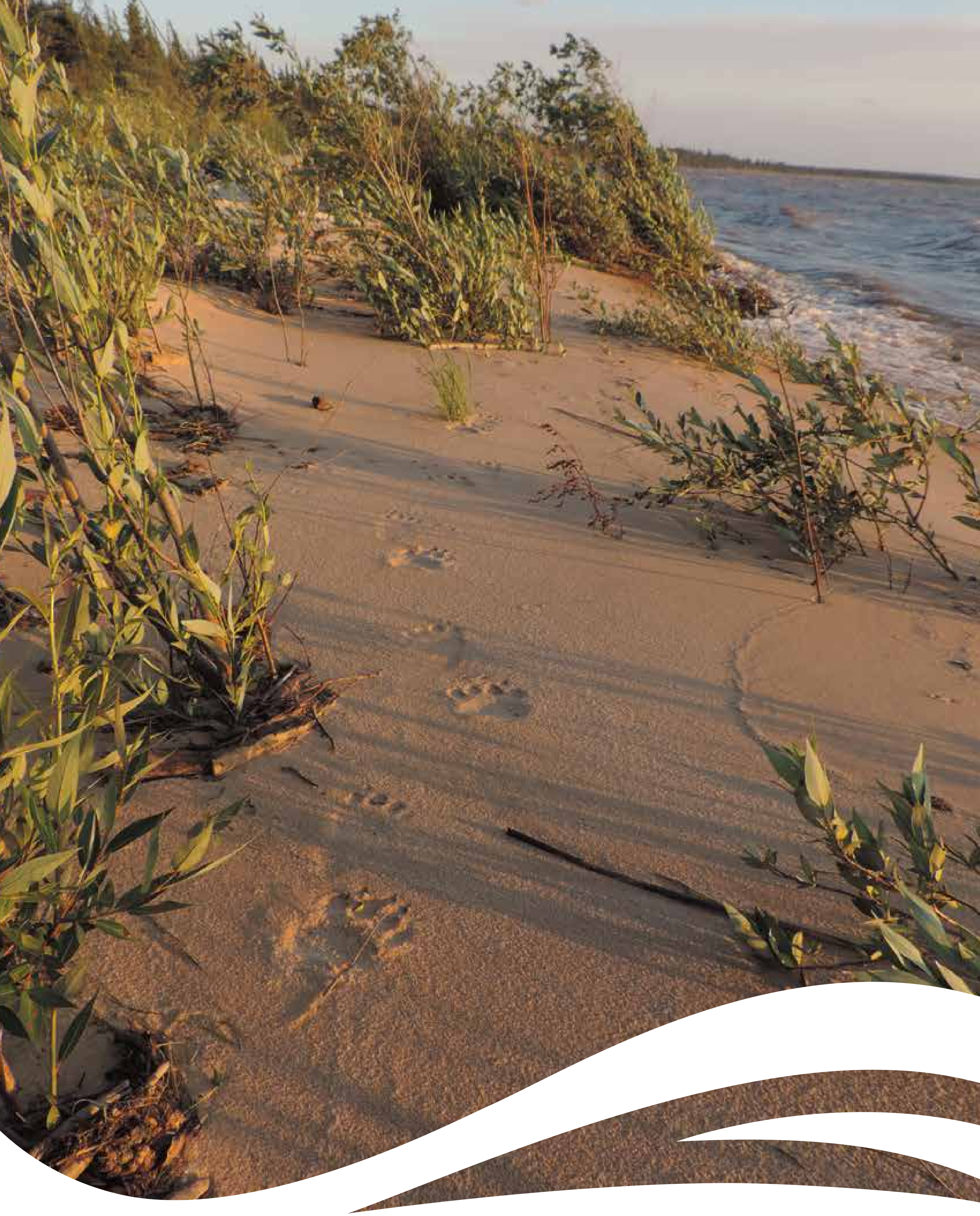
[42] *ACIMS: Alberta Conservation Information Management System. For more information: http://www.albertaparks.ca/albertaparksca/management-land-use/alberta-conservation-information-management-system-(acims).aspx*

BUILDING ON THE PROJECT

The BMCCA project made considerable progress in identifying the potential effects of climate change on Alberta's biodiversity and in exploring potential adaptation responses. However, effectively addressing the effects of climate change on Alberta's biodiversity will require continued research that broadens and refines the results from this project.

Continued effort and further research is necessary to:

1. *Expand and refine modeling of species and ecosystem distributions in Alberta, especially with a focus on representing uncertainty in ways that can be incorporated into management and planning.*
2. *Better understand ecological responses to climate change in the province, including the rate and nature of ecosystem transitions, in-situ adaptation, the interactions and lags between species and habitat transitions, the role of landscape connectivity, and how interactions between climate change and future land use may impact species and ecosystem distributions.*
3. *Identify and address the consequences of climate change for aquatic species and ecosystems, which are potentially highly sensitive to climate change.*
4. *Understand the responses of species of interest to changes in environmental conditions and evaluate potential targeted management actions in terms of their social and economic costs through field research and pilot studies. A starting point would be to address species identified as high vulnerability by the Climate Change Vulnerability Index and species with dramatic projected range shifts.*
5. *Further develop the provincial biodiversity monitoring system to ensure data are collected to: detect early signals of climate change impacts; validate and refine biodiversity projections based on climate envelope modeling; evaluate adaptive management actions; and effectively describe current conditions, as benchmarks for future reference.*
6. *Better understand and address the policy implications of incorporating climate change into provincial planning and management, including for regional land use planning, and accommodate the uncertainty associated with projecting the consequences of future climate change.*
7. *Enable Alberta's municipalities to incorporate climate change into their planning and to implement adaptation strategies, including ecosystem-based adaptations.*
8. *Improve public awareness and understanding of climate change and its consequences for our species, ecosystems and communities as an essential prerequisite for public and political support for new approaches to management and policy.*



THE PROJECT TEAM

The Biodiversity Management and Climate Change Adaptation project was led by the Alberta Biodiversity Monitoring Institute with contributions from a diverse team of scientists and applied researchers from collaborating institutions across the province and beyond.

Alberta Biodiversity Monitoring Institute

Dan Farr
Lindsay Monk
Tara Narwani
Amy Nixon
Chris Shank
Shannon White

Alberta Innovates Technology Futures

Shauna-Lee Chai

Miistakis Institute

Guy Greenaway
Rachelle Haddock
Greg Chernoff
Tracy Lee
Ken Sanderson

University of Alberta

Erin Bayne
Ryan Fisher
Scott Nielsen
Jennine Pedersen
Richard Schneider
Diana Stralberg
Jessica Stolar
Jian Zhang

University of Saskatchewan

Jeffrey Lane

Alberta Environment and Sustainable Resource Development

Angele Vickers

The BMCCA Project Steering Committee

The BMCCA project benefited from the guidance and expertise of the project's Steering Committee, which included representatives from Alberta Environment and Sustainable Resource Development, Alberta Agriculture and Rural Development and Alberta Municipal Affairs. We are grateful for the dedication they brought to this project.

PROJECT REPORTS AND PUBLICATIONS

All reports and publications will be available at www.biodiversityandclimate.abmi.ca/resources/reports-publications. BMCCA project team members are highlighted in bold.

Peer-reviewed Publications

Fisher, R. J., T. I. Wellicome, **E. M. Bayne**, R. G. Poulin, L. D. Todd, and A. T. Ford. *In review.* Extreme precipitation causes reduced nest reoccupation and reproductive output in an endangered raptor. Journal of Applied Ecology

Laux, C. M., C. Nordell, **R. J. Fisher**, J. W. Ng, T. I. Wellicome, **E.M. Bayne.** *In review.* Ferruginous hawks alter parental behaviour in response to approaching storms. Journal of Ornithology.

Schneider, R. R., K. Devito, N. Kettridge, and E. Bayne. *Submitted.* Moving beyond bioclimatic envelope models: integrating upland forest and peatland processes to predict ecosystem transitions under climate change in the western Canadian boreal plain.

Schneider, R. R., and **E. M. Bayne.** *2015.* Reserve design under climate change: from land facets back to ecosystem representation. PLoS One 10(5):e0126918.

Shank, C. C. *In press.* Are American pikas (*Ochotona princeps*) in the Canadian Rockies vulnerable to climate change? Canadian Field Naturalist

Stralberg, D., E.M. Bayne, S. G. Cumming, P. Sólymos, S. J. Song, and F. K. A. Schmiegelow. *In revision.* Conserving boreal forest birds in a rapidly changing climate: a modified refugia approach. Diversity and Distributions.

Stralberg, D., S. M. Matsuoka, A. Hamann, E. M. Bayne, P. Sólymos, F. K. A. Schmiegelow, X. Wang, S. G. Cumming & S. J. Song. 2015. Projecting boreal bird responses to climate change: the signal exceeds the noise. Ecological Applications **25:**52-69.

Stolar, J. and **S. E. Nielsen.** *In revision.* Mitigating potential losses of Alberta's rare vascular plants and butterflies under climate change and resource use. Ecosphere.

Stolar, J. and **S. E. Nielsen.** 2015. Accounting for spatially-biased sampling effort in presence-only species distribution modelling. Diversity and Distributions **21:**595-608.

Wellicome, T.I., **R.J. Fisher,** R.G. Poulin, L.D. Todd, **E.M. Bayne,** T.D. Flockhart, J. Schmutz, K. De Smet & P. James. 2014. Return rate of endangered burrowing owls in Canada is influenced by weather during migration and on their wintering grounds. The Condor **116:**446-458.

Zhang, J., S. E. Nielsen, J. Stolar, Y. Chen, and W. Thuiller. *In review.* Gains and losses of plant species and phylogenetic diversity for a northern high-latitude region. Diversity and Distributions.

Final Reports

Chai, S.-L., A. Nixon, J. Zhang, and **S. Nielsen.** 2014. Predicting invasive plant responses to climate change: Prioritization and mapping of new potential threats to Alberta's biodiversity. Prepared for the Biodiversity Management and Climate Change Adaptation Project. Alberta Biodiversity Monitoring Institute, Edmonton, Alberta, Canada. 64pp.

Fisher, R. and **E. Bayne.** 2014. Climate change adaptation plan for Burrowing Owls in Alberta. Prepared for the Biodiversity Management and Climate Change Adaptation Project. Alberta Biodiversity Monitoring Institute, Edmonton, Alberta, Canada. 63pp.

Nixon, A., R. J. Fisher, D. Stralberg, and **E. Bayne.** 2015. Projected responses of Alberta grassland songbirds to climate change. Prepared for the Biodiversity Management and Climate Change Adaptation Project. Alberta Biodiversity Monitoring Institute, Edmonton, Alberta, Canada. 53pp.

Shank, C. C., and **E. M. Bayne.** 2015. Climate change adaptation plan for Ferruginous Hawks in Alberta. Prepared for the Biodiversity Management and Climate Change Adaptation Project. Alberta Biodiversity Monitoring Institute, Edmonton, Alberta, Canada. 42pp.

Shank, C. C., and **A. Nixon.** 2014. Climate change vulnerability of Alberta's native terrestrial biodiversity: a preliminary assessment. Prepared for the Biodiversity Management and Climate Change Adaptation Project. Alberta Biodiversity Monitoring Institute, Edmonton, Canada. 62pp.

Schneider, R. R. 2014. Conserving Alberta's biodiversity under climate change: a review and analysis of adaptation measures. Prepared for the Biodiversity Management and Climate Change Adaptation Project. Alberta Biodiversity Monitoring Institute, Edmonton, Alberta, Canada. 65pp.

Schneider, R. R. 2013. Alberta's biodiversity under a changing climate: past, present and future. Prepared for the Biodiversity Management and Climate Change Adaptation Project, Alberta Biodiversity Monitoring Institute, Edmonton, Alberta, Canada. 97pp.

Interim Reports

All interim reports were prepared as progress reports for the Biodiversity Management and Climate Change Adaptation Project, Alberta Biodiversity Monitoring Institute, Edmonton, Alberta, Canada.

Bayne, E. and **D. Stralberg.** 2015. Bird community composition along elevation and latitudinal gradients in Alberta's mixedwood forest: analogues for our future climate? 26pp.

Bayne, E., and **S. Nielsen.** 2012. Scientific support for assessing the vulnerability of Alberta's biodiversity to climate change. 15pp.

Chernoff, G. 2014. A blueprint for engagement: Stakeholder engagement strategy for the Adapt-action tool. 14pp.

Chernoff, G. 2013. Downscaling climate data for climate change adaptation action planning in Alberta. 19pp.

Fisher, R. and **E. Bayne**. 2013. Protecting rare grassland birds from extreme weather events. 15pp.

Fisher, R. and **E. Bayne.** 2012. Protecting rare grassland birds from extreme weather events. 17pp.

Greenaway, G. 2014. Navigating with narratives: Using a narrative approach to connect climate change implications and adaptation actions. 30pp.

Greenaway, G. 2013. Making resilience matter: Communications strategy for the local adaptations sub-project. 20pp.

Greenaway, G. 2013. Where resilience meets policy: A review of southern Alberta municipal policies for climate change adaptation strategy insertion points. 43pp.

Greenaway, G., T. Lee, G. Chernoff and **K. Sanderson.** 2013. Proposed action plan approach for local adaptation to climate change in Alberta. 50pp.

Greenaway, G., T. Lee, G. Chernoff, and **K. Sanderson.** 2012. Review of possible tools for local adaptation to climate change in Alberta. 78pp.

Haddock, R., and **G. Greenaway. 2014.** Groundwork: understanding user assumptions and bases for the Adapt-action tool. 68pp.

Lane, J. 2014. Climate change and assisted migration of montane mammals. 15pp.

Lee, T., G. Chernoff, and **K. Sanderson.** 2014. Environmental changes and implications of climate change for rural communities in the Grassland Natural Region of Alberta. 31pp.

Lee, T. and **K. Sanderson.** 2014. Ecosystem-based Adaptation (EbA): The role of EbA to address climate change in Southern Alberta. 21pp. Nielsen, S. 2013. Technologies for conserving climate-sensitive species at risk: rare plants. 19pp.

Nixon, A., M. Iravani, T. Habib, and **S. R. White.** 2015. Climate change and the provision of ecosystem services in Alberta: an initial assessment of impacts and adaptation strategies on Alberta's rangeland. 21pp.

Nordell, C. and **E. M. Bayne.** 2015. REACT Ferruginous Hawk climate change study summary. 12pp.

Pedersen, J., S. Nielsen, and E. MacDonald. 2014a. Assisted migration of the northern blazing star and long-leaved bluets in Alberta: 2014 progress report. 19pp.

Pedersen, J., S. Nielsen, and E. MacDonald. 2014b. Assisted migration of the long-leaved bluets and northern blazing star in Alberta. 19pp.

Sanderson, K. 2013. Climate change adaptation action plans – Alberta process review. 18pp.

Shank, C. C. 2012. Framework for assessing the vulnerability of Alberta's biodiversity to climate change. 61pp.

Stralberg, D., E. Bayne, and **S. Nielsen.** 2014. Hills refugia project: 2014 update. 25 pp.

Stralberg, D., R. R. Schneider, and **E. M. Bayne.** 2014. Summary: Climate refugia for boreal birds in Alberta. 1p.

Stralberg, D. and **E. M. Bayne.** 2013. Modeling avifaunal responses to climate change across Alberta's Natural Regions. 98pp.

Stralberg, D. 2012. General circulation model recommendations for Alberta. 9pp.

White, S. R., M. Bilton, F. Slowik, E. Bork, K. Tielborger, J. F. Cahill. A novel approach to predicting species responses to climate change in the Canadian prairies. 16pp.*

Report content in preparation for submission to peer-reviewed publication. Summary available online.

GENERAL TERMS

This report was produced as part of the Biodiversity Management and Climate Change Adaptation Project. This project is led by the Alberta Biodiversity Monitoring Institute, with collaborators from the University of Alberta, Alberta Innovates Technology Futures, the University of Saskatchewan, and the Miistakis Institute. The project receives its core funding from the Climate Change and Emissions Management Corporation. Additional support was provided by the Boreal Avian Modelling Project and the Alberta Conservation Association.

Photo credits:

Cover photo: badlands, credit: Steve Brusselers/ p.6: boreal, credit: Charlie Sikkema/ p.17: Tennessee Warbler, credit: Paul Reeves; Ovenbird, credit: Stubblefield Photography/ p.19: Western Meadowlark, credit: Tom Reichner; Sprague's Pipit, credit: Glenn Bartley/ p.22: Glacier Lily, credit: Varina Crisfield/ p.23: native prairie, credit: Monica Dahl/ p.25: Purple Pitcher Plant, credit: Kendal Benesh; Coyote, credit: Angel DiBilio; Harlequin Duck, credit: Peter Massas; Great Plains Toad, credit: Laurel Badura/ p.26: American Pika, credit: Chris Kolaczan/ p.28: Burrowing Owl in flight, credit: Troy Wellicome/ p.29: Ferruginous Hawk, credit: Tom Reichner/ p.30: Tamarisk, credit: Christian Musat/ p.32: Elk, credit: Nick Parayko/ p.35: Burrowing Owls, credit: Troy Wellicome; Ferruginous Hawk nest, credit: Janet Ng/ p.36: Columbian Ground Squirrel, credit: Craig Harding / p.39: Northern Blazing Star, credit: Scott Nielsen/ p.44: Cypress Hills, credit: Pictureguy/ p.46: monitoring, credit: Daina Anderson/ p.47: Medicine Hat, credit: Brenda Carson/ p.50: storm, credit: Kate Tucker/ p.55: bryophyte, credit: Ashley Hillman/ p.58: Black Bear tracks, credit: Daina Anderson.

ABMI

BMCCA
Biodiversity Management
& Climate Change Adaptation

FSC LOGO

EDMONTON OFFICE

Alberta Biodiversity Monitoring Institute
CW 405 Biological Sciences Centre
University of Alberta
Edmonton, Alberta
Canada, T6G 2E9

www.biodiversityandclimate.abmi.ca

Alberta Biodiversity Monitoring Institute
@ABbiodiversity