

Climate Change Impacts to Biodiversity in the Prairie Provinces

**Prepared for Prairies Regional Adaptation Collaborative (PRAC)
And
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Alberta Environment and Sustainable Resource Development**

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The Regional Adaptation Collaboratives Program was a partnership led by Natural Resources Canada to advance local climate change adaptation and decision-making. The Prairie Regional Adaptation Collaborative (PRAC) was one of several regional partnerships across the country, and it focused on three themes: water supply and demand, drought and flood planning, as well as forest and grassland ecosystems. Under the latter theme, one of three case studies to be examined in more detail was that of climate change impacts to biodiversity and species at risk in the Prairie Provinces.

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Specific objectives and content of this report were developed in collaboration between Alberta Fish and Wildlife Division and the Pembina Institute. Sachi Gibson, Paul Cobb, and Nathan Lemphers from the Pembina Institute researched and prepared the report, carrying out literature reviews, various policy analyses, and writing; Roberta Franchuk provided editorial and layout assistance. Fish and Wildlife biologists Lisa Matthias and Gavin Berg provided overall project direction, outlined questions and topics to be addressed by the report, supplied resource material, wrote segments of the report, and edited and formatted the final report. Robin Gutsell provided additional editorial support and other Fish and Wildlife staff provided further input.

Executive Summary

Climate change is increasingly recognized as a major threat to biodiversity; experts estimate high climate-related species extinction in coming decades. Ecosystem and species responses to climate change have been observed across a wide range of taxonomic groups and geographic distributions.

This report is intended to aid in the development of climate change adaptation options that biologists and resource managers can implement to help species and habitats in the Prairie Provinces cope with the impacts of climate change.

Existing species at risk processes provide robust mechanisms for initially identifying and working towards the conservation of those species at highest risk of extinction from an area. An evaluation of the degree to which climate change is currently incorporated into existing species at risk practices provides a key starting point for discussing more broadly the potential climate change impacts to biodiversity in the Prairie Provinces.

The Alberta Species at Risk Program is used as a case study to perform a gap analysis with regards to the integration of climate change information in species status assessments and recovery planning. This examination ends with action-based recommendations for better integrating climate change science and adaptation planning into species at risk work. A review of relevant climate change policy from Alberta provides context for this analysis.

A broad literature review then summarizes the current state of knowledge with regards to species and ecosystem responses to climate change. By recognizing characteristics of and examples of species that have demonstrated susceptibility to climate change impacts, biologists can better identify those species and other components of biodiversity that might be at highest risk from climate change in Alberta, Saskatchewan, and Manitoba.

Relevant climate scenarios and modeling are summarized for Alberta to assist in moving forward with assimilating climate change information into current species at risk work. Resources for accessing similar information for other jurisdictions are provided.

The report then undertakes an extensive exploration of climate change vulnerability and risk assessments for biodiversity that have been developed and used by a variety of conservation organizations worldwide. These various methods are compared and contrasted as potential approaches for identifying the elements of biodiversity that will be at highest risk from climate change impacts in the Prairie Provinces.

Overall recommendations are a) to integrate climate change assessment and adaptation into existing conservation processes like species at risk programs by following the recommended actions; and b) to initiate comprehensive vulnerability assessments for biodiversity using the recommended models, which include an “expert characterization approach”, and a “resilience approach” to assessing vulnerability.

1. Introduction

1.1 Project goal, objectives, and outcomes

The current and projected impact of climate change on ecosystems, habitats, and species has been described and documented in a growing body of international and local research.¹ Government agencies, researchers and practitioners, are engaged in efforts to better understand these impacts, and to incorporate climate change into planning and risk assessment.

The Regional Adaptation Collaboratives Program was a partnership led by Natural Resources Canada to advance local climate change adaptation and decision-making. The Prairie Regional Adaptation Collaborative (PRAC) was one of several partnerships across the country, and focused on three themes: water supply and demand, drought and flood planning, and forest and grassland ecosystems. Under the latter theme, one of three case studies to be examined in more detail was that of climate change impacts to biodiversity and species at risk in the Prairie Provinces.

Goal

The ultimate goal of this work is to aid in the development of climate change adaptation options that biologists and resource managers can implement on the ground to help the large variety of wild species and habitats in the Prairie Provinces cope with pending habitat and environmental shifts stemming from human-caused climate change.

Objectives

Immediate objectives under this goal include the following:

- 1 Evaluate existing species at risk methods and practices in the Prairie Provinces to evaluate the degree to which climate change knowledge and science are currently integrated:
 - Use Alberta's Species at Risk Program and supporting policy development as a case study.
- 2 Review and summarize scientific and conservation-based literature that documents and discusses known or predictable biological responses to climate change and is applicable to biodiversity in the Prairie Provinces.
- 3 Provide a non-technical introductory review of climate scenarios and modeling as a reference for biologists, followed by a summary of future climate scenarios in the prairies:

¹ This report documents a cross section of that research. See bibliography for list of publications.

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- Focus on Alberta climate scenarios to accompany objective 1 and to support moving forward with recommendations for integrating climate change science into species at risk processes.
- 4 Review vulnerability and risk assessment methodologies undertaken across Canada and internationally to find an approach for broadly identifying elements of biodiversity in the Prairie Provinces with the highest risk to expected climate change impacts.
- Some elements of biodiversity may not be included in species-level risk assessment and recovery processes (e.g., habitats, ecosystems, population- and genetic-level biodiversity, species that may anticipate pressures over longer conservation time frames like the next 50 to 100 years or more), requiring additional assessment methods for identifying biodiversity at highest risk from climate changes in the prairies.

Outcomes

Objective 1 will provide recommendations for improved integration of climate change information into existing species at risk processes. This will assist in future identification of species already addressed by species at risk programs that may be at elevated risk from current and anticipated climate change impacts. Furthermore, existing and future species at risk conservation and recovery efforts can be strengthened by using recommended pathways for integrating climate change information.

Objective 2 will provide a robust literature review of what conservationists already know to be important responses that species and other elements of biodiversity have demonstrated in the face of a changing climate. By recognizing characteristics of and examples of species that have demonstrated susceptibility to climate change impacts, biologists can better identify those species and other components of biodiversity that might be at highest risk from climate change in the Prairie Provinces.

Objective 3 will help biologists move forward with assimilating climate change information into current species at risk work.

Recommendations stemming from objective 4 will allow resource management agencies across the Prairie Provinces to select an approach to risk assessment that could be implemented locally for identifying those biodiversity elements most at risk from anticipated climate changes.

Next Steps

An immediate next step is to use the recommendations from this report to identify the populations, species, habitats, and ecosystems at highest risk from climate change impacts in the Prairie Provinces.

Once these highest risk elements of biodiversity are identified, conservation and resource management agencies can focus on priorities for developing and implementing climate change adaptation options to help biodiversity cope with climate change.

1.2 A species at risk case study for the Prairie Provinces

The research presented in this report applies broadly to habitat and species at risk conservation across the Prairie Provinces, using the processes and species under the Alberta Species at Risk Program (Alberta Sustainable Resource Development, Fish and Wildlife Division) as an illustration and starting point. The program is a well-established example of endangered species conservation and policy in the prairies. *A Strategy for the Management of Species at Risk in Alberta* was first created in 1997, with an updated strategy published in 2008.² The approaches to species at risk assessment and recovery in Alberta are consistent with those in other Canadian and international jurisdictions.

Alberta Sustainable Resources Development (SRD) developed a framework to assess climate change vulnerability and risk to broad ecosystem services (see section 2). Using that framework the Fish and Wildlife Division identified a number of key projected climate change impacts for biodiversity for which there was a high degree of vulnerability and risk. Among these was the possibility of increased numbers of species at risk and the need to understand climate change vulnerability and risk at a finer resolution for individual species, populations and habitats.

After assessing the integration of climate change adaptation knowledge into the existing species at risk process, this report will investigate other avenues for integrating climate change knowledge and science more broadly into biodiversity risk assessment, conservation, and management. A glossary of some of the climate change terms used in the report is provided in appendix 7.1.

² Fish and Wildlife Division. 2008. Alberta's strategy for the management of species at risk (2009-2014). Edmonton, AB: Alberta Sustainable Resource Development, Fish and Wildlife Division.

2. Climate Change and Species at Risk Policy

The following section describes policy work that has been undertaken in Alberta in the area of climate change impacts and adaptation, including the work done by Alberta Sustainable Resource Development and its Fish and Wildlife Division, to complement a more comprehensive examination of mechanisms to integrate climate change adaptation planning into species conservation processes.

A considerable amount of planning and policy development for climate change adaptation has been carried out in the Prairie Provinces. Research has been completed on both climate scenarios and climate impacts, review documents synthesizing climate research within the region have been published, and federal and provincial governments have developed frameworks and processes to support climate change adaptation. The work completed to date is invaluable because a critical component of developing adaptive capacity is increasing the capacity to understand and interpret the challenge, and to explore possible avenues for adaptation to change.

However, relatively little documentation exists to demonstrate actions that have been taken to increase resiliency or adapt to climate change. A present challenge for agencies responsible for biodiversity conservation and management is that existing frameworks and tools designed to support climate change adaptation action and initiatives lack the necessary depth from ecological and species-specific perspectives to fully evaluate drivers of vulnerability, exposure and sensitivity to climate change. The gap between the existing tools and the identified needs of agencies like Alberta Fish and Wildlife is a primary driver for the work presented in this report.

Alberta has already created some important overarching policy for species management and conservation, as well as climate change adaptation, which together will help to support the objectives. Namely, to identify which species and populations are going to be most vulnerable and at-risk from climate change impacts.

2.1 Climate change adaptation in Alberta policy and planning

In Alberta, important foundational work has been undertaken to support adaptation action, including vulnerability assessments, research and publication of climate scenarios, and the development of the *Climate Change Adaptation Framework Manual*.^{3,4}

³ Alberta Sustainable Resource Development. 2010. Climate change adaptation framework manual. Edmonton, Alberta.

⁴ Weber, M., D. Davidson, and D. Sauchyn. 2008. Climate change vulnerability assessment for Alberta. Final Report to Alberta Environment; Climate Change, Air and Land Policy Branch. Edmonton, Alberta.

The following sections outline key documents, resources and networks that together provide a picture of ongoing work on climate science, impacts and adaptation in the province and region.

2.1.1 Alberta Climate Change Plan

The Alberta government recognizes in *Alberta's 2008 Climate Change Strategy* the need to reduce vulnerability to climate change impacts. Focus areas include water, biodiversity, agriculture, forestry in addition to municipal infrastructure and energy.⁵

The plan identifies several primary actions relevant to climate change adaptation: the coordination of policy and research (the Prairies Adaptation Research Collaborative is noted), discussion of climate change risks with Albertans, and the development of appropriate responses to adapt to climate change.

The inclusion of language addressing adaptation to climate impacts extends farther back than the 2008 strategy. A 2002 climate change strategy for Alberta outlined as an objective, to “manage longer-term climate risks, including: adapt to address probable impacts of climate change on the province.” That strategy included funding impacts and adaptation research through the Prairie Adaptation Research Collaborative.⁶

2.1.2 Climate change adaptation initiatives at Alberta Sustainable Resource Development

Alberta SRD's work on climate change adaptation includes reports that precede *Alberta's 2008 Climate Change Strategy*. In 2007 SRD commissioned work to increase understanding of climate risk to SRD's core business areas, and to build the foundation for practical climate change adaptation strategies. The report identified vulnerabilities, presented a preliminary assessment of risk and provided recommended 'next steps' for the development of adaptation strategies.

The vulnerability assessment task of that work followed a three-question process: (i) identify the projected ecosystem impacts, (ii) assess the sensitivity to climate change of the component of the ecosystem, and (iii) assess the adaptive capacity of the component of the ecosystem and/or of SRD.⁷

The results of the vulnerability assessment were illustrated graphically according to sensitivity and adaptive capacity (see table below).

⁵ Government of Alberta. 2008. *Alberta's 2008 climate change strategy*. Edmonton, Alberta.

⁶ Government of Alberta. 2002. *Albertans and climate change: a strategy for managing environmental and economic risks*. Edmonton, Alberta.

⁷ Alberta Sustainable Resource Development. 2007. *Climate change adaptation framework*. Edmonton, Alberta.

Table 1: Categorization of vulnerability for (2007)

		Adaptive Capacity	
		High	Low
Sensitivity	High	Moderate Vulnerability	High Vulnerability
	Low	Low Vulnerability	Moderate Vulnerability

Following the vulnerability assessment, a risk assessment was undertaken using risk matrix that included likelihood of occurrence, and assessed several areas of risk (strategic, financial, technological, physical operations, human capital, modeling and valuation, public confidence and political, and jurisdictional) in order to identify a final risk ranking. The risk assessment was a second step after vulnerability assessment to determine the likelihood and severity of the expected climate change impacts, before looking at adaptation options.

The results highlighted some areas of high-risk relevant to Fish and Wildlife's mandate, including the following:

- shifts in distribution and range of species (classified under biodiversity)
- declines in water quantity and quality (classified under hydrology and resources)
- changes in flow patterns (classified under hydrology and resources)
- increases in surface temperatures (classified under hydrology and resources)
- shifts in vegetation and grazing zones (classified under agriculture)
- reduced overall bioproductivity as a result of poor soil moisture (classified under agriculture)
- declines in ground and surface water (classified under hydrology and water resources)
- increased invasive species (classified under forests)⁸

The results also identified some areas of medium-risk relevant to Fish and Wildlife's mandate:

- increased threat to populations of wild species from extreme weather events (classified under biodiversity)
- changes in bioproductivity (increased plant productivity with longer and warmer growing seasons where not constrained by water shortage) (classified under primary production)

⁸ Notably the mountain pine-beetle.

-
- changes in timing of biological events (e.g., flowering phenology) (classified under pollination)

Lastly, the report attempted to identify organizational capabilities and adaptation options. The organizational capabilities were described as (i) people, (ii) process, (iii) technology, and (iv) governance. Many of the identified adaptation options involved improvements in monitoring and reporting capabilities, stakeholder and community engagement and education, and the expansion of programs (e.g., increase forestation) or zones (e.g., shift allowable grazing zones).⁹

2.1.3 Regional Adaptation Collaboratives

Regional Adaptation Collaboratives (RACs) were the main vehicle for federally supported climate change adaptation initiatives and research for three years, with a budget of \$30 million. The program was announced in December 2007.¹⁰

The goal of the program was to “catalyze coordinated and sustained adaptation planning, decision-making and action, across Canada’s diverse regions.” The RACs were partnerships involving different levels of government and organizations.¹¹

The Prairies Regional Adaptation Collaborative involved extensive cooperation and participation among Natural Resources Canada, the University of Regina’s Prairies Adaptation Research Collaborative, agencies from the provincial governments of the three Prairie Provinces, industry, universities, and climate research institutes.

The primary activities for the Prairie Region Adaptation Collaborative (PRAC) focused on water supply and demand, drought and flood planning, and, forest and grassland ecosystems. The objective was to advance climate change adaptation decision making in relevant policy areas.¹²

2.1.4 Climate Change Adaptation Framework and Manual (2010)

The Alberta Climate Change Adaptation Team (ACCAT) is a cross-departmental working group charged with coordinating climate change adaptation work across the province. As early as 2005-2006, the team was working on vulnerability assessments to determine which sectors of the provincial economy were vulnerable to short-term climate variability and long-term climate change.¹³

⁹ Alberta Sustainable Resource Development. 2007. Climate change adaptation framework. Edmonton, Alberta.

¹⁰ Natural Resources Canada. 2012. Regional adaptation collaboratives. Accessed May 3, 2012. URL: <http://www.nrcan.gc.ca/earth-sciences/climate-change/community-adaptation/regional-collaborative/679>.

¹¹ Natural Resources Canada. 2012. Regional adaptation collaboratives. Accessed May 3, 2012. URL: <http://www.nrcan.gc.ca/earth-sciences/climate-change/community-adaptation/regional-collaborative/48>.

¹² Natural Resources Canada. 2012. Prairie regional adaptation collaborative. Accessed May 3, 2012. URL: <http://www.nrcan.gc.ca/earth-sciences/climate-change/community-adaptation/regional-collaborative/175>. See also background information available at PARC: <http://www.parc.ca/rac/>.

¹³ Alberta Environment. 2006. Leading the way - working together - making a difference. Ministry of Environment 2005-2006 Annual Report. Government of Alberta, Edmonton, Alberta.

Alberta SRD has also established a Team Taking Action on Climate Change that has concentrated on climate change adaptation policy development. The Climate Change Adaptation Framework and Manual (the framework) outlined in this section is the direct outcome of work initiated by these provincial and departmental working groups.

The framework is designed as an evidence-based decision-support tool that provides a “consistent yet flexible approach to understanding where an organization may be vulnerable to climate change impacts”.¹⁴ It is a broad framework for land, resource and infrastructure management, centered on the recognition that “climate change may threaten an organization’s ability to achieve its strategic objectives. Development of climate change adaptation plans should therefore be integrated with strategic planning and Enterprise Risk Management (ERM) processes.”¹⁵

According to the framework, climate change is one of many risks that must be evaluated in the ERM process. The comprehensive understanding of all risks evaluated in the ERM process consequently helps in the development of robust strategic plans. *Climate change risk must be measured in proportion to other risks.* This relationship between ERM, strategic planning, and climate change risk, is illustrated in Figure 1.

¹⁴ Alberta Sustainable Resource Development, 2010. Climate change adaptation framework manual. Edmonton, Alberta.

¹⁵ Ibid.

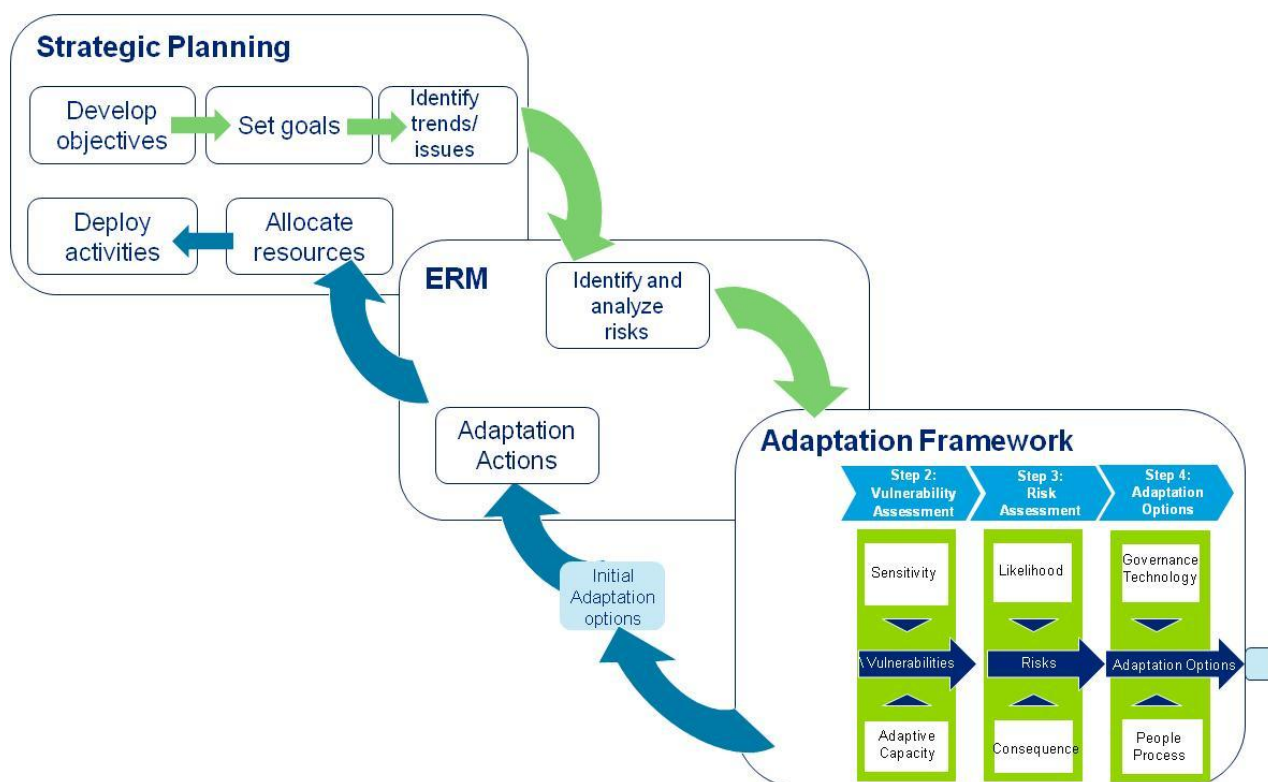


Figure 1: Climate Change Adaptation Framework as part of strategic planning and enterprise risk management¹⁶

The key principles of the framework are as follows: integration with strategic planning, standardized processes (to enable comparability of risk), continuity of process, and stakeholder involvement.

The adaptation framework and manual were designed to guide any interested agency or jurisdiction through a process of understanding sensitivities and existing adaptive capacity, which subsequently informs assessment of vulnerability and climate change risks according to likelihood and magnitude. Having completed this work, decision makers are to be able to identify appropriate adaptation options.

The framework outlines a multi-step process: (1) establish management team, (2) determine scope and complete preparation, (3) complete vulnerability assessment, (4) complete risk assessment, (5) identify adaptation actions, and (6) the development of adaptation strategies. These activities are summarized in Table 2.

The framework and guidance document (the manual) outline leading adaptation practices, namely, building adaptive capacity, embedding climate change into planning, identifying ‘win-win’ opportunities, and monitoring and re-assessing actions.

¹⁶ Ibid.

Table 2: Activities in the adaptation framework

Main elements of the framework	Highlights of process outlined in guide
Adaptation management team	An adaptation management team must be named, including coordinator, strategic planning team and technical team. Key tasks for each group: <ul style="list-style-type: none">• Coordinator (lead climate change preparedness, liaison between technical and strategic teams)• Strategic planning team (develop terms of reference, prioritize and implement options identified)• Technical team (identify relevant impacts, conduct assessments, identify adaptation options)
Scope and preparation	The main work items in this step are to develop an understanding of the primary ecosystem services that the users' mandates are dependent upon, identification of any adaptation work that is ongoing, review of climate impacts as they affect the organization's strategic plan, and to outline the scope of the current assessment.
Vulnerability assessment	The primary activities in this step are to understand sensitivity to climate change, to evaluate adaptive capacity, and to analyze and prioritize vulnerability (where vulnerability is a factor of adaptive capacity and sensitivity).
Risk assessment	Identified vulnerabilities are characterized in terms of risk following a standardized risk evaluation based on likelihood and consequence. Risks are ranked from minor to severe, and five areas of consequence are identified (financial, strategic, operational, environment and safety, and public perception).
Adaptation option	The activity undertaken here is to develop adaptation options for the areas identified with highest risks to climate change impacts, and that match the organization's capabilities.

2.1.5 Initial biodiversity work under the Climate Change Adaptation Framework

Alberta Fish and Wildlife, along with other agencies within SRD, undertook a preliminary vulnerability and risk assessment for their core business as it relates to various ecosystem services. The broad framework under which this work was done was not designed specifically for identifying species that are at additional or new risk as a result of climate change but rather to identify overall natural systems and processes at risk.

2.2 Species at risk policy and practice

Alberta's Strategy for the Management of Species at Risk (2009-2014) is consistent with national and international processes and partnerships to conserve and recover threatened and endangered species.¹⁷ The Alberta Species at Risk strategy outlines six components that form the core of the program:

1. General status: rank the relative security of all wild species to prioritize risk assessment, data collection and conservation initiatives.
2. Detailed status: assess and document the risk of becoming extinct from the region for those species having a general status that suggests concern.
3. *Wildlife Act* listing: formally designate species that are endangered or threatened.
4. Recovery planning: develop provincial recovery plans for all threatened or endangered species.
5. Preventing species from becoming at risk: develop management plans for Species of Special Concern, to prevent them from becoming endangered or threatened; carry out special management and monitoring practices for other rare and sensitive species.
6. Implementing recovery and management actions: coordinate and facilitate the implementation of recovery or management plans, with actions carried out through cooperative efforts of a variety of agencies and stakeholders.

A word search for the terms “climate” or “climate change” or “adaptation” was carried out for the strategy. None of these terms appears in the document. However, the processes described in the strategy provide clear openings for the inclusion of climate change information.

Table 3 identifies key recommendations that could be taken within the existing framework of the Alberta Species at Risk Program to address climate change risks and adaptation options for species at risk. These identified opportunities could be expanded upon to prioritize those actions that should be addressed first. For example a project timeline could be created to identify highest priority and easiest-to-implement actions alongside those recommendations that would require more time and/or resources to implement. These recommendations are also applicable to other jurisdictions and agencies responsible for species at risk conservation.

There are clear opportunities to integrate climate change knowledge and adaptation actions in all stages of species at risk conservation, from general status assessments, to recovery planning and implementation. Section 5 of this report explores other possible approaches to assessing climate change risk for species (e.g., as a separate process from existing species at risk practices).

¹⁷ Fish and Wildlife Division. 2008. *Alberta's strategy for the management of species at risk* (2009-2014). Edmonton, AB: Alberta Sustainable Resource Development, Fish and Wildlife Division.

Table 3: Opportunities to include climate change in *Alberta's Strategy for the Management of Species at Risk*

Strategy	Existing activity	Recommended pathway for inclusion of climate change	Recommended action items
General status	Carry out a General Status exercise to evaluate the relative security of wild populations of all species, in a manner consistent with other Canadian jurisdictions using the <i>Guidelines for Assessing the General Status of Wild Species in Canada</i> .	<p>Use the National General Status Working Group as a forum to discuss climate change.</p> <p>Initiate dialog between biologists and climate experts to match general status data needs with climate scenario outputs.</p>	<p>Review guidelines for general status assessments for opportunities to include climate change related information.</p> <p>Provide recommendations for changes to assessment guidelines that will better encompass climate change science and risk assessment. For example, incorporate determinants of species vulnerability to climate change (see Section 3.1) in the general status assessment guidelines.</p> <p>Provide users of the guidelines with up-to-date information on climate change scenarios. Several hubs for climate science and scenarios exist and could be explored as data sources for this exercise.¹⁸</p>

¹⁸ Possible sources of information include Prairie Adaptation Research Collaborative (www.parc.ca), Pacific Climate Impacts Consortium (www.pacificclimate.org), and Climate Change Scenarios Network (www.cccsn.ca).

Strategy	Existing activity	Recommended pathway for inclusion of climate change	Recommended action items
General status	Work toward including all known vertebrate, invertebrate, and plant species in the general status process...and incorporate new taxonomic groups.	Include scientific information and expert opinion on species sensitivity to climate change impacts to inform prioritization of new taxonomic groups to include in future general status assessments.	Consult with experts of as many taxonomic groups as possible to gather information on known or perceived sensitivity and vulnerability to predicted climate change impacts. For example, design a short questionnaire about known or expected responses of the taxonomic groups to projected climate change impacts. Survey experts using these questions to help inform which taxonomic groups are highest priorities for future general status assessments from a climate change perspective.
General status	Continue to build functional linkages to Fish and Wildlife databases and other data sources. Where data and information are limited, provide opportunity for broad input and use expert knowledge and opinion.	Engage climate change experts in information-sharing processes. Link to climate modeling and scenarios networks, focusing on opportunities to share information on biophysical climate modeling.	Build communication pathways between biodiversity data sources and climate-based data sources to explore opportunities for modeling biological responses to climate change.
Detailed status	Prioritize and select among candidates for detailed status evaluation each year.	Identify species that are at increased risk from climate change to assist in prioritization for detailed status assessment.	Review measures by which species are selected for detailed status assessment to determine the degree to which a species' vulnerability to climate change should be considered.

Strategy	Existing activity	Recommended pathway for inclusion of climate change	Recommended action items
Detailed status	Collect, compile, and report on the information necessary to evaluate detailed status for a species and predict future risks.	Gather climate change science and expert opinion for the species.	Seek out up-to-date information on climate change scenarios relevant to the species' range. Explore existing data and model output sources, and utilize climate change expertise as needed, to formulate an idea of current and future risks to the species from climate change impacts.
Detailed status	Prepare and publish several detailed status reports each year.	Integrate climate change knowledge into detailed status reporting process.	<p>Include a section about climate change in each report. Explain the mechanisms by which climate change threatens the species, and the degree of vulnerability and risk specific to climate change, in as much detail as possible, using a combination of science/data and expert opinion.</p> <p>In addition to evaluating direct impacts, consider interactions between climate and other existing stressors, and indirect impacts (e.g., impacts to other species: predator-prey interactions, symbiotic relationships).</p> <p>Include estimated timeframes for expected changes to the species' habitat and potential impacts to populations.</p>

Strategy	Existing activity	Recommended pathway for inclusion of climate change	Recommended action items
Detailed status	Assess the relative risk of extinction according to IUCN guidelines, using the detailed status report and other information.	Incorporate known or predicted current and future species responses (e.g., declines) to climate change impacts into the detailed evaluation.	Use climate modeling expertise to predict rate of population change over the next 10 years and/or 3 generation lengths after incorporating forecasted changes from climate impacts. Incorporate expert opinion on species response to climate change impacts to refine the status assessment as needed to represent the relative risk to the species across the province.
Detailed status	Designate species for which information is considered inadequate to determine listing as data deficient species. Develop and implement appropriate data collection strategies for these species	Identify data deficient species that have traits that increase vulnerability to climate change.	Design data collection and research strategies that will increase our understanding of the species' responses to climate change.
Legal listing	Designate a staff biologist to be the provincial species coordinator to lead recovery planning and implementation.	Increase capacity of staff biologists to use and understand climate data and scenarios.	Develop and disseminate climate change information to biologists in various formats such as newsletters, webinars, and guest speakers.

Strategy	Existing activity	Recommended pathway for inclusion of climate change	Recommended action items
Recovery planning	Establish recovery teams to develop provincial recovery plans for endangered and threatened species.	<p>Fully integrate climate change science and expert opinion into recovery plans.</p> <p>There might be resistance to adding a new member for each team, maybe this should just be for ones that are particularly sensitive or vulnerable or whatever you call it – or could recommend <u>considering</u> it on a team by team basis. Or suggest that they line up an expert to deliver advice on an as-needed basis.</p> <p>Or maybe we need a standing committee of cc experts who could advise all of our teams – would that work?</p>	<p>Provide guidance for the integration of climate change into recovery plans in recovery planning guidelines.</p> <p>For example, include climate change under descriptions of threats where relevant.</p> <p>Determine how best to integrate climate change adaptation actions into the usual 5-year planning window for action plans.</p> <p>Develop climate change mitigation and adaptation options under the recovery strategy and action plan and implementation table where appropriate.</p>
Recovery planning	Include representation from the department, appropriate technical specialists, and stakeholders on species recovery teams.	Include regional climate change experts on species recovery teams or carry out in-depth consultation with climate change experts during the recovery planning process.	<p>Create a database of climate change experts who are able to participate in recovery team activities.</p> <p>Invite climate change experts to participate on recovery teams/in recovery planning. Identify and secure funding as necessary to ensure participation of climate experts.</p>
Prevention	Identify species for which management plans are needed.	Consider climate change vulnerability in prioritizing species for which management plans are needed.	Identify species of special concern and may be at risk/sensitive species that would be good candidates for special management planning because of climate-change-related sensitivity.

Strategy	Existing activity	Recommended pathway for inclusion of climate change	Recommended action items
Prevention	Prepare and publish management plans for sensitive species.	Develop climate change adaptation strategies and actions within management plans.	Identify climate-change-specific threats and address them with mitigation and adaptation strategies and actions in management plans.
Prevention	Encourage and facilitate research needed to fill data gaps for data deficient species that those that have undetermined general status.	Identify and address data needs related to climate change impacts. What climate trends and indicators are of most relevance to the species' biology? Examples include water availability and timing, water temperatures, length of growing season, and frequency of heavy precipitation events.	Initiate dialog between regional biologists and climate experts to match data needs with climate scenario outputs.
Prevention	Work collaboratively to incorporate preventative management for sensitive species into conservation and stewardship programs.	Identify groups of species that may share climate change vulnerabilities. Consider climate change adaptation options for the management plan that could be carried out by other agencies under more comprehensive climate change adaptation planning.	Consider management planning for multiple-species groups that may be susceptible to climate change impacts in a particular region or habitat. Share species management plans with other agencies and stakeholders. Participate and provide input into the development of programs and strategies in sectors that have a direct impact on wild species, such as forestry and agriculture. This will help to ensure that actions or strategies developed for those sectors can accommodate the changing needs of species.

Strategy	Existing activity	Recommended pathway for inclusion of climate change	Recommended action items
Recovery implementation	Coordinate and facilitate the implementation of recovery plans.	Carry out those recovery and management actions related to climate change mitigation and adaptation.	<p>Participate in multi-agency and multi-stakeholder climate change impact and adaptation working groups to ensure that climate change adaptation activities support species management and recovery.</p> <p>Identify species recovery and management actions that are dependent on actions taken in other sectors, and communicate species needs to decision-makers in those sectors.</p> <p>Focus on implementation of climate change adaptation actions that can help multiple-species groups cope with climate change impacts in a particular region or habitat.</p>
Recovery implementation	Encourage the development of standards, guidelines, beneficial management practices.	Develop standards, guidelines and management best practices that are adaptive and respond to and include climate change information.	Climate change information will continue to evolve and emerge; as new information is acquired, standards, policies and guidelines should be able to reflect up to date information and best practices. Where possible, design guidelines and best practices that encourage the inclusion of new information.
Recovery implementation	Encourage review of land and water resource management policies to help with species at risk conservation and prevention.	Identify current weaknesses in land and water resource policies from a climate change perspective.	Integrate climate-change-related recommendations to any revision of land and water policy that addresses species at risk concerns.

Strategy	Existing activity	Recommended pathway for inclusion of climate change	Recommended action items
Recovery implementation	Review implementation of recovery plans annually to track progress.	Ensure that climate change adaptation strategies and actions that are necessary for species conservation and recovery are implemented.	Evaluate implementation of climate-change-related activities in recovery plans.
Recovery implementation	Create new partnerships with universities, government and non-government organizations to implement research-related recovery and management actions.	Increase outreach to climate science networks, develop forums and networks for information sharing and research that address conservation biology and climate change.	The creation of a collaborative forum for knowledge sharing has been undertaken in several regions in Canada. Examples include Ontario's Regional Adaptation Collaborative, which established the Climate Change Adaptation Community of Practice, an active forum for practitioners and experts to ask questions, and to share knowledge and new information. ¹⁹

2.3 Work to date on species at risk and climate change

2.3.1 Status assessments

The following section provides a brief review of where and how climate change has been included in publicly available general status assessments and detailed status reports in Alberta.

¹⁹ The Ontario Centre for Climate Impacts and Adaptation Resources (<http://www.climateontario.ca/>) is a university-based resource for researchers and stakeholders. The centre operates the facilitated Climate Change Adaptation Community of Practice (<http://www.ccadaptation.ca>), where members share knowledge and information through the user-generated library, a newsfeed, frequent webinars and events, and a member database of over 400 professionals that can be searched by area of expertise. Saskatchewan recently launched the SaskAdapt site (www.saskadapt.ca), a similar initiative focusing on prairie-specific science, experience and action.

General Status Assessment

The general status process is coordinated nationally every 5 years, with each province and territory providing jurisdictional ranks for Canada-wide assessments of species. Alberta's 2010 general status assessment report covered 5235 species, summarized by group and reported in the table below.²⁰ While nearly half of species are listed as secure (2594), 1094 are listed as sensitive or may be at risk; 1026 are listed as undetermined.

Table 4: Summary of general status assessment for Alberta, 2010

Taxonomic group	At Risk	Extirpated	May be at risk	Sensitive	Undetermined	Secure	Exotic/ Alien	Total
Amphibians	1		3	3		3		10
Birds	8	1	4	63	11	214		409
Bivalves			2	3				6
Black flies				3	9	60		72
Bumblebees				1	27	2		30
Butterflies			1	20	37	104		166
Crayfish								1
Fish	6		2	7	11	25	10	62
Gastropods	1		3	14	50	27	2	97
Ground beetles			8	4	162	216		400
Horse flies					14	36		50
Lady beetles				11	26	40		80
Lichens			109	43	33	186		380
Macromoths		1	1	5	12	72		95
Mammals	5	1	4	13	6	56		95
Mosquitoes				2	11	31		44

²⁰ General status assessments are publicly available online at:
<http://www.srd.alberta.ca/FishWildlife/SpeciesAtRisk/GeneralStatusOfAlbertaWildSpecies/GeneralStatusOfAlbertaWildSpecies2010/SearchForWildSpeciesStatus.aspx>

Taxonomic group	At Risk	Extirpated	May be at risk	Sensitive	Undetermined	Secure	Exotic/ Alien	Total
Mosses	1		25	211	126	159		522
Odonates				16	11	42		70
Predaceous diving beetles			3	2	23	130		158
Reptiles	1		2	5				8
Spiders			5	4	319	267		606
Vascular plants	5	1	270	222	148	924		1874
Total	28	4	442	652	1036	2594	12	5235

Inclusion of climate change in general assessment

“Climate change” is referenced on 70 separate occasions in the 2010 general status assessment as a potential threat for species, which is just over 1% of the total number of species assessed. The references are found in 36 instances for species that are ranked as “may be at risk”; 34 for species that are “sensitive”. All references to climate change fall within the background notes of vascular plants, but no other taxonomic groups.

Potential impacts listed all fall within the theme of habitat destruction or degradation, including wetlands, floodplains and changes to river dynamics. The following excerpts from the Alberta general status assessment provide examples of the level of detail to which climate change was evaluated:

- Saltmarsh Sandspurry: Threats to population and habitat include livestock grazing and wetland desiccation induced by climate change.
- Saltwater Cress: Habitat threatened by climate change and subsequent wetland desiccation, and grazing along saline springs and shores.
- Chaffweed: Small number of occurrences; distribution limited to the Grasslands Natural Region. Wetland habitat threatened by desiccation resulting from climate change; populations susceptible to livestock grazing in ephemeral wetlands.
- Cuckoo Flower: Small populations, few occurrences. Habitat desiccation threatened by climate change and deforestation in watershed.

- Sudetan Lousewort: Very small populations, few occurrences; range restricted to Caribou Mountains. Habitat threatened by oil and gas development, and desiccation resulting from climate change.

Detailed Status Reports²¹

66 detailed status reports were reviewed to assess the presence and degree of information included relating to climate change impacts.²² Twenty-four of the status assessments (38%) discussed climate change as a potential limiting factor for the species; climate change was not discussed in the remaining assessments. The following table identifies which detailed assessments include some discussion of anthropogenic climate change (emphasized in bold).

Table 5: Survey of detailed status reports for discussion of climate change impacts

Taxonomic group	Species	Year of the report/update	Discussion of climate change?
Mammals	American badger	2002	no
	Grizzly bear	2010	no
	Swift fox	1997	no
	Wolverine	1997	no
	Northern long-eared bat	2009	yes
	Ord's Kangaroo rat	1997	no
	Red tailed chipmunk	1999	yes
	Wood bison	2002	yes
Vascular plants	Limber pine	2007	yes
	Slender mouse-ear cress	2009	yes
	Small flowered sand verbena	2003	no
	Soapweed	2001	yes
	Tiny cryptanthus	2004	yes
	Western blue flag	2005	yes
	Western spiderwort	2001	no
	Whitebark pine	2007	yes

²¹ All information in this section taken from detailed status reports posted by Alberta Fish and Wildlife, available online. Accessed February 7, 2012. URL: <http://www.srd.alberta.ca/FishWildlife/SpeciesAtRisk/DetailedStatus/Default.aspx>.

²² The review and analysis done for this report differentiates between references to climate (current climate and habitat for the species) and “climate change” (anthropogenic climate change as a potential limiting factor for the species).

Taxonomic group	Species	Year of the report/update	Discussion of climate change?
Non-vascular plants	Porsilds bryum	2006	yes
Invertebrates	Banff springs snail	2002	yes
	Verna's flower moth	2008	no
	Yucca moth	2002	yes
	Weidemeyer's admiral	2005	no
Birds	Barred owl	2005	yes
	Bay-breasted Warbler	2001	no
	Black-throated green warbler	1999	no
	Brown creeper	2003	no
	Burrowing owl	2005	no
	Cape may warbler	2001	no
	Ferruginous hawk	2006	no
	Harlequin duck	2001	no
	Loggerhead shrike	1999	yes
	Long-billed curlew	1998	no
	Mountain plover	2003	yes
	Northern pygmy owl	1999	no
	Prairie falcon	2002	no
	Peregrine falcon	1997	no
	Piping plover	1997	no
	Sage grouse	1998	no
	Sage thrasher	2004	yes
	Short-eared owl	2000	no
	Sprague's pipit	1997	no
	Trumpeter swan	2000	no
	Western grebe	2006	no
	White-winged scoter	2002	no
	Whooping crane	2001	yes
	Willow flycatcher	2001	no
Amphibians	Columbia spotted frog-	1998	yes
	Northern leopard frog-	2003	no

Taxonomic group	Species	Year of the report/update	Discussion of climate change?
	Canadian toad-	1998	no
	Great plains toad	2009	no
	Plains spadefoot	1999	no
	Long-toed Salamander	1999	no
Fish	Athabasca rainbow trout	2009	yes
	Arctic grayling	2005	yes
	Bull trout	2009	yes
	Lake sturgeon	2002	no
	Westslope cutthroat trout	2006	yes
	Pygmy whitefish	2011	yes
	St. Mary shorthead sculpin	2004	no
	Shortjaw cisco	2002	yes
	Stonecat	2004	no
	Western silvery minnow	2003	no
Reptiles	Plains hognose snake	1998	no
	Prairie rattlesnake	1997	no
	Short-horned lizard	2004	no

The level of detail to which climate change is included in the detailed status reports varies from species to species. In some cases, climate change is mentioned only once as a potential threat to habitat. In other cases, climate change is recognized as having complex direct and indirect effects on habitat, predator or prey species, water temperature, or foraging abilities. Table 6 provides examples of how climate change is discussed in detailed status reports.

Table 6: Possible climate-related threats listed in detailed status reports

Species	Reference to climate change
Western blue flag (1999)	The detailed status report references a 1993 citation regarding general threats of climate change to vascular plants, and a 1998 study that suggested climate change impacts may bring about improved opportunities for plants such as western blue flag that occur in Alberta at the northern edge of their North American range. Climate change is described on one hand as an overall limiting factor for the species, but with potentially favourable conditions for populations at the northern end of the range. The overall degree of threat posed by climate change impacts is unclear.
Soapweed (2001)	The report discusses that peripheral populations more so than populations in the center of a species range are adapted to a wider scope of environmental conditions. Thus, marginal populations, like the soapweed population in southern Alberta, which occurs at the northern edge of the species' North American range, may be considered pre-adapted to climate change impacts that may threaten populations in the remainder of the species range.
Banff springs snail (2002)	Consequences of changes to hydrologic flow regimes in the Sulphur Mountain springs are considered for the species. The status report notes that seasonal changes are expected in flows in the face of climate change, and that flow cessations may be expected. Water flow and climate change are presented as one limiting factor for the species, but the level of threat is not described.
Arctic grayling (2005)	The status report discusses habitat fragmentation and water temperature changes as a result of a number of factors, including climate change. Maximum summer water temperatures are listed as an area of particular concern since survival of juveniles at 22.5°C is 100% but survival dropped to 0% at 24.5°C. Grayling are shown to avoid areas of habitat with temperatures above a certain threshold. Significant climate change threats are clearly demonstrated in the status report for this species.
Western small-footed bat (2008)	This report notes a lack of clarity on how climate will impact the species. Possible impacts from drier climate are identified, including increased evaporative losses, leading to more frequent winter arousal and winter flights with negative consequences on fat stores. However, potentially shorter winter seasons may offset this threat. Distributional ranges may shift, necessitating greater flight distances, which may not be possible to because of the species' relatively poor flight ability.
Athabasca rainbow trout (2009)	Combined habitat pressures, including climate change and other alterations to the watershed are described in the status report as threats to this species. Water temperature preferences and upper lethal tolerance are listed. A lack of data and insufficient capacity to complete necessary modeling for evaluation of climate change threat are noted. Climate impacts are anticipated for the species, and the need to complete predictive modeling to increase knowledge of impacts is identified.

Species	Reference to climate change
Woodland caribou (2001, 2010)	<p>An overarching recognition that warming associated with climate change may alter habitat and population dynamics is noted in the status reports for caribou. Other risks noted include increased forest fire hazard and outbreak of forest insects like mountain pine beetle, changes in snow conditions, and changes to forage type/quality/abundance. Potential increases in predation, as a result of climate-facilitated changes in prey species distribution or abundance, are also noted as having potential impact.</p> <p>The level of detail in the woodland caribou assessments reflect the volume of research and conservation that has occurred in the province for this species. Climate change is recognized as a complex limiting factor for woodland caribou in these reports.</p>

In cases where climate change is listed as a potential threat, the discussion focuses primarily on general trends in habitat, including impacts on forests and water, but does not (or cannot) typically quantify the nature or severity of the threat. In short, it appears there is recognition of the potential threat or increased risk associated with climate change, but that the background research needed to quantify the level of risk is lacking. An example is the consequence of increased water temperatures on fish populations; in both cases from the table above, the detailed status report notes that high water temperature negatively impacts fish populations (including causing fatalities above critical thresholds) but there is little discussion or reference that outlines current and observed trends in water increases, or projected water temperature changes under different climate scenarios.

2.3.2 Recovery planning and implementation

Published Alberta species at risk recovery plans were scanned for the keywords “climate change.” As with general status assessments and detailed status reports, the presence and level of detail provided regarding climate change information in recovery plans and recovery implementation updates is inconsistent across species. Table 7 shows for which species climate change was included in recovery plans. Table 8 summarizes the climate change information from species at risk recovery plans.

Table 7: Survey of recovery plans for discussion of climate change impacts

Taxonomic group	Species	Year of the report/update	Discussion of climate change?
Mammals	Grizzly bear	2008	no
	Ord's kangaroo rat	2005	no
	Swift fox	2007	no
	Woodland caribou	2005	no
Vascular	Soapweed	2006	no

plants			
	Western blue flag	2002	no
	Western spiderwort	2005	no
Non-vascular plants	Porsilds bryum	2010	no
Invertebrates	Yucca moth	2006	no
Birds	Burrowing owl	2005	yes
	Ferruginous hawk	2009	yes
	Peregrine falcon	2005	no
	Piping plover	2010	no
	Greater-sage grouse	2005	yes
	Trumpeter swan	2006	no
Amphibians	Northern leopard frog	2005	yes
Fish	Shortjaw cisco	2007	yes
	Western silvery minnow	2008	yes

Table 8: Possible climate-related threats listed in recovery plans

Species	Reference to climate change
Western blue flag (2002)	The recovery plan for western blue flag does not explicitly mention climate change as a habitat threat, but lists the drought of 2000-2001 as an event that exacerbated ongoing challenges.
Northern leopard frog (2005)	The recovery plan states that northern leopard frogs are sensitive to drought, and thus climatic factors, including increased ultraviolet radiation from depleted ozone layer, have likely contributed to declines in population size.
Burrowing Owl (2005)	Efforts to determine the cause of burrowing owl decline include support for climate change studies. The plan notes: "Climate change in Alberta may affect burrowing owl habitat and must be investigated. There could be local applications to mitigate effects." (p.24) The plan also suggests that climate change should be incorporated into landscape models that investigate the cumulative impacts of human activity on the burrowing owl.
Shortjaw cisco (2007)	The recovery plan mentions that climate change could lead to loss of habitat or reduction in quality of habitat, and notes that warming could be particularly detrimental to the shortjaw cisco, which prefers cold, well-oxygenated lakes.
Western silvery minnow	The recovery plan states that the threat posed by climate change

Species	Reference to climate change
(2008)	(including impact on water availability, temperatures and other factors) is impossible to evaluate at the time of writing, and cannot be mitigated locally. It was identified as one of six primary categories of threat and the plan recommends further scientific studies.
Ferruginous hawk (2009)	The recovery plan includes “climate change” as a specific limiting factor for the ferruginous hawk, including potential for changes to migratory behaviour, milder winters leading to decreased ground squirrel hibernation success (with resulting effects on prey availability), and the potential of more tree and nest damage due to greater frequency of high wind events. It notes that these threats are of unknown significance, requiring increased research and monitoring, including the possibility that benefits to the species from climate change may be possible. The recovery plan includes direction to promote research on the impacts of climate change on ferruginous hawks and their habitat.
Sage grouse (2010)	The recovery plan notes that the effects of climate change and potential future climate change on the species are not well understood. It also notes that the source of the species decline is poorly understood, but that recurring drought and climate change may have an impact.

The species at risk recovery plans that address climate change do so primarily in discussions of threats to species, rather than in action plans and implementation tables. The lack of climate change adaptation actions in these recovery plans may reflect, among other things, the time-sensitive nature of recovery implementation and the need to address the most immediate threats to species at risk first.

However, the recovery planning process provides an opportunity to identify, within the typical 5-year timeframe for a species recovery plan, actions that can be taken now, to help species at risk deal with anticipated shifts in habitat conditions as a result of climate change.

3. Known Biological Responses to Climate Change

Climate change is increasingly recognized as a major threat to biodiversity, leading to estimates of high climate-related species extinction in coming decades.²³ Ecosystem and species responses to climate change have been observed across a broad range of taxa and geographic distributions.²⁴

Four overall types of species and population responses to climate change have been summarized in literature: persistence (in cases where climate change does not exceed the tolerance of a species' niche requirements or phenotypic plasticity), range migration (including the colonization of new habitats), adaptation (through evolutionary processes), or extirpation.^{25,26}

At the species level recent research has demonstrated correlations between climate change and shifts in species distribution (to higher latitudes and elevations) and density^{27,28,29,30}; changes in phenology (timing of seasonal activities, such as flowering or migration)³¹; changes in

²³ Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M. Ferreira de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips and S.E. Williams. 2004. Extinction risk from climate change. *Nature* 427: 145-148.

²⁴ Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421: 37-42.

²⁵ Davis, M.B., R.G. Shaw and J.R. Etterson. 2005. Evolutionary responses to changing climate. *Ecology* 86: 1704-1714.

²⁶ Hewitt, G.M., and R.A. Nichols. 2005. Genetic and evolutionary impacts of climate change. In *Climate Change and Biodiversity*, eds. T.E. Lovejoy and L. Hannah. Yale University Press, New Haven, CT.

²⁷ Beever, E.A., C. Ray, J.L. Wilkening, P.F. Brussard, and P.W. Mote. 2011. Contemporary climate change alters the pace and drivers of extinction. *Global Change Biology* 17: 6.

²⁸ Williams, J.W., S.T. Jackson, and J.E. Kutzbach. 2007. Projected distributions of novel and disappearing climates by 2100 A.D. *Proceedings of the National Academy of Sciences* 104: 5738-5742.

²⁹ Halpin, P.N. 1997. Global climate change and natural-area protection: management responses and research directions. *Ecological Applications* 7: 828-843.

³⁰ Walther, G-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J-M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. *Nature* 416: 389-395.

³¹ Ibid.

physiology (function of the organism) and morphology (form or shape of the organism)^{32,33}; and changes in genetics.^{34,35}

In ecosystems, the response of individual species to climate change alters interspecific interactions and can ultimately lead to changes in system properties.³⁶ Climate change has been observed to correlate with changes in the composition of ecological communities, interactions among species, and the structure and dynamics of ecosystems.^{37,38}

3.1 Species and system sensitivity to climate change

“Species that are in greatest danger of climate-change driven extinction are those with high susceptibility to climatic changes, that also have distribution ranges that will experience large climatic changes and where their adaptive capacity is low.”³⁹ – International Union for Conservation of Nature

While the responses to climate change that species and ecosystems will exhibit are highly contextual, scientific studies and assessment approaches have identified several characteristics that can help predict which species are likely to be most susceptible to the impacts of climate change. Susceptibility to climate change can also be exacerbated by features that more generally increase vulnerability to decline, extirpation and extinction.⁴⁰

3.1.1 Determinants of species sensitivity to climate change

Several vulnerability assessment processes have attempted to identify characteristics that make a species particularly susceptible to climate change. For some illustrative examples of the determinants of susceptibility applied by vulnerability assessments, we explain three lists below:

³²Hill, J.K., C.D. Thomas, and O.T. Lewis. 1999. Flight morphology in fragmented populations of a rare British butterfly, *Hesperia comma*. *Biological Conservation* 87: 277–284.

³³Hanski, I., C. Erälahti, M. Kankare, O. Ovaskainen, and H. Siren. 2004. Variation in migration propensity among individuals maintained by landscape structure. *Ecology Letters* 7: 958–966.

³⁴Thomas, C.D. 2005. Recent evolutionary effects of climate change. In *Climate change and biodiversity*, eds. T. E. Lovejoy and L. Hannah. Yale University Press, New Haven, CT.

³⁵Parmesan, C. Ecological and evolutionary responses to recent climate change. 2006. *Annual Review of Ecology, Evolution, and Systematics* 37: 637–669.

³⁶Glick, P., B.A. Stein, and N.A. Edelson, eds. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

³⁷Ibid.

³⁸Shaver, G.R., J. Canadell, F.S. Chapin III, J. Gurevitch, J. Harte, G. Henry, P. Ineson, S. Jonasson, J. Melillo, L. Pitelka, and L. Rustad. 2000. Global warming and terrestrial ecosystems: A conceptual framework for analysis. *BioScience* 50: 871–882.

³⁹International Union for the Conservation of Nature. 2012. Climate change and species. Accessed May 3, 2012. URL: http://www.iucn.org/about/work/programmes/species/our_work/climate_change_and_species/

⁴⁰A glossary in Appendix 7.1 provides definitions for reference.

from the International Union for Conservation of Nature (IUCN)⁴¹, the United States Environmental Protection Agency's (EPA) framework⁴², and the assessment of Australia's biodiversity under climate change.⁴³ The IUCN informs species conservation in Canada and internationally, and the United States and Australia are jurisdictions with scientific approaches and conservation challenges that are comparable to a Canadian context.

Using a workshop consultation with 31 biologists, the IUCN developed the following list of qualities that can be used to diagnose a species' susceptibility to climate change:

- Specialized habitat and/or microhabitat requirements: the potential threats posed by this characteristic are compounded when a species has several life stages, each with different specialized habitat or microhabitat requirements
- Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle
- Dependence on a specific environmental trigger that is likely to be disrupted by climate change (e.g., cues for migrating, breeding, germination, etc.): the potential threat posed by this characteristic is compounded if different life cycle stages rely on different cues, or if males and females rely on different cues
- Dependence on interspecific interactions that are likely to be disrupted by climate change (e.g., interactions with prey, hosts, or symbionts)
- Poor ability to disperse to a new or more suitable range⁴⁴

The framework developed by the U.S. Environmental Protection Agency's National Centre for Environmental Assessment incorporates more specific information about environmental tolerances and habitat specificity in their assessment of vulnerability to climate change.⁴⁵ The list of variables included in the EPA's model for sensitivity to climate change includes components that are similar to the IUCN's factors, and incorporates the following traits:

- Physiological vulnerability to temperature change
- Physiological vulnerability to precipitation change

⁴¹ Galbraith, H., and J. Price. 2009. A framework for categorizing the relative vulnerability of threatened and endangered species to climate change. Prepared for the Global Change Research Program, National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency.

⁴² Foden, W., Mace, G., Vié, J.-C., Angulo, A., Butchart, S., DeVantier, L., Dublin, H., Gutsche, A., Stuart, S. and Turak, E. 2008. Species susceptibility to climate change impacts. In *The 2008 review of the iucn red list of threatened species*, eds. J.-C. Vié, C. Hilton-Taylor and S.N. Stuart. Gland, Switzerland.

⁴³ Government of Australia. 2009. Australia's biodiversity and climate change: a strategic assessment of the vulnerability of Australia's biodiversity to climate change: summary for policy makers. Prepared for the Australian Government by the Biodiversity and Climate Change Expert Advisory Group. Commonwealth of Australia, Department of Climate Change.

⁴⁴ Ibid.

⁴⁵ Galbraith, H., and J. Price. 2009. A framework for categorizing the relative vulnerability of threatened and endangered species to climate change. Prepared for the Global Change Research Program, National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency.

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- Vulnerability to climate-change-induced extreme weather events
 - Dispersive capability
 - Degree of habitat specialization
 - Likely extent of habitat loss due to climate change
 - Abilities of habitats to shift at the same rate as the species
 - Habitat availability within new range of species
 - Dependence on temporary inter-relationships, and
 - Dependence on other species⁴⁶

The Australian strategic vulnerability assessment notes similar physiological and life history traits that influence vulnerability in response to climate-related disturbances. In the Australian case, these traits are used as context for overall understanding of the complexity of climate-related vulnerability. The Australian Biodiversity and Climate Change Expert Advisory Panel lists six characteristics:

- Narrow range of physiological tolerance to factors such as temperature, water availability and fire
- Low genetic variability
- Long generation times and long time to sexual maturity
- Specialized requirements for other species (e.g., for a disperser, prey species, pollinator or photosynthetic symbiont) or for a particular habitat that may itself be restricted (e.g., a particular soil type)
- Poor dispersers
- Narrow geographic ranges⁴⁷

While they differ in the extent of specificity of the variables, these three lists are largely in accordance with one another. They all make reference to narrow physiological tolerances, dependence on specific relationships with other species and species assemblages, and limited ability to move to where conditions may be more suitable or adapt quickly (in an evolutionary sense) to a changing environment.

The sensitivity of ecosystems and communities can depend on the combined sensitivities of the component species, as well as other system sensitivities. For example, the Pacific Northwest Climate Change Vulnerability Assessment, conducted by the University of Washington and collaborators, included system sensitivities such as overall hydrological sensitivities, proximity to the coast, and dependence on the effects of disturbance regimes as determinants of system susceptibility to climate change.⁴⁸

⁴⁶ Ibid.

⁴⁷ Government of Australia. 2009. Australia's biodiversity and climate change: a strategic assessment of the vulnerability of Australia's biodiversity to climate change: summary for policy makers. Prepared for the Australian Government by the Biodiversity and Climate Change Expert Advisory Group. Commonwealth of Australia, Department of Climate Change.

⁴⁸ Glick, P., B.A. Stein, and N.A. Edelson, eds. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

The vulnerability assessment model applied in the Canadian grassland-forest transition zone conducted for the Saskatchewan Climate Change Impacts and Adaptation Directorate took a different approach, instead assuming that ecological responses to future climate change would likely be similar to past responses to climate change.⁴⁹ Their approach did not identify particular characteristics of component species or qualities of the ecosystem that would be expected to be linked to sensitivity; instead they treated historical vulnerability to climate change, not as a determinant, but as a potential indicator of future vulnerability.⁵⁰

It is worth noting as well, both when estimating vulnerability based on species or system characteristic, and when estimating vulnerability based on historic data, that individuals, species and ecosystems often respond to changing conditions in an abrupt way, after a period of little noticeable change. Species and systems responses may not be linear, but instead respond to “tipping points” or thresholds that may be more easily surpassed by increased frequency of extreme weather events (e.g., floods, droughts, storms) than changes in overall averages.⁵¹

3.1.2 Interaction between climate-related and non-climate-related sensitivity

Many climate change vulnerability assessments do not include in their analyses determinants of general vulnerability to extinction and decline, as these stressors may be more likely to be already included in existing conservation or management approaches, such as protected areas planning or species-at-risk assessments. However, there is potential for interaction between climate change impacts and other stressors that needs to be weighed for each species.

The interaction between climate-change vulnerability and more general susceptibility to extinction pressures is unclear. The interaction is likely to be complex (both direct and indirect impacts on the species): it could increase or decrease total pressure on species. Overall climate change vulnerability is a combination of exposure to climate change impacts, sensitivity to those impacts, and ability to adapt. Some models, such as the EPA’s framework, suggest integrating climate and non-climate stressors into an overall measure of species vulnerability through a sort of averaging (see table below).⁵² Other models isolate climate-related vulnerability in their analysis and leave it up to managers to bring climate indicators together with more conventional approaches to species assessment.

⁴⁹ Sauchyn, D., M. Johnston, M. Vetter, J. Piwowar, E. Wheaton, E. Barrow, N. Henderson, V. Wittrock, G. Yu, C. Hart, M. Lou, V. Swarbrick, M. Ranalli, and J. Vanstone. 2007. The vulnerability of land management in the grassland-forest transition to climate change impacts on ecosystems and soil landscapes. Prairie Adaptation Research Collaborative, CCIAD Project A733, 2007.

⁵⁰ Ibid.

⁵¹ Government of Australia. 2009. Australia’s biodiversity and climate change: a strategic assessment of the vulnerability of Australia’s biodiversity to climate change: summary for policy makers. Prepared for the Australian Government by the Biodiversity and Climate Change Expert Advisory Group. Commonwealth of Australia, Department of Climate Change.

⁵² Galbraith, H., and J. Price. 2009. A framework for categorizing the relative vulnerability of threatened and endangered species to climate change. Prepared for the Global Change Research Program, National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency.

Table 9: EPA's overall species vulnerability scores, combining climate and non-climate sensitivity.

Climate change vulnerability	Non-climate vulnerability			
	Critically vulnerable	Highly vulnerable	Less vulnerable	Least vulnerable
Critically vulnerable	Critically vulnerable	Critically vulnerable	Highly vulnerable	Less vulnerable
Highly vulnerable	Critically vulnerable	Critically vulnerable	Highly vulnerable	Less vulnerable
Less vulnerable	Critically vulnerable	Highly vulnerable	Less vulnerable	Least vulnerable
Least vulnerable	Critically vulnerable	Highly vulnerable	Less vulnerable	Least vulnerable
Likely to benefit from climate change	Highly vulnerable	Less vulnerable	Least vulnerable	Least vulnerable

The IUCN process for species assessment forms the basis for all species at risk evaluation in Canada. IUCN guidelines are built on well-tested characteristics that identify species that are likely to become threatened or endangered from various stressors. Of those basic traits, the following may interact with the climate-change characteristics listed in section 3.1.1 to worsen a species' overall vulnerability:

- Low reproductive rate
- Small population size
- Extreme fluctuations in population size
- Long generation times
- Low genetic diversity⁵³

An important consideration for a comprehensive climate-change risk assessment for biodiversity is that species may also be susceptible to climate change without having been previously identified as vulnerable through other species-at-risk processes. In the IUCN's analysis of climate vulnerability among birds, amphibians, and corals, they found that the intersection between climate-related vulnerability and conventional measures of endangerment differed across taxonomic groups.

Among amphibians, 32% of all species are already on the *IUCN Red List of Threatened Species*, of which 75% are also susceptible to climate change. But the IUCN's analysis also found that

⁵³ International Union for the Conservation of Nature. 2012. Climate change and species. Accessed May 3, 2012. URL: http://www.iucn.org/about/work/programmes/species/our_work/climate_change_and_species/

28% of amphibian species that are not currently considered “threatened” are likely to be susceptible to climate change.⁵⁴

Table 10: IUCN summary of threatened amphibian species and susceptibility to climate change⁵⁵

Amphibians		Threatened		Total
Susceptible to climate change?		Yes	No	
	Yes	1488 (24%)	1729 (28%)	52%
	No	503 (8%)	2502 (40%)	48%
Total		32%	68%	6,222

A lower percentage of bird species are already globally threatened (12%) but 80% of bird species that are already globally threatened are also susceptible to climate change.

Table 11: IUCN summary of threatened bird species and susceptibility to climate change⁵⁶

Birds		Threatened		Total
Susceptible to climate change?		Yes	No	
	Yes	976 (10%)	2462 (25%)	35%
	No	246 (2%)	6172 (63%)	65%
Total		12%	88%	9856

A large overlap between categories of “threatened” species and susceptibility to climate change suggests a heightened extinction risk among species that already lack resilience to non-climate stressors. However, the presence of susceptibility to climate change among non-listed species may be a warning that additional species may approach endangerment in future years as a result of climate change.

⁵⁴ Foden, W., Mace, G., Vié, J.-C., Angulo, A., Butchart, S., DeVantier, L., Dublin, H., Gutsche, A., Stuart, S. and Turak, E. 2008. Species susceptibility to climate change impacts. In *The 2008 review of the iucn red list of threatened species*, eds. J.-C. Vié, C. Hilton-Taylor and S.N. Stuart. Gland, Switzerland.

⁵⁵ Table reproduced from Foden, W., Mace, G., Vié, J.-C., Angulo, A., Butchart, S., DeVantier, L., Dublin, H., Gutsche, A., Stuart, S. and Turak, E. 2008. Species susceptibility to climate change impacts. In *The 2008 review of the iucn red list of threatened species*, eds. J.-C. Vié, C. Hilton-Taylor and S.N. Stuart. Gland, Switzerland.

⁵⁶ Ibid.

4. Summary of Predicted Climate Change for Alberta

“The greatest challenges to Albertans are associated with the loss of natural capital and ecosystem services due to drought, reduced water availability, and ecosystem transition.”⁵⁷

4.1 Climate Science Background - Scenarios and Modeling

This section provides a summary of climate scenarios and modeling, their uses and limitations, and some of the existing challenges for using this information in climate change adaptation research and policy development. This non-technical review provides necessary context for the discussion in Section 4.2 of climate projections for Alberta and, together, sections 4.1 and 4.2 provide an introduction for biologists who are beginning to integrate knowledge about climate change impacts into regional and local biodiversity risk assessments.

4.1.1 What are climate scenarios and models?

Climate scientists and climate research centres around the world develop unique modeling programs that provide insight into what the climate will look like under a variety of scenarios. To provide consistency, standardized scenarios have been developed and outlined by the Intergovernmental Panel on Climate Change (IPCC) and are commonly used in these climate models. In this way, the results can be compared and/or aggregated as needed.

The scenarios developed by the IPCC are based on narratives that include projected trends in greenhouse gas emissions, as well as possible trends in social and technological change. The scenarios range from high emissions and slow technology change, to lower emissions growth and rapid shift to cleaner energy and away from energies that produce high emissions.^{58,59} The scenarios that have been developed are referred to as SR-A2 (high emissions scenario), SR-A1B (medium emissions scenario), and SR-B1 (low emissions scenario).

Global emissions are currently greater than ‘worst-case’ emissions scenarios from the IPCC Fourth Assessment Report. This means that there is a possibility that ‘worst-case’ climate model

⁵⁷ Weber, M., D. Davidson, and D. Sauchyn. 2008. Climate change vulnerability assessment for Alberta. Final Report to Alberta Environment; Climate Change, Air and Land Policy Branch. Edmonton, Alberta.

⁵⁸ The suite of scenarios developed for IPCC reports were referred to as the Special Report on Emissions Scenarios.

⁵⁹ Full descriptions of the scenarios are available through the IPCC. See Emissions Scenarios: Summary for Policy Makers. A special report of Working Group III of the IPCC. <http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf>.

outputs (i.e., those that use the IPCC Fourth Assessment Report high emissions scenarios as input) underestimate climate change impacts.

General Circulation Models (GCMs) mathematically model the circulation of the planet's atmosphere and oceans. They are commonly used for weather forecasting, understanding the current climate, and projecting future climate change. GCMs have relatively low resolution (i.e., provide results on a coarser scale). Outputs from GCMs typically have a horizontal resolution of 250-600 km.⁶⁰ GCMs provide “geographically and physically consistent estimates of regional climate change which are required in impact analysis”.⁶¹ Therefore, the results of GCMs only provide prospective users with coarse information on a regional scale.

Since GCMs are not able to take into account some physical processes such as those related to clouds, or to account for local geographic factors such as mountains, they do not always provide results with the level of detail that is necessary for comprehensive regional impacts analysis.

A variety of methods are used to improve the resolution of climate modeling and derive results at local scales. The process of developing regional climate models (RCMs) from GCMs is commonly referred to as ‘downscaling’.

Common output timeframes for climate models are 2020s, 2050s and 2080s.⁶²

Common output indicators include the following:

- Surface temperature (monthly, seasonal and annual)
- Humidity (relative, specific)
- Precipitation (monthly, seasonal and annual)
- Sea level pressure
- Wind speed (mean, meridional, zonal)

The primary resources from Canada for climate science and scenarios in Canada include the following:⁶³

- Canadian Climate Change Scenarios Network (CCCSN)
- University of Alberta, Alberta Climate Data.⁶⁴
- Pacific Institute for Climate Science (PICS)

⁶⁰ Intergovernmental Panel on Climate Change. 2012. What is a General Circulation Model (GCM)? Accessed May 3, 2012. URL: http://www.ipcc-data.org/ddc_gcm_guide.html.

⁶¹ Ibid.

⁶² Models produce outputs for a 30-year period. Outputs for the 2020s, for example, represent the anticipated average climate for the 30-year average period of 2011-2040 based on the model and scenario selected. This average is often compared to a baseline 1961-1990, or 1971-2000, although different or custom baseline periods can be selected from existing data.

⁶³ For more information on the information available through each of the resources listed, refer to Appendix 7.2.

⁶⁴ University of Alberta, Faculty of Agricultural, Life and Environmental Sciences. Department of Renewable Resources, Alberta School of Forest Science and Management. 2012. Climate data for Alberta. Accessed February 15, 2012. URL: <http://www.rr.ualberta.ca/en/Research/ClimateChange/ClimateDataforAlberta.aspx>.

- Ouranos Consortium
- Pacific Climate Impacts Consortium (PCIC)
- Prairie Adaptation Research Collaborative (PARC)
- Hazards.ca

4.1.2 Strengths and weaknesses of various climate models at different scales

Some of the pros and cons of GCMs compared to downscaled models are outlined in the table below. Researchers and institutions that require new or proprietary climate modeling and outputs for impacts analysis and adaptation planning can use publicly available data or request specific outputs that are generated from the different types of models. The models and downscaling techniques have advantages and disadvantages, such as cost, which may affect the users' decision.

4.1.3 Developing an understanding of climate variability and extremes

Understanding the potential for changes in climate variability and extremes is important for many climate impacts studies. Extremes are events with very low temporal frequency, and this is difficult to model. There are two main approaches to this challenge that are used for impacts studies. The first method is statistical, in which future variables and extremes are derived by adjusting from an observed baseline. This method assumes no relative change in variability between the baseline and the future climate period under analysis. There are some constraints with this method, particularly in regions where local climate forcings (i.e., major water bodies, great lakes, and mountains) play a key role in climate. Downscaling can help reduce some of the constraints. A second approach does take into some potential changes in variability and extremes through time. However, additional use of downscaling models is generally needed for the highest extreme values. Understanding variability and extremes continue to be one of major challenges in climate research.

Table 12: GCMs vs. RCMs

Model type	Advantages	Disadvantages
General Circulation Models (GCMs)	Simulations are longer and typically include all IPCC scenarios; many variables are included; data are readily available.	Information is coarse in scale and can be of limited use in impact models where regional or local-scale climate information is essential. Daily characteristics may be unrealistic except for very large regions. Models are computationally expensive.
Regional Climate Models (dynamical downscaling)	Provides highly resolved information that incorporates many variables. Provides better representation of large scale phenomena and some weather	Computationally very expensive, fewer scenarios available.

Model type	Advantages	Disadvantages
	extremes than GCMs.	
Regional Climate Models (statistical downscaling)	<p>Provides high resolution information (in grid or non-uniform regions). Some techniques address diverse range of variables.</p> <p>Computationally inexpensive, rapid application from multiple GCMs and scenarios.</p>	<p>Assumes constant empirical relationships in the future: i.e., that the statistical relationships developed for the present day climate also hold under the different forcing conditions of possible future climates.</p> <p>Requires access to daily observational surface and/or upper air data, a limited number of variables are produced using some techniques.</p>

4.1.4 Bioclimate profiles

Climate variability is an important consideration for multidisciplinary studies, including ecology and biodiversity conservation. Bioclimate profiles provide ‘climate at a glance’ by summarizing information on a site-by-site basis in graphical form, and for a number of variables.⁶⁵

Bioclimate profiles can include the following variables:

- Temperature (monthly, seasonal and annual, as well as extremes)
- Degree day accumulations with threshold temperatures relevant for energy use (e.g., Heating and Cooling Degree Days) and agricultural applications (e.g., Corn Heat Units, Growing Degree Days)
- Probability of frost- and freeze-free seasons
- Monthly total precipitation, actual and potential evapotranspiration
- Frequency of precipitation: number of days with rain and days with snow
- Water surplus and deficit

Bioclimate profiles have been developed for over 500 locations in Canada, with approximately 80 available for Alberta, and are available for three time periods (2020s, 2050s, and 2080s) through the Canadian Climate Change Scenarios Network (CCCSN).⁶⁶

A user-friendly “localizer” tool is also available through the CCCSN, providing information on selected locations across Canada (outputs of this tool are seasonal and annual precipitation and temperature projections for 2020s, 2050s and 2080s).⁶⁷

⁶⁵ Climate Change Scenarios Network. 2012. Climate change scenarios network. Accessed February 15, 2012. URL: <http://cccsn.ca/tools/viz-bioclimate/bioclimate.pl>.

⁶⁶ Ibid.

⁶⁷ The localizer tool can be found on the home page of CCCSN at www.cccsn.ca.

4.1.5 IPCC Assessment Reports

The Intergovernmental Panel on Climate Change produces a series of reports every 4 to 5 years synthesizing the current state of climate change knowledge. The IPCC collects published scientific research on climate change and synthesizes it into three main reports. This work is done by three working groups:

1. Working Group I produces reports on the physical science basis of climate change.
2. Working Group II produces reports on impacts and adaptation.
3. Working Group III produces reports on greenhouse gas emissions reductions and mitigation.

In 2013 and 2014, the IPCC will publish its Fifth Assessment Report. The report from Working Group I will be published in 2013, and the other Working Groups will publish reports in 2014. The new report will include results from climate science models and research centres around the world, and results will be based around a series of new “Representative Concentration Pathways (RCPs)”. These will provide the basis for analysis and climate scenarios.

4.2 Future climate projections in Alberta

Past work on climate change impacts in Alberta demonstrates that the province is warming at a rate that exceeds the global average, and that future variability, including scenarios for the 2020s, will exceed recent natural variability.⁶⁸

Overall, a decrease in water availability is expected. This is a result of a combination of factors: temperature rise will be concentrated in winter and spring affecting timing of water flows in major watersheds (earlier spring runoff), increased water loss from evapotranspiration, and the loss of water stored as ice and snow. Warmer and generally drier conditions are a consistent outcome of climate modeling.⁶⁹

Precipitation decreases are likely to be most apparent in summer, though the changes are relatively minor and variable. A consistent result of climate models is decreased volume of precipitation expected by the 2080s.⁷⁰

The impacts will include decreased surface water, lower stream and lake levels, and decreases in soil moisture.⁷¹

⁶⁸ Climate Change Scenarios Network. 2012. Climate change scenarios network. Accessed February 15, 2012. URL: <http://cccsn.ca/tools/viz-bioclimate/bioclimate.pl>.

⁶⁹ Ibid.

⁷⁰ Ibid.

⁷¹ Ibid.

4.2.1 Predicted impacts to ecosystem services

Vulnerability to climate change and adaptive capacity of ecosystems and species in Alberta will be linked with the adaptive actions taken across sectors – including agriculture, forestry, municipal water, and oil and gas. “Developing meaningful adaptation strategies requires an understanding of the vulnerabilities of species, ecosystems and social systems to climate change.”⁷² The potential for increased demands for irrigation in the agriculture sector as a result of increased water stress, or the need for the forestry sector to operate in new geographic areas as viability and productivity of forests change or migrate, are examples of why consideration of both social and ecosystem impacts are important.

While some research has concluded that the agricultural and forestry sectors will benefit from increasing temperatures, provided adaptation to reduced moisture occurs in a timely manner,⁷³ this hypothesis has recently been questioned for the forestry sector. Additional stresses (increased survival rates for pests, decreased water availability) may outweigh the benefits associated with warmer temperatures and longer growing seasons. A recent study analyzing results from over 20 000 sites nationally indicates that (even in the absence of fires and pests) forests in the three Prairie Provinces are currently shrinking – producing less biomass per unit area - as a result of climate change. The study found that trees in the prairies were growing more slowly and dying younger during the period from 1963 to 2008, with trends accelerating after 2000. The primary cause is linked to drought – reduced precipitation and increased temperatures.⁷⁴

Potentially adverse impacts on the forestry and agriculture sectors include survival and increase of insect pests, weeds, and other invasive species. Insects and fires in particular could increase disturbances in the forest sector, with correlating impacts on ecosystems and species.⁷⁵

Other ecosystem services, including biodiversity, water cycling, soil formation, primary production, pollination, air quality and carbon storage have been reviewed by Alberta Sustainable Resource Development in the context of climate change vulnerability and risk. Initial findings indicate high vulnerability across a number of ecosystem services, including: increased erosion and sedimentation including impacts to fish and aquatic biodiversity, increased probability of extreme conditions (flooding and drought) and increased competition for water resources. This vulnerability translated into a high level of risk to biodiversity and to water cycling, including the potential for eutrophication and loss of wetlands.

Tourism revenue may change or shift as well, and while the impacts on tourism and recreation are uncertain, there is potential for decreased revenue in winter (e.g., skiing) or water-based activities, potentially offset by increased activity and revenue in other sectors.⁷⁶

⁷² Gleeson, G., J. Gray, P. Douglas, A. Lemieux, C.J. Neilsen. 2011. A practitioner’s guide to climate change adaptation in Ontario’s ecosystems. Ontario Government, Ministry of Natural Resources. Sudbury, Ontario.

⁷³ Weber, M., D. Davidson, and D. Sauchyn. 2008. Climate change vulnerability assessment for Alberta. Final Report to Alberta Environment; Climate Change, Air and Land Policy Branch. Edmonton, Alberta.

⁷⁴ Canadian Press. 2012. Climate change shrinks forests in three Prairie Provinces: Finding belies assumption that global warming improves growing conditions. *CBC News*, January 31, 2012. Accessed May 3, 2012. URL: <http://www.cbc.ca/news/technology/story/2012/01/31/sci-climate-change-forests.html>.

⁷⁵ Ibid.

Overall, socioeconomic vulnerability is expected to be higher in the southern regions of Alberta and the prairies. Where there is reliance on agriculture (higher exposure to impacts), water stress is expected to be most acute, and generally lower economic resources (fewer resources for adaptation).⁷⁷

Table 13: Climate impacts in agriculture and forestry⁷⁸

Sector	Exposure to climate change impacts	Possible benefits	Possible costs
Agriculture	Increased temperature and heat waves; increased frequency and severity of drought; reduced water availability, storms, flooding, CO ₂ fertilization	Improvements to productivity due to warmer and longer growing season, and CO ₂ fertilization; northern expansion of arable land	Productivity losses from heat stress, flooding, and drought; drought-driven increased irrigation demand; increased pests and disease; heat stress in animals and reduced forage
Forestry	Increased average temperature, increased soil moisture deficits, increased lightning, reduced water availability, CO ₂ fertilization	Possible increased forest productivity from warmer and longer growing season ⁷⁹	Possible decreased forest productivity from warmer and drier growing season conditions. Increased disturbance from pests and disease as a result of warmer winters; increased frequency and size of fires; loss of forest ecosystems and ecosystem services

4.2.2 Predicted extreme weather events

There is an expected increase in the frequency of forest fires in the northern boreal regions, as well as increased flooding in Alberta.⁸⁰ Increased flooding (including heavy precipitation events)

⁷⁶ Weber, M., D. Davidson, and D. Sauchyn. 2008. Climate change vulnerability assessment for Alberta. Final Report to Alberta Environment; Climate Change, Air and Land Policy Branch. Edmonton, Alberta.

⁷⁷ Ibid.

⁷⁸ Ibid.

⁷⁹ Note that this finding is contrary to Canadian Press. 2012. Climate change shrinks forests in three Prairie Provinces: Finding belies assumption that global warming improves growing conditions. *CBC News*, January 31, 2012. Accessed May 3, 2012. URL: <http://www.cbc.ca/news/technology/story/2012/01/31/sci-climate-change-forests.html>.

⁸⁰ Canadian Press. 2012. Climate change shrinks forests in three Prairie Provinces: Finding belies assumption that global warming improves growing conditions. *CBC News*, January 31, 2012. Accessed May 3, 2012. URL: <http://www.cbc.ca/news/technology/story/2012/01/31/sci-climate-change-forests.html>.

may affect slope stability, water drainage and municipal infrastructure. Failures in these systems may affect downstream ecosystems.

In the southern regions, seasonal and persistent droughts (over multiple years) could have both ecological and socioeconomic consequences. However, the Grasslands Natural Region has evolved in a semi-arid climate, where prolonged droughts are not uncommon, and is adapted to drought.⁸¹

The Institute for Catastrophic Loss Reduction, a Canadian centre focused on disaster prevention research, published a report on observed and projected climate trends with the aim of supporting adaptation initiatives. The report focused on intensity and frequency of severe events and extreme weather. Findings for Alberta (southern, central and northern regions treated separately) are reported in the table below. Findings for Manitoba and Saskatchewan are also included in the report, available at the Institute's website at: <http://www.iclr.org/climateextremesbruce.html>

The findings include an increase in the number of severe winter storms (characterized by winds greater than 100 km/h), and increases in number of lightning strikes (province wide) and burned forest areas (primarily in central and northern Alberta). Nationally, the area burned by wildfires has increased by 100,000 sq km for each degree Celsius of temperature increase.⁸² The expectation of the increased wildfire activity is echoed south of the Canadian border, where measured increases in wildfire activity are apparent. The study concluded that for the northern (U.S.) Rocky Mountains, higher large-wildfire frequency, longer wildfire duration and longer wildfire seasons were attributable to climate change. The increases were greatest at mid-elevation and strongly associated with increased spring and summer temperatures and earlier snowmelt.⁸³ Daily streamflows (the amount of flow required to maintain the values of a stream) are expected to continue declining, in parallel with decreases in snowpack and glacier mass.⁸⁴

⁸¹ Ibid.

⁸² Bruce, J. 2011. Climate change information for adaptation: climate trends and project values for Canada from 2010 to 2050. ICLR Research Paper Series - No. 50.

⁸³ Westerling, T.W., A.L., Hidalgo, H.G., Cayan, D.R., Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 1161: 940-943.

⁸⁴ Bruce, J. 2011. Climate change information for adaptation: climate trends and project values for Canada from 2010 to 2050. ICLR Research Paper Series - No. 50.

Table 14: Climate trends and projections by Alberta region, for 2050s⁸⁵

Indicator	Southern Alberta	Central Alberta	Northern Alberta
Annual temperature	2-4 °C increase	2-4 °C increase	2-4 °C increase
Number of severe winter storms	8-15% increase	8-15% increase	8-15% increase
Lightning	20% increase	20% increase	20% increase
High intensity precipitation events (20-year frequency)	Current 20-year events occur every 10-15 years	Current 20-year events occur every 10-15 years	Current 20-year events occur every 10-15 years
High intensity precipitation events (20-year frequency)	10-15% increase in intensity	10-15% increase in intensity	10-15% increase in intensity
Freezing Precipitation	(not reported)	Increase	Little change
Minimum streamflow	10-20% decrease	20% decrease	20% decrease
Wildfire burn area	(not reported)	Area burned increase by 15%.	Increase in lightning and wildfire by approximately 20%
Snowpack	40% decrease from long-term average	30% decrease	25% decrease
Flash floods	More frequent in spring and summer in small river basins.	(not reported)	(not reported)
Severe drought	Doubled frequency of severe events	Doubled frequency of severe events	Doubled frequency of severe events

4.2.3 Predicted and documented biophysical changes

Significant ecological changes are anticipated in Alberta “including transitions to unprecedented ecosystems”. These changes include the possibility of a general degradation of species diversity.⁸⁶

International research suggests that change is underway, and could result in significant changes for ecosystems in Alberta and across the Prairie Provinces. Distributions of species around the world are shifting to higher elevations and higher latitudes at a rate of 11.0 m and 16.9 km per

⁸⁵ Ibid.

⁸⁶ Weber, M., D. Davidson, and D. Sauchyn. 2008. Climate change vulnerability assessment for Alberta. Final Report to Alberta Environment; Climate Change, Air and Land Policy Branch. Edmonton, Alberta.

decade, respectively.⁸⁷ A European study projects that loss of 80% of suitable habitat in Europe will affect 36-55% of alpine species, 31-51% of subalpine species, and 19-46% of montane species by 2080s.⁸⁸

Recent work that modeled terrestrial ecosystem sensitivity to climate change reported biome-scale changes and identified the northern boreal as a ‘hotspot’ of change. Significant incursion of boreal into tundra regions is expected, as is incursion of temperate grassland into southern regions of the boreal. Low latitude forests are thought to be susceptible to invasion by grassland species because of changes in water balance (increased evaporation due to higher temperature is not offset by higher precipitation).⁸⁹ The report finds “the greatest potential for climate-driven species turnover is at the northern and southern transitions zones or ecotones of the boreal forest”.⁹⁰ The Prairie Ecozone in southern Alberta is also expected to experience significant impacts from climate change.⁹¹

Current ecosystems in Alberta are expected to experience stress to an unprecedented extent.⁹² The following table outlines some areas of change.

Table 15: Projected ecosystem trends and changes in Alberta⁹³

Indicator	Projected trends in Alberta
Native species	Decline or extirpation
Alien species	Alien and/or resilient native species increase in numbers or distribution
Vector-borne diseases	Conditions for vector-borne diseases could improve
Growing seasons	Longer and warmer growing seasons increasing plant productivity in the absence of other constraints (water, moisture)
Aquatic habitats	Water temperatures are expected to increase as surface and ambient temperatures increase Aquatic habitats will experience stress from lower surface water and

⁸⁷ Chen, I.-C., J.K. Hill, R. Ohlemuller, D.B Roy, and C.D Thomas. 2011. Rapid range shifts of species associated with high levels of climate warming. *Science* 333: 1024-1026.

⁸⁸ Engler, R. et al. 2011. 21st century climate change threatens mountain flora unequally across Europe. *Global Change Biology* 17: 2330-2341.

⁸⁹ Bergengren, J. C., D. E. Waliser, and Y. L. Yung. Ecological sensitivity: a biospheric view of climate change. *Climatic Change* (2011): 433-457.

⁹⁰ Ibid.

⁹¹ Thorpe, J. *Vulnerability of Prairie Grasslands to Climate Change*. 2011. Prairie Regional Adaptation Collaborative, Saskatchewan Research Council Publication No. 12855-2E11, Saskatchewan.

⁹² Weber, M., D. Davidson, and D. Sauchyn. 2008. Climate change vulnerability assessment for Alberta. Final Report to Alberta Environment; Climate Change, Air and Land Policy Branch. Edmonton, Alberta.

⁹³ Ibid.

Indicator	Projected trends in Alberta
	<p>associated changes in water quality</p> <p>Decreases in overall snowpack and earlier spring runoff (in some regions this could mean higher than average streamflow in March, and lower than average in autumn)</p> <p>Increases proportion of overall precipitation as rain and not snow</p> <p>Decreases in surface water availability due in part to increased evapotranspiration (primarily in the south), indications of no-change of increasing flows in the north</p> <p>Reduced water volume in lakes and rivers</p>

The impacts of these changes include additional stress on urban water and irrigation demands. Serious impacts related to water balance are expected in the Grassland and Parkland natural regions.⁹⁴

Changes in water availability have already been observed in Alberta. Measured impacts to date include decrease in streamflow in southern Alberta, which leads to a prediction of a continuing decline in future decades.⁹⁵ The projected impact of climate change on aquatic habitat will be significant for many species; downscaled climate models combined with hydrological models have predicted a 47% decrease in suitable trout habitat across the interior western United States.⁹⁶

Climate-related phenology trends have also been recorded. Studies have shown that species in central Alberta parks with earliest bloom dates have seen those dates advance two weeks over the past 70 years, while advances for later-blooming species ranged from zero to six days. These species exhibited a higher than expected sensitivity to the warming trends.⁹⁷

Alberta researchers identified areas of reduced forest productivity in the Dry Mixedwood and Peace River Parkland natural regions during the 2002 regional drought.⁹⁸ Researchers also project (with results based on multiple models) complete loss of trembling aspen (*Populus tremuloides*) by the 2080s over the Northern Boreal zone and the Boreal Plains of Alberta, while the Foothills and Taiga plains are expected to maintain populations.⁹⁹ The research describes adaptation lag as mismatch in environment and genotypes caused by relatively fast

⁹⁴ Ibid.

⁹⁵ Rood, S.B., Samuelson, G.M., Weber, J.K. and Wyrot, K.A. 2005. Twentieth-century decline in streamflows from the hydrographic apex of North America. *Journal of Hydrology* 306:215–233.

⁹⁶ Ibid.

⁹⁷ Beaubien, E. and A. Hamann. 2011. Spring flowering response to climate change between 1936 and 2006 in Alberta, Canada. *BioScience* 61: 514–524.

⁹⁸ Gray, L. K., T. Gylander, M. S. Mbogga, P. Chen, and A. Hamann. 2011. Assisted migration to address climate change: recommendations for aspen reforestation in western Canada. *Ecological Applications* 21:1591–1603.

⁹⁹ Ibid.

environmental change and comparably slow evolutionary response; the results of adaptation lag include sub-optimal productivity and higher than normal mortality.¹⁰⁰

Black spruce is projected to lose much of its currently suitable habitat, particularly in low elevation regions, whereas white spruce may utilize an increasing land base.¹⁰¹ Researchers did not uncover new tree species that will be particularly suited to new habitat in Alberta, with the possible exception of ponderosa pine. While there is uncertainty between different models, some models project extensive areas of appropriate habitat across the province for this pine species.¹⁰² Newly suitable habitat, however, does not guarantee that the species will eventually colonize that area naturally if the new habitat is outside the range of the species' potential for dispersal.

Duck populations common to the western boreal are anticipated to be affected by climate change as well, primarily as a result of changes in spring timing and snow cover duration. Late-nesting species with reduced flexibility in breeding timing [scaup (*Aythya* spp.) and scoter (*Melanitta* spp.) species] will experience the greatest decline. These species have fixed breeding timing and are unlikely to re-nest if their first clutch is lost. The mallard (*Anas platyrhynchos*) and American wigeon (*Anas americana*), by comparison, have flexible timing in their nesting and commonly will re-nest if first clutch is lost.¹⁰³ Only mallard was expected to see relative increases in population (8% increase by 2080s); for scoter, populations were expected to decline from baseline values by 10% in the 2020s, and by 31% by the 2080s.¹⁰⁴

4.2.4 Locations of greatest vulnerability

The summary report prepared for Alberta Environment, *Climate Change Vulnerability Assessment for Alberta*, concludes that terrestrial ecosystems at sharp ecological gradients are most at risk in Alberta, including margins between grassland and forest, and gradients in mountains.¹⁰⁵ A report completed by Jeff Thorpe for the Prairies Regional Adaptation Collaborative also finds that climate change is expected to have major impacts in the Prairie Ecozone, causing vegetation shifts northward.¹⁰⁶ According to the *Climate Change Vulnerability Assessment for Alberta* the classes of ecosystems that are most vulnerable include the following:¹⁰⁷

¹⁰⁰ Ibid.

¹⁰¹ Gray, L. K. and A. Hamann. 2011. Strategies for reforestation under uncertain future climates: guidelines for Alberta, Canada. *PloS one* 6: e22977.

¹⁰² Ibid. See Figure 3. Pg. 5.

¹⁰³ Drever, M.C., R.G. Clark, C. Derksen, S.M. Slattery, P. Toose, and T.D. Nudds. 2012. Population vulnerability to climate change linked to timing of breeding in boreal ducks. *Global Change Biology* 18: 480-492.

¹⁰⁴ Ibid. Snow cover is used as a proxy for wetland phenological timing in this research.

¹⁰⁵ Weber, M., D. Davidson, and D. Sauchyn. 2008. Climate change vulnerability assessment for Alberta. Final Report to Alberta Environment; Climate Change, Air and Land Policy Branch. Edmonton, Alberta.

¹⁰⁶ Thorpe, J. *Vulnerability of Prairie Grasslands to Climate Change*. 2011. Prairie Regional Adaptation Collaborative, Saskatchewan Research Council Publication No. 12855-2E11, Saskatchewan.

¹⁰⁷ Ibid.

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- Moisture-limited forests, including the island forests (e.g., Cypress Hills), the lower-elevation southern foothills forests, and, most critically, the southern boreal. Impacts on forests are already being measured.¹⁰⁸
 - Aquatic ecosystems, including pothole wetlands, mountain-source rivers, and northern lake and river systems. These will be subject to lower water levels, warmer water temperatures, and declines in water quality for human use. Many prairie aquatic species will be at higher risk of extirpation, and migratory waterfowl populations will likely decline.
 - Fescue prairie, in the Rocky Mountain Foothills and along the northern edge of the Prairie Ecozone. This is highly fragmented and vulnerable to exotic invasion.
 - Ecosystems vulnerable to exotic invasion, especially areas of native vegetation that are fragmented by development or cultivation, and transitional ecotones that contain species at the limits of their range.
 - Aquatic ecosystems will be impacted by lower water availability, changes in streamflow levels, and increases in water temperature. This will affect species such as the arctic grayling, Banff Springs snail and Athabasca rainbow trout as outlined in the detailed status assessments completed, though the extent of the risk and vulnerability is not well understood.¹⁰⁹
 - Changes in water availability and wetlands will have an impact on migratory birds.¹¹⁰ The southern region of the province is expected to have the sharpest decline.

The 2011 report on *Vulnerability of Prairie Grasslands to Climate Change* prepared under PRAC includes the following expectations:

- Vegetation zones are expected to shift northward, with forest replaced by aspen parkland and grassland, and with current grassland types replaced by those found further south. Species with long-distance dispersal and generalist habitat requirements will be more likely to move or adapt in response to climate change, while slow-dispersing or habitat specialist species are more likely to lag behind. Invasive species are expected to thrive under climate change.
- Grassland production is expected to decrease, along with increased occurrence of low-production years (i.e., drought).
- The number and area of wetlands is expected to decrease, leading to losses in duck production and other wetland biodiversity

¹⁰⁸ Canadian Press. 2012. Climate change shrinks forests in three Prairie Provinces: Finding belies assumption that global warming improves growing conditions. *CBC News*, January 31, 2012. Accessed May 3, 2012. URL: <http://www.cbc.ca/news/technology/story/2012/01/31/sci-climate-change-forests.html>.

¹⁰⁹ From detailed status reports by Alberta Fish and Wildlife.
<http://www.srd.alberta.ca/FishWildlife/SpeciesAtRisk/DetailedStatus/Default.aspx>.

¹¹⁰ Ibid.

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- Species at risk will be affected, with specific impacts depending on the biology and habitat requirements of each species.
 - Impacts will vary by grassland type. Northern fescue prairie and other moister regions are expected to be most severely affected, as a result of low total area, high habitat fragmentation, and high potential for invasion. Mixed prairie is expected to have greater capacity to adjust to climate change.¹¹¹

Similar results were found by University of Alberta researchers, namely that grassland is projected to shift northwards into much of existing parkland, and that 12-21% of Alberta's boreal is projected to be converted to parkland, over a period of 50 years.¹¹²

¹¹¹ Thorpe, J. *Vulnerability of Prairie Grasslands to Climate Change*. 2011. Prairie Regional Adaptation Collaborative, Saskatchewan Research Council Publication No. 12855-2E11, Saskatchewan.

¹¹² Hamann, A. and T. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. *Ecology* 87: 2773–2786.

5. Review of Climate Change Vulnerability Assessments for Biodiversity

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. – International Panel on Climate Change (IPCC), Glossary of Terms used in the Fourth Assessment Report

A climate change vulnerability assessment process can synthesize multiple sources of data to predict how an element of biodiversity (e.g., a population, species, and ecosystem) is likely to respond to climate change in a given region. Vulnerability is often defined, as in the above definition from the IPCC, as the combination of sensitivity or susceptibility to changes in climate variables, exposure to the impacts of climate change, and ability to adapt. See Table 1 for an illustration of vulnerability. Some vulnerability assessments focus on all elements (sensitivity/susceptibility, exposure, and ability to adapt), and others focus only on one or two elements. For biodiversity in the Prairie Provinces a key factor then is the ability of a species or system to adjust to changes, for example by range migration, phenotypic plasticity, or evolutionary adaptation. Elements of biodiversity (e.g., species, ecosystems) that experience the greatest changes in climate variables, exhibit high sensitivity to those changes, and have the least ability to adapt quickly, are those most vulnerable to climate change.¹¹³

A vulnerability assessment can identify what species or other components of biodiversity are likely to be vulnerable to climate change, which can help set conservation priorities. A well-designed vulnerability assessment can also elucidate why those elements are likely to be vulnerable, which can help guide potential management and conservation responses.¹¹⁴

The focus of an assessment can be on a particular species or system across its entire range, for example, the IUCN's approach to vulnerability assessment looks at species of birds across their global distribution. An assessment can also be carried out on a species or system within a particular area. For example the NatureServe Vulnerability Index tends to be applied in

¹¹³ Gleeson, G., J. Gray, P. Douglas, A. Lemieux, C.J. Neilsen. 2011. A practitioner's guide to climate change adaptation in Ontario's ecosystems. Ontario Government, Ministry of Natural Resources. Sudbury, Ontario.

¹¹⁴ Glick, P., B.A. Stein, and N.A. Edelson, eds. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

delineated areas, such as a state.¹¹⁵ In both cases, sensitivity to climate change tends to be constant across the range, while exposure and adaptive capacity can vary across the area in question. In this section, we review a range of approaches to vulnerability assessments in Canadian, American, and international contexts in order to evaluate the options available for looking at the vulnerability of different components of biodiversity (e.g., genes, populations, species, habitats, ecosystems) in the Prairie Provinces.

5.1 Tools and approaches for vulnerability assessment of biodiversity

This study reviewed ten climate change vulnerability assessment approaches applied in other jurisdictions to determine the effect of climate change impacts on biodiversity. The tools reviewed include approaches that focus on population level, species level, and system level effect. They are organized by this review into five categories. These tools can complement the vulnerability assessment framework already developed by Alberta Sustainable Resource Development by providing enhanced capacity to examine specific conservation and biodiversity challenges.¹¹⁶

The first set of vulnerability approaches relies primarily on expert characterization to determine what species or system is likely to be most vulnerable. These approaches often involve a questionnaire that leads the user to identify whether a given species or habitat possesses traits that are associated with greater sensitivity to climate change. These assessments may or may not also include consideration of whether the species is likely to be exposed to climate change impacts. Often these tools are used to complement methods to identify or manage for threatened and endangered species or habitats.

The second set of approaches involves bioclimate models, or other forms of spatial modeling. These approaches combine existing models (e.g., habitat composition, general vegetation models, species distributions) with climate projections (e.g., sea-level rise, changes in temperature and precipitation) to determine the likely effect of climate change on species and habitat distribution and persistence. These approaches have significant data requirements and are confined to particular systems (e.g., eastern coastal wetland habitats, prairie watersheds). They produce general habitat projections, but can be used as a preliminary step to identifying species or systems that are likely to be vulnerable to climate change and may require management interventions.

The third kind of approach is a hybrid between expert characterization and bioclimate modeling, as exemplified by the Pacific Northwest Climate Change Vulnerability Assessment. This approach used both expert opinion to assess sensitivity of species and systems, and applied climate projections and soil data to a General Vegetation Model to predict range migrations for a subset of the birds and mammals of interest. This approach may be suitable for a well-resourced

¹¹⁵ Ibid.

¹¹⁶ Alberta Sustainable Resource Development. 2010. Climate change adaptation framework manual. Edmonton, Alberta.

assessment process with multiple partners with diverse conservation interests who can share data and other resources.

The fourth kind of approach uses historical data as an indication of how species and systems are likely to respond to future climate change. This approach is exemplified by a series of studies in the grassland-forest transition zone in Saskatchewan. Under this model, several related pieces of research were undertaken in a particular habitat to better understand how the species and systems responded to recent climate change. This approach produces detailed scientific and statistical information on a particular habitat of interest.

The fifth and final approach is a comprehensive “resilience approach” to a vulnerability assessment. This approach was applied in Australia’s national assessment of the vulnerability of the country’s biodiversity to climate change. In this case, an expert advisory panel compiled research on climate projections, observed effects of climate change thus far, and expectations of what the future will hold with respect to biodiversity changes under three CO₂ concentration scenarios. The vulnerability assessment was the basis for recommending a set of policy and management strategies and tools for building resilience, intervening proactively, and making policy and management more flexible.

The ten examples of vulnerability assessment tools are summarized in Tables 16-20. The approaches are compared in section 5.2.

Table 16: Expert characterization approaches - based on in-depth expert knowledge and data sources

	Coverage	Non-climate stressors	Climate-related variables	Ranking/Results	Limitations	Treatment of uncertainty	Data sources
US Environmental Protection Agency's Threatened and Endangered Species Vulnerability Framework—developed by Manomet Centre and WWF^{117 118}	Threatened and endangered species only (initially applied to six U.S. listed species, could be applied more broadly with sufficient data).	Quantifies current vulnerability to extinction (based on abundance, range, demographics, life history).	Based on potential physiological, behavioural, demographic and ecological response (multiple choice questions).	Combines current and incremental climate-change-related vulnerabilities. Maps to four categories: “critically,” “highly,” “less,” and “least” vulnerable. Species narratives provide context.	Rationale for how the baseline vulnerability and climate-change-related vulnerability are combined in the ranking matrix is not entirely clear.	In each step, uncertainty recorded as “high” (estimated probability of 70% or more) “medium” (30-70%) or “low” (< 30%).	Experimental or observational data. Data are sparse for most species; rankings may be based on expert opinion (based on closely related species, current range correlated with climate variables, range changes).

¹¹⁷ Galbraith, H., and J. Price. 2009. A framework for categorizing the relative vulnerability of threatened and endangered species to climate change. Prepared for the Global Change Research Program, National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency.

¹¹⁸ Glick, P., B.A. Stein, and N.A. Edelson, eds. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C. Case study 2.

	Coverage	Non-climate stressors	Climate-related variables	Ranking/Results	Limitations	Treatment of uncertainty	Data sources
System for Assessing Vulnerability of Species to Climate Change (SAVS) – developed by the USDA Forest Service¹¹⁹	Terrestrial vertebrates (pilot tested in Middle Rio Grande and Coronado National Forest).	Not applicable. Assessment does not include threats that are not climate-related. Should be used in conjunction with other indicators.	Based on habitat, physiology, phenology, biotic interactions (22 multiple choice questions).	Score from -20 (most resilient) to plus 20 (most vulnerable). Not linear (i.e., species with score of 10 not twice as likely to decline as species with score of 5).	Cannot include every possible response to climate change; instead allows for a group of species to be assessed on equal criteria. Managers should not use the score to set a numerical cut-off.	Uncertainty estimate based on % of questions with inadequate or conflicting information. For each question, user must specify if info used was “adequate” or “not adequate and conflicting.”	Literature review or expert knowledge of each species (climate-relevant biological data, best available knowledge of future exposure to direct and indirect climate effects).

¹¹⁹ Bagne, K.E., M.M. Friggens, and D.M. Finch. 2011. A system for assessing vulnerability of species (SAVS) to climate change. United States general technical report RMRS-GTR-2572011. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

	Coverage	Non-climate stressors	Climate-related variables	Ranking/Results	Limitations	Treatment of uncertainty	Data sources
NatureServe Vulnerability Index¹²⁰	Terrestrial and aquatic; plants and animals—Applied in several states (e.g., West Virginia, Nevada).	Not applicable. Does not include or overlap with conservation status factors. Should be used in conjunction with other indicators.	Inherent sensitivity plus exposure. Sensitivity: species scored for 17 factors. Exposure: downscaled climate models across species' range.	Five categories: “extremely,” “highly,” “moderately” vulnerable, “presumed stable” or “likely to increase” within an assessment area.	Focus is on a particular region.	Calculates measure of confidence in species info as “very high,” “high,” “moderate,” “low.” User can select more than one answer if uncertain.	Downscaled climate predictions from Climate Wizard citation; requires expert knowledge about species' distribution, natural history; a team of scientists is best.

¹²⁰ NatureServe. 2011. Guidelines for using the NatureServe vulnerability index. NatureServe, Arlington. Accessed May 3, 2012. URL: <http://www.natureserve.org/prodServices/climatechange/ccvi.jsp>.

	Coverage	Non-climate stressors	Climate-related variables	Ranking/Results	Limitations	Treatment of uncertainty	Data sources
IUCN: Species Susceptibility to Climate Change ^{121, 122}	All taxa (first assessment: birds, amphibians, corals).	Not applicable. To be used separately from Red List rankings, then overlaid to compare (e.g., how many listed species are susceptible to climate change; how many susceptible species are not yet listed, etc.	Identified over 90 biological traits that may be associated with enhanced susceptibility to climate change, consolidated into five groups of traits. ¹²³	Binary: “Yes, susceptible” or “no, not susceptible.” A susceptible species possesses any one or more of susceptibility traits.	Assumes: species’ susceptibility is associated with the possession of specific biological traits; possession of any one of the traits increases susceptibility. Does not assess exposure, only susceptibility.	“Data deficient” species are marked, and excluded from some analyses; uncertainty not assessed on a species-by-species basis if data are considered sufficient.	IUCN Red List and BirdLife International’s World Bird Database: taxonomy, distribution, habitats, and threats. Additional information: published and unpublished data, online resources, literature, and expert knowledge.

¹²¹ Foden, W., Mace, G., Vié, J.-C., Angulo, A., Butchart, S., DeVantier, L., Dublin, H., Gutsche, A., Stuart, S. and Turak, E. 2008. Species susceptibility to climate change impacts. In *The 2008 review of the iucn red list of threatened species*, eds. J.-C. Vié, C. Hilton-Taylor and S.N. Stuart. Gland, Switzerland.

¹²² International Union for the Conservation of Nature. 2007. Workshop: species vulnerability traits. Accessed June 14, 2012. URL: http://cmsdata.iucn.org/downloads/species_vulnerability_workshop_report.pdf.

¹²³ 1. Specialized habitat and/or microhabitat requirements; 2. Narrow environmental tolerances or thresholds likely to be exceeded; 3. Dependence on specific environmental triggers or cures that are likely to be disrupted by CC; 4. Dependence on interspecific interactions that are likely to be disrupted by CC; 5. Poor ability to disperse or colonize to new or more suitable range.

	Coverage	Non-climate stressors	Climate-related variables	Ranking/Results	Limitations	Treatment of uncertainty	Data sources
Habitat vulnerability in Massachusetts' Wildlife Action Plan ^{124, 125, 126}	20 habitats in Massachusetts.	Experts asked to identify non-climate stressors that would exacerbate effects of climate change.	Each habitat assessed by experts primed with climate modeling, general determinants of vulnerability, "straw man" assessments for each habitat	Scoring system 1-7 (7: at risk of being entirely eliminated from the state; 4: unaffected; 1: likely to expand); supported by a narrative.	Based exclusively on expertise at workshop.	3-point scoring for uncertainty of vulnerability scores (high, medium, low). High: more likely than not to conform to stated vulnerability score.	Expert knowledge: Workshop presented: 2 climate scenarios (2x and 3x of atmospheric CO ₂), background (published science).

¹²⁴ Glick, P., B.A. Stein, and N.A. Edelson, eds. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

¹²⁵ Manomet Center for Conservation Sciences and Massachusetts Division of Fisheries and Wildlife. 2010. Climate change and Massachusetts Fish and Wildlife: volume 2 habitat and species vulnerability. Massachusetts Division of Fisheries and Wildlife, Westborough, MA.

¹²⁶ Gregg, R. M. 2011. Integrating climate change into the Massachusetts state wildlife action plan using an expert panel-based vulnerability assessment. Case study on a project of the Massachusetts Department of Fish and Game and Manomet Center for Conservation Sciences (EcoAdapt's State of Adaptation Program). Accessed May 3, 2012. URL: <http://www.cakex.org/case-studies/981>.

Table 17: Bioclimatic and other spatial models - based on complex mapping and modeling, requiring high quality data

	Coverage	Determinants of general vulnerability	Determinants of climate vulnerability	Ranking/Results	Limitations	Treatment of uncertainty	Data sources
Vulnerability to sea-level rise in Chesapeake Bay (SLAMM Model) ^{127, 128, 129}	Coastal wetland habitats, from NJ to VA: swamp, tidal swamp, inland fresh marsh, tidal fresh marsh, (brackish) marsh, saltmarsh, estuarine beach, tidal flat, ocean beach.	Not applicable. Should be used in conjunction with other indicators.	Habitat sensitivity: ecological traits (e.g., tolerance for salinity of plant species). Exposure: land elevation, sea-level rise. Adaptive capacity: intrinsic and extrinsic.	Displayed as percentage changes in habitat, and illustrated on maps. Saltmarsh results were also used to assess vulnerability of shorebirds, based on bird per ha of habitat. ¹³⁰	Model is specific to coastal wetland habitats, with well-defined management goals.	Areas of uncertainty for each model input (e.g., projections for sea-level rise). Multiple scenarios help to manage uncertainty risk.	Habitat composition data: National Wetland Inventory. Coastal elevation data: USGA National Elevation Dataset. Historical sea-level change: NOAA. Relative sea-level change: scientific literature, expert opinion.

¹²⁷ Glick, P., B.A. Stein, and N.A. Edelson, eds. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

¹²⁸ Glick, P., A. Staudt, and B. Nunley. 2008. Sea-level Rise and coastal habitats of the Chesapeake Bay region: technical report. National Wildlife Federation, Reston, VA.

¹²⁹ Glick, P., A. Staudt, and B. Nunley. 2008. Sea-level Rise and coastal habitats of Chesapeake Bay: summary report. Reston, VA: National Wildlife Federation, 2008.

	Coverage	Determinants of general vulnerability	Determinants of climate vulnerability	Ranking/Results	Limitations	Treatment of uncertainty	Data sources
Predicting the Impact of Climate Change on Fragmented Prairie Biodiversity: A Pilot Landscape Model (SK) ¹³¹	Pilot model included two study watersheds in the southern portion of the prairie ecozone: Moose Jaw River and Frenchman River, but could be used in any prairie watershed.	Not applicable.	Assumes vulnerability is correlated with low ecological integrity (including terrestrial and aquatic habitat loss and fragmentation) and dispersal capacity of plants and animals.	No ranking. Only modeled changes in vegetative regime. Could be used to identify priority habitat connections and at-risk species.	Model is specific to prairie watershed systems.	Uncertainty is treated statistically in the model outputs.	Model based on government data sources and previous work ¹³² Plant and animal dispersal based on literature search of previous 30 yrs.

¹³⁰ Centre for Conservation Biology. 2009. Impact of sea-level rise on marsh bird populations. *Conservation Cornerstones*. Accessed May 3, 2012. URL: http://www.ccb-wm.org/news/2009_MayAug/sea_level_rise_marshBirds.htm.

¹³¹ James, P., K. Murphy, R. Espie, D. Gauthier, and R. Anderson. 2001. Predicting the impact of climate change on fragmented prairie biodiversity: a pilot landscape model. Final report to The Climate Change Action Fund, Saskatchewan.

¹³² Model based on the following existing data sets for Saskatchewan: vegetation and water cover (from satellite imagery) soils, ecological classification, hydrological data, species distributions, and human infrastructure.

Table 18: Hybrid approaches - expert characterization combined with bioclimatic models

	Coverage	Determinants of general vulnerability	Determinants of climate vulnerability	Ranking	Limitations	Treatment of uncertainty	Data sources
Pacific Northwest Climate Change Vulnerability Assessment¹³³	Assessed over 400 species and systems across the Pacific Northwest.	Not applicable.	Intrinsic sensitivity assessed for species, systems using sensitivity index. ¹³⁴ Climate projections and soil data input to Global Vegetation Model (GVM), then used to calculate range shifts for 12 birds and mammals.	Sensitivity index results 1 – 100 where 100 is most sensitive.	Resource intensive (3-4 years, approximately \$800,000).	Experts assign level of uncertainty when completing sensitivity index. GVM assigns levels of uncertainty to model outputs. Multiple climate projections (6) mitigate risk of uncertainty.	Expert knowledge, GVMs, scientific literature, climate projections, soil data, range maps.

¹³³ Glick, P., B.A. Stein, and N.A. Edelson, eds. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

¹³⁴ Estimated sensitivity of individual species integrates the following: ability to disperse and whether barriers to dispersal exist; dependence on disturbance; physiology and ecology (e.g., sensitivity to temperature, precipitation, salinity, temperature, precipitation, pH, CO₂); dependence on and persistence of climatically sensitive habitats (e.g., alpine areas, shallow wetlands, perennial streams); generalist or specialist; dependence on persistence of other species. Estimated sensitivity of ecosystems and communities: hydrological sensitivities, component species sensitivities, proximity to the coast, effects of disturbance regimes.

Table 19: Historical approach - based on multiple scientific studies of historical responses to climate change

	Coverage	Determinants of general vulnerability	Determinants of climate vulnerability	Ranking	Limitations	Treatment of uncertainty	Data sources
Vulnerability of land management in the grassland-forest transition to CC impacts on ecosystems and soil landscapes (SK)¹³⁵	One priority ecotones: the ecological gradient from grassland to forest in Canada's western interior, focus on soil and ecosystem responses (approx. 135,600 km ²).	Not applicable.	Core assumption: historic responses will help predict vulnerability to future climate change. A suite of studies used remote sensing, aerial photos, tree ring data, pollen analysis, lake productivity.	Vegetation productivity correlated to temperature, precipitation, and drought severity; tree rings show more growth during high precipitation and low temperature; pollen abundance sensitive to summer precipitation and annual temperature.	Lack of significant findings of vulnerability could be due to short timeframes, small sample size. Causal relationships cannot be deduced from correlations.	Uncertainty treated in statistical analyses in each study; no overall estimate of uncertainty completed thus far.	Extensive use of existing data sets and climate models.

¹³⁵ Sauchyn, D., M. Johnston, M. Vetter, J. Piowar, E. Wheaton, E. Barrow, N. Henderson, V. Wittrock, G. Yu, C. Hart, M. Lou, V. Swarbrick, M. Ranalli, and J. Vanstone. 2007. The vulnerability of land management in the grassland-forest transition to climate change impacts on ecosystems and soil landscapes. Prairie Adaptation Research Collaborative, CCIAD Project A733, 2007.

Table 20: High-level resilience approach - based on broad understanding of climate change impacts and ongoing scientific research

	Coverage	Determinants of general vulnerability	Determinants of climate vulnerability	Ranking	Limitations	Treatment of uncertainty	Data sources
Strategic Assessment of the Vulnerability of Australia's Biodiversity to Climate Change ^{136,137}	All of Australia.	Not applicable.	Physiological and life history traits influence species vulnerability, illustrates general potential pathways of community change resulting from independent responses; notes importance of threshold effects.	No ranking of vulnerability; instead assesses general vulnerability (and possible success of adaptation tools) in references to “runaway,” “stabilization” and “recovery” greenhouse gas scenarios.	Intended to inform an overall frame and management orientation for adaptation approaches, rather than identify particular species or systems of concern.	Substantive attention paid to dealing with nonlinearity, uncertainty and data gaps.	Compiled by a Biodiversity and Climate Change Expert Advisory Group.

¹³⁶ Government of Australia. 2009. Australia's biodiversity and climate change: a strategic assessment of the vulnerability of Australia's biodiversity to climate change: technical synthesis. Prepared for the Australian Government by the Biodiversity and Climate Change Expert Advisory Group. Commonwealth of Australia, Department of Climate Change.

¹³⁷ Government of Australia. 2009. Australia's biodiversity and climate change: a strategic assessment of the vulnerability of Australia's biodiversity to climate change: summary for policy makers. Prepared for the Australian Government by the Biodiversity and Climate Change Expert Advisory Group. Commonwealth of Australia, Department of Climate Change.

5.2 Choosing an approach for biodiversity vulnerability assessments

Over time the methods and purposes of vulnerability assessments have matured from studies designed only to estimate the amount of biodiversity loss towards processes designed to inform adaptation responses. Assessments have evolved from linear to more complex analyses, from strictly quantitative approaches to combinations of qualitative and quantitative data and results, from science-driven to policy-driven projects, from analyses that dictate users to those that involve users in the actual tool design and assessment process.¹³⁸

In addition to a shift in methodology the range of approaches available to assess the vulnerability of biodiversity to climate change reflects the diverse set of choices that practitioners can make in using a tool. The breadth of vulnerability assessment approaches reflects different decisions made about the intended audience, scope, and purpose of the exercise. In particular, the vulnerability assessments we examined differed in the group of experts or managers who would be using the tool, the time and funding available to the project, the conservation question that the vulnerability assessment needed to answer, and the focus of the effort (e.g., on species at risk or important habitats).

5.2.1 User group

Often the development of a vulnerability assessment tool involves partnerships among several organizations and agencies to support the development of a tool, and/or to test the approach. Expert workshops or ongoing cross-expert collaboration is present in almost every tool development process we found. Early engagement of the range of people likely to use the tool or implement its results can facilitate sharing of data sources and expert knowledge, ease tailoring of the approach to where and how the vulnerability assessment will be used by scientists and managers, and allow for better integration into existing planning and prioritization processes.

For example, vulnerability assessments may be conducted as part of, or to complement, wildlife management plans, species-at-risk recovery plans, or species status assessments. Assessments could be undertaken by individual provinces or by an inter-jurisdictional collaborative where appropriate for the biodiversity elements of interest. The knowledge and needs of the target user group for the vulnerability assessment can influence the choice of tool; and often the experts themselves can be part of the process of crafting a method or approach.

5.2.2 Cost

Vulnerability assessments range in terms of the time and cost required. The resources available translate roughly to the scope of the project. For example, the U.S. Environmental Protection Agency's initial assessment of six threatened and endangered species cost approximately \$60,000 and took under a year to complete. In contrast, the Pacific Northwest Assessment cost \$800,000 and took approximately three years. In general, expert characterization approaches,

¹³⁸ Füssel, H-M. and R.J.T. Klein. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change* 75: 301-329.

which assess several species based on existing expert knowledge, often in the context of a workshop or via an online tool, less expensive and faster to conduct. Modeling habitat niches and how they will change under climate change scenarios is more expensive and takes more time. More detail and greater coverage (e.g., more species or habitats, a larger area) make the process more expensive and more time-consuming. The amount of money and time an organization has to devote to a vulnerability assessment will affect to some extent the choice of tool.

An unknown variable is the relative cost of identifying and implementing adaptive actions for ecosystems or species. If compared to the cost of developing and implementing recovery programs for species at risk - for example \$2.89-million and 25 person-years for a provincial grizzly bear recovery program or \$436,000 for the western silvery minnow¹³⁹ - it appears that avoiding the addition of new species to threatened or endangered lists as a result of climate change impacts could be a cost savings measure over the long term.

5.2.3 What is the conservation question?

The conservation question that needs to be answered by a vulnerability assessment will affect to some extent the level of detail and certainty that will be required of the method. For example, the IUCN asked the following in their study: how many listed species are likely to be susceptible to climate change, and how many not-yet-listed species are likely to be susceptible to climate change? The conservation question meant that they could not limit their scope to only current endangered species, but instead needed to focus on a few taxa for which data of a high enough quality were available for both listed and non-listed species worldwide. The IUCN scope was global, and included only birds, amphibians and corals. It also sorts species into only one of two categories: susceptible and not susceptible, which is appropriate to their binary question.

In contrast, one application of the SLAMM model in the Chesapeake Bay assessment asked this question: how will climate change alter the habitat available for shorebird populations? That study concentrated on climate change impacts to shorebird habitat. The Saskatchewan case asked: what was the historical response of vegetation to climate change in the grassland-forest transition zone, and what can that tell managers and scientists about future vulnerability?

5.2.4 Species or system of interest

The conservation focus of a climate change vulnerability assessment for biodiversity is the context in which the conservation question must be answered. This includes both whether individual species or habitats are of greatest interest, but also the scope of the effort, in terms of number of species, particular taxa, or geographic area. For example, the habitat vulnerability assessment conducted for Massachusetts' Wildlife Action Plan looked at 20 habitats of interest. The vulnerability assessment in the Saskatchewan case looked only at one priority region - the grassland-forest transition - that was identified in a climate scenario as likely to be exposed to climate impacts. The EPA Framework was initially piloted with six species, but in general was focused on threatened and endangered species. The approach applied by the USDA Forest

¹³⁹ From published species recovery plans. Accessed June 14, 2012. URL: <http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/LegalDesignationOfSpeciesAtRisk/RecoveryProgram/RecoveryPlans.aspx>.

Service included only terrestrial vertebrates, and the Pacific Northwest Assessment included an impressive 400 species and systems.

5.3 Challenges for vulnerability assessments

Despite the variety of tools applied to conduct a vulnerability assessment, each approach faces common challenges with respect to application across multiple taxa, coping with uncertainty and imperfect data availability, and dealing with the interaction between climate change stressors and non-climate stressors.

5.3.1 Fit across taxonomic groups and habitat types

As with species at risk status assessments, defining and calibrating criteria that can be used across taxa for climate change vulnerability assessments poses a challenge; important components of the life history of a mollusc, for example, may be different from those of a migratory bird. Diverse expert feedback in the process of designing and testing the approach, such as the IUCN's expert workshop, can help ensure that the factors used in the climate change vulnerability assessment process are appropriate across the species or systems of concern.¹⁴⁰

Once categories of species traits or habitat traits are selected for a vulnerability assessment method, their relative importance as an indicator of species or habitat vulnerability may still be unequal across taxa and landscapes. For example, high susceptibility to temperature changes may inhibit Species A, even if no other susceptibility-linked traits are present, while species B's vulnerability to climate change may result from the cumulative effects of temperature changes, hydrological changes, and the effect of climate change on prey availability. Frameworks treat this challenge differently. The IUCN's model will find a species "susceptible" to climate change if it displays at least one of the identified traits.¹⁴¹ The EPA Framework, as a comparison, guides the user to generate scores for each trait, and then tally the scores to generate an overall indication of susceptibility.¹⁴²

Different assessment criteria may also be necessary depending on the level of biodiversity considered (e.g., population, species, ecosystem). For the Pacific Northwest Climate Change Vulnerability Assessment, the sensitivity of all individual species is based on ability to disperse and whether barriers to dispersal exist; dependence on disturbance; physiology and ecology; dependence on and persistence of climatically sensitive habitats; being a generalist or specialist; and dependence on persistence of other species. The sensitivity of ecosystems and communities

¹⁴⁰ International Union for the Conservation of Nature. 2007. Workshop: species vulnerability traits. Accessed June 14, 2012. URL: http://cmsdata.iucn.org/downloads/species_vulnerability_workshop_report.pdf.

¹⁴¹ Foden, W., Mace, G., Vié, J.-C., Angulo, A., Butchart, S., DeVantier, L., Dublin, H., Gutsche, A., Stuart, S. and Turak, E. 2008. Species susceptibility to climate change impacts. In *The 2008 review of the iucn red list of threatened species*, eds. J.-C. Vié, C. Hilton-Taylor and S.N. Stuart. Gland, Switzerland.

¹⁴² Galbraith, H., and J. Price. 2009. A framework for categorizing the relative vulnerability of threatened and endangered species to climate change. Prepared for the Global Change Research Program, National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency.

is estimated based on hydrological sensitivities, component species sensitivities, proximity to the coast, and the effects of disturbance regimes.¹⁴³

The challenge of fit can also be overcome by creating a tool that is specific to a smaller set of habitats. For example, the modeling of vulnerability to sea-level rise in Chesapeake Bay includes only coastal wetland habitats, and the vulnerability assessment of fragmented prairie biodiversity in Saskatchewan works only with prairie watersheds.

5.3.2 Uncertainty and data availability

Coping with unavoidable uncertainty is one common challenge for all vulnerability assessment methods. Assessments often require a substantial amount of data about individual species life history and demographics, which may vary in availability and accuracy. Even when some of the data needed are available, they may be sparse, poorly collected, statistically insufficient, or biased.¹⁴⁴ The general status process for wild species in Canada (see Section 2.3.1) reinforces the need for improved data. For example in Alberta approximately 1 in 5 species of those assessed have an “undetermined” general status.

Downscaled climate projections and global vegetation models (GVMs) also come with uncertainty based on the limitations of their input data, the validity of their model assumptions, and the intrinsic difficulty of using projections into an uncertain future. The effectiveness of scoring or categorization depends on quality of data and the accuracy of the assumptions used to make the assessment. For this reason, frameworks are often tested by initially running a few data-rich species, or taxa through the assessment. For example, the EPA framework was first tested with six listed species; the IUCN approach tested with birds, amphibians and corals.

But even with the best data, all assessments will unavoidably involve some degree of speculation as to how species or systems will react to climate change and other future stressors, since non-climatic influences tend to dominate short-term biological changes. Predictions of the response of a species or system to the impacts of climate change have unavoidable uncertainty. For example, a 2003 study of species responses to regional climate change found that 57% of species showed strong responses consistent with expectations of how they would respond to climate change, 32% showed no significant change, and 11% exhibited responses that were opposite to anticipated responses to climate change.¹⁴⁵ The predictive power of any model is limited to some extent, and may be better suited to broad analysis across regions, as opposed to being applied to local situations.

To help deal with this uncertainty, vulnerability assessments can and should be understood as approximations or indications of comparative vulnerabilities or susceptibilities and incorporated into management decisions with the understanding that they cannot be perfectly accurate. Efforts

¹⁴³ Glick, P., B.A. Stein, and N.A. Edelson, eds. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C. Case study 7.

¹⁴⁴ Botkin, D.B., H. Saxe, M.B. Araújo, R. Betts, R.H.W. Bradshaw, T. Cedhagen, P. Chesson, T.P. Dawson, J.R. Etterson, D.P. Faith, S. Ferrier, A. Guisan, A. Skjoldborg Hansen, D.W. Hilbert, C. Loehle, C. Margules, M. New, M.J. Sobel, and D.R.B. Stockwell. 2007. Forecasting the effects of global warming on biodiversity. *BioScience* 57: 227.

¹⁴⁵ Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421: 37-42.

to improve transparency by documenting assumptions and recording the reasoning for them can help improve accuracy. Additionally, transparency and proper documentation will support evaluation and review as new data arise that may support or contradict existing data or assumptions. Data sources should be specified, and evaluation of uncertainty can be incorporated into the process itself. In situations where lack of published data requires more reliance on expert opinion, groups of experts may be more accurate than a single source. Many attempts to assess vulnerability involve multiple scenarios, multiple modeling methods, and/or multiple partner organizations with attempts to incorporate multiple sources of expert knowledge.

5.3.3 Relationship of climate vulnerability to non-climate stressors

As discussed earlier, some species that are considered threatened or endangered as a result of non-climate stressors may also be vulnerable to climate change; however, some species that have been found to be particularly vulnerable to climate change aren't yet listed as endangered or threatened from other stressors.¹⁴⁶

Climate change vulnerability assessments face the common challenge of disentangling the incremental risk (or benefit) of climate change from the effects of other stressors. The possibility of interaction effects between climate and non-climate stressors complicates this effort. For example, landscape fragmentation is a stressor in itself, as well as a barrier to a species' ability to shift its range in the face of climate change impacts.¹⁴⁷ Furthermore, even when the expected vulnerability of a species is checked against observed or historical data, it is difficult, if not impossible, to attribute particular species responses to anthropogenic climate change.¹⁴⁸

¹⁴⁶ For example, both the application of the NatureServe Vulnerability Index process in Nevada, and the IUCN's assessment of global bird, amphibian, and coral populations, found listed threatened species that were not deemed vulnerable to climate change, and unlisted species that were deemed vulnerable to climate change impacts.

¹⁴⁷ Botkin, D.B., H. Saxe, M.B. Araújo, R. Betts, R.H.W. Bradshaw, T. Cedhagen, P. Chesson, T.P. Dawson, J.R. Etterson, D.P. Faith, S. Ferrier, A. Guisan, A. Skjoldborg Hansen, D.W. Hilbert, C. Loehle, C. Margules, M. New, M.J. Sobel, and D.R.B. Stockwell. 2007. Forecasting the effects of global warming on biodiversity. *BioScience* 57: 227.

¹⁴⁸ Parmesan, C. Duarte, E. Poloczanska, A.J. Richardson and M.C. Singer. 2011. Overstretching attribution. *Nature Climate Change* 1: 2–4.

6. Next Steps: Identify Species and Habitats Most Vulnerable to Climate Change

Agencies responsible for the conservation and management of wild species typically participate and engage in conservation and species management through a variety of types of legislation and processes. For example relevant pieces of policy and legislation in the Prairie Provinces include endangered species legislation at federal and provincial levels, wildlife acts, and a wide variety of natural resource planning policies and guidelines.

The case study of the Alberta Species at Risk Program illustrates that the Alberta Fish and Wildlife Division is ideally positioned to integrate climate change impacts and adaptation into its biodiversity mandate:

- Through the development of the Alberta Climate Change Adaptation Framework and other past research, a significant amount of ‘groundwork’ has been completed to date.
- The work of the Alberta Fish and Wildlife Division is inherently similar to climate adaptation work in that it involves a process of continuously integrating new information, reviewing progress and redeveloping strategies.
- Staff biologists and experts have already begun to integrate climate risk and adaptation in species general and detailed assessments.

However, integrating climate change into planning may present some challenges. Namely, that the planning horizon for species evaluation and recovery planning, as well as other legislation, generally occurs within a timeframe that is shorter (e.g., recovery plans in Alberta are typically 5 years, although objectives within them may span longer time periods) than the available outputs from climate change models (e.g., 2020s, 2050s and 2080s). While this appears to be a significant obstacle, it is important to recall that climate change models and their outputs are based on scenarios of emissions and technology, and that the actual vulnerability of species is dependent on the exposure and adaptive capacity of the species, plus any number of other factors. Climate models therefore should be understood not as an ‘end-point’ around which species recovery plans should be designed, but as an indicator of potential new vulnerability that informs current strategic and action-based response.

Another challenge is the availability and accessibility of information, as well as the suitability of the information for planning and evaluation purposes. Currently, climate change models and outputs are available through a variety of Canadian and international sites, but they require (to

varying degrees) a level of user understanding and comfort that staff from fish and wildlife agencies and conservation organizations may not presently have. The existence of some user-friendly tools aims to alleviate this challenge, but tangible questions remain: how can researchers translate climate variables such as average temperature and precipitation to ecosystem or species indicators necessary for risk assessment? How can researchers understand the local implications for global climate models?

To resolve these and other challenges inherent in integrating climate change impacts and adaptation across activities of agencies within the Prairie Provinces like Alberta Fish and Wildlife, an overarching objective of increasing knowledge and capacity with respect to climate change could be adopted. This report highlights a number of opportunities, both general and specific, in which this theme could apply.

Table 3 in Section 2.2, for example, highlights a number of actions that can be undertaken immediately to integrate climate change with current management strategy process for species at risk. Action items highlighted include dissemination of climate model summary reports to ecosystem and species experts, increasing dialogue and collaboration (in a variety of forums) between species and climate experts, and the development of research and data strategies that incorporate climate to help to increase understanding of the link between ecosystems, species and climate change.

The development of strategies for increasing resilience of Alberta ecosystems and species will intersect with both development and adaptation strategies in other sectors, including forestry and agriculture. Strategies that effectively address risk in the forestry sector for example, may have unintended consequences and may limit natural or planned adaptive capacity of biodiversity. The development of adaptation strategies by government agencies responsible for biodiversity should be coordinated with other sectors to identify if (or more likely, where) potential conflicts are present. Similarly, where biologists are engaged in external processes (e.g., consultations over industrial developments or land-use planning) they should increasingly present a species and ecosystem perspective that incorporates an awareness of climate change impacts.

As agencies like Alberta Fish and Wildlife complete additional work to identify the highest-risk habitats, ecosystems and species, there will be increased capacity to share that knowledge with internal and external stakeholders. The following sections present recommendations in this regard.

6.1 Recommendation 1: Integrate climate change assessment and adaptation into existing conservation processes

Within existing species at risk processes, the Alberta case study showed that the inclusion of climate change in status assessment and recovery planning is incomplete. Detailed status assessments and recovery plans show some integration of climate change impacts to species, but vary in the depth to which climate change is discussed.

The existence of climate change information within some species at risk reports suggests that the biologists developing status assessments and recovery plans are already increasing their capacity

to understand climate impacts and include these impacts in biological conservation work. Additional support, including tools for understanding climate scenarios, and vulnerability assessment tools, are needed.

Species at risk biologists could then increase the effectiveness of this integration of climate knowledge into larger conservation arenas by supporting capacity development and networking between the conservation and climate communities.

A detailed suite of recommended actions to more fully integrate climate change science and knowledge into existing species at risk processes is provided in section 2.0.

6.2 Recommendation 2: Comprehensive climate change vulnerability assessments for biodiversity

International research points to a large overlap between categories of threatened species and susceptibility to climate change. This suggests there is a heightened extinction risk among species that already lack resilience to non-climate stressors. However, the presence of susceptibility to climate change among non-listed species may be a warning that additional species may approach endangerment in future years as a result of climate change.

6.2.1 Step 1: Expert characterization approach.

Within the Prairie Provinces, agencies responsible for biodiversity conservation could complete an analysis of species and habitat vulnerability based on expert characterization. Alberta Fish and Wildlife Division has begun some of this work using the Adaptation Framework developed by SRD's TTACC. The starting point of that analysis was to identify categories of ecosystem services, with subsequent analysis of exposure, adaptive capacity, and vulnerability for each service.

An analogous approach could provide a more detailed assessment of vulnerability by completing expert characterization where the starting point of analysis is a species or habitat. Points of analysis would include the following: species or habitat, trait, exposure; and sensitivity, adaptive capacity, and risk (see sample table below).

Table 21: Sample expert characterization vulnerability assessment

Ecosystem, Region or Taxa	Trait	Exposure to climate change impacts	Sensitivity	Adaptive Capacity	Risk

Vulnerability and risk assessment would be based on expert characterization, which could be completed based on participation of broad range of experts including climate scientists and modelers.

The primary advantage of this approach is that vulnerability and risk assessment aligns with ongoing provincial adaptation processes. A drawback of this approach is the need to first identify which habitats, taxa or species require prioritization, and finding experts to carry out this work. To complete this assessment, resources and time are needed for collaboration and input across a range of disciplines.

6.2.2 Step 2: Resiliency approach

The approach commissioned by the Australian Government (described in Section 5.1) provides a strategic assessment of the vulnerability of species, ecosystems and overall biodiversity to climate change. It is based on large-scale understanding of climate change impacts and current and ongoing research. The outcomes provide guidance that support management decision making and the development of approaches that increase resiliency broadly.

Advantages of this approach are as follows: avoiding the necessity of having to pick a region, habitat, or species before analysis begins; the opportunity to complete a broad assessment that supports management decision-making that increases overall biodiversity resiliency. This approach supports the constant integration of new knowledge and science by not relying on single or limited numbers of projections of future climate change that may shift as new scenarios and models are developed.

An important advantage of this approach is that it may identify regions and species that are vulnerable to climate change that may not be identified if the user is required to first narrow scope to a region or species before developing more detailed analysis (as would be the case in other approaches). In this sense, this approach would build on the existing foundation of work and provide guidance to support the integration of climate projections in existing processes, including general and detailed status assessments, and recovery planning.

A broader strategic assessment of species and habitat vulnerability guided by a multi-disciplinary body may support coordination of adaptation actions across sectors that are inter-dependent. For example, including representation from the forestry and agriculture sectors in an expert advisory panel would ensure that adaptation actions taken by that sector do not have negative consequences for resiliency or adaptive capacity of Alberta's ecosystems or species.

A coupling of approaches that are broad and specific is ideal to start planning towards climate change adaptation for biodiversity. Agencies across the Prairie Provinces can take steps within existing and innovative species-specific conservation processes to integrate climate change science into conservation practice, as well as look to larger collaborative opportunities for a resiliency approach to biodiversity assessment.

7. Appendices

7.1 Definitions

Adaptation: Any activity that reduces the negative impacts of climate change and/or positions people to take advantage of new opportunities that may be presented.

Adaptive capacity: The potential, capability or ability of a system to adapt to climate change impacts.

Baseline/Reference: Any datum against which change is measured. It might be a "current baseline", in which case it represents observable, present-day conditions. It might also be a "future baseline", which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.

Biodiversity: The variety of life at all levels of biological systems, including species diversity, ecosystem diversity, and genetic diversity.

Forecast/Prediction: When a projection is designated "most likely" it becomes a forecast or prediction. A forecast is often obtained using physically-based models, possibly a set of these, outputs of which can enable some level of confidence to be attached to projections.

Projection: Used in two senses in the climate change literature. In general usage, a projection can be regarded as any description of the future and the pathway leading to it. However, a more specific interpretation has been attached to the term "climate projection" by the IPCC when referring to model-derived estimates of future climate.

Risk: A combination of the likelihood that a negative outcome will occur and the severity of consequence if the negative outcome does occur.

Scenario: A scenario is a coherent, internally consistent and plausible description of a possible future state of the world (IPCC, 1994). It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions). A set of scenarios is often adopted to reflect, as well as possible, the range of uncertainty in projections. Other terms that have been used as synonyms for scenario are "characterization", "storyline" and "construction".

Sensitivity or susceptibility: The likelihood that a species or system would be affected by the impacts of climate change.

Vulnerability: The degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed; it is a function of the sensitivity and adaptive capacity of a system (e.g., a species, a biological community, a human organization).

7.2 Canadian climate change science and impacts resources

Source	Description
Cccsn.ca	<p>Produces scenario maps, scatter plots, data and bioclimate profiles (for 500 locations)</p> <p>Scenarios up to and including Fourth Assessment Report. Ensemble scenarios used for many tools.</p> <p>Includes quick “localizer” tool.</p> <p>Downscaling tools are available.</p>
Hazards.ca	<p>Does not include scenarios or modeling</p> <p>Regional (pacific and Yukon, prairies and northern, Ontario, QC, Atlantic).</p> <p>Outputs include image files and pdfs.</p> <p>Plans to include appropriate scenarios for impacts and adaptation.</p> <p>(Note, above is review of prairies/north site, each region has different sites and outputs. B.C./Yukon has links to trends documents and data files (xcl)</p>
PICS http://pacificclimate.org/tools-and-data/regional-analysis-tool	<p>Available outputs include:</p> <p>Maps</p> <p>Files, including GIS files (geotiff, georeferenced)</p> <p>Data (CSV files)</p> <p>Scatter plots</p> <p>Regional Analysis Tool is similar to “plan2adapt” but has a more complex user interface and provides more options but does use the same data to generate results.</p> <p>The Regional Analysis Tool allows users to:</p> <ul style="list-style-type: none"> • Select from predefined regions and generate maps, plots and data for a specific time horizon (50s, 80s, etc.) • define custom regions and generate maps, plots, and data • generate maps showing projected changes for a specific region under one or more GCMs, with included grid boxes highlighted • acquire metadata from a specific region from all of the selected GCMs, with the option of displaying percentiles across selected GCMs • compare specific climate variables for each GCM ensemble • plot how climate variables change over time for each GCM ensemble • display box plots for each future climate projection over the GCM ensemble
PICS (B.C. only) http://plan2adapt.ca	<p>Simplified, user-friendly tool. Easy access to maps, graphs for each time period, output and region.</p>

	<p>Does not provide data outputs.</p> <p>Simplified, but uses same data as PCIC regional analysis tool.</p>
<p>Ouranos Consortium (ouranos.ca)</p>	<p>Mandate to develop hydro-climatic scenarios and to develop tools for climate scenarios (provided to/for partners).</p> <p>“Provide partners with regional climate projections suited to their needs, using the best available tools.”</p> <p>Also, provide regional climate models.</p>
<p>Prairie Adaptation Research Collaborative (http://www.parc.ca/)</p>	<p>Summary reports of scenario work available online.</p> <p>Scenarios and tools for Alberta, Saskatchewan, Manitoba available.</p>

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