

**CLIMATE CHANGE AND ENDANGERED SPECIES IN CANADA: A SCREENING LEVEL
IMPACT ASSESSMENT AND ANALYSIS OF SPECIES AT RISK MANAGEMENT AND POLICY**

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Environmental Studies
in
Geography

Waterloo, Ontario, Canada, 2008

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

Climate is a long-term driver of ecological change, but the rapidity with which climate is projected to change over the next century may push the limitations of ecological adaptability, to the detriment of biodiversity. Given their typically small populations, limiting biological traits and exposure to external stressors, species currently classified as “at risk” may be among the most vulnerable to climate change and least capable of adapting naturally. A screening level assessment of the impacts of climate change on endangered species in Canada was conducted by integrating knowledge of the current status and characteristics of each endangered species with projections of climate change and climate change impacts. It was determined that climate change may have a potential overall negative influence on more than half of all endangered species in Canada. However, while relatively few species were predicted to respond in an overall positive or neutral manner to climate change, a large portion of endangered species were classified as having insufficient information to generate a decision on the net influence of climate change; in many cases, these species were located at the northern extent of their range in warmer regions of Canada and have the potential to experience at least some benefits under climate change provided that other stressors are sufficiently mitigated. These results, as well as the inherent vulnerability of species at risk to environmental change, the potential for species at risk distributional shifts and the likelihood of increasing rates of species imperilment, demonstrate the need for greater consideration of the implications of climate change in species at risk management and policy. Canada’s Species at Risk Act (SARA) does not explicitly address the issue of climate change and limitations exist in SARA’s time-sensitive definition of wildlife species eligible for protection in Canada and in the interpretation of SARA’s mandates in the context of anthropogenically driven climate change. It is recommended that climate change be systematically considered in all species at risk assessments, recovery strategies and management plans and that SARA’s definition of a wildlife species be reevaluated in light of shifting species distributions under climate change. Further recommendations to identify “values” that will assist in prioritizing species for conservation, to reassess the concept of an invasive species under climate change and to implement strategies that focus more broadly on the conservation of biodiversity and ecological integrity rather than individual species may require ethically complex discussions and decisions on the part of species at risk managers and policy makers. Future research should focus on informing species at risk management and policy by improving modeling capabilities at the species level, conducting in-depth analyses of priority species, and building knowledge of alternative species conservation strategies such as assisted colonization.

ACKNOWLEDGEMENTS

I would like to extend sincere thanks to my advisor, Dr. Daniel Scott, for the knowledge, guidance and freedom he provided throughout the course of this project. I would also like to thank my committee member, Dr. Stephen Murphy, and the two readers of this thesis, Dr. Jean Andrey and Dr. Brendon Larson, for their thoughtful questions, comments and suggestions for improvement.

I gratefully acknowledge the financial assistance provided by the Social Sciences and Humanities Research Council (SSHRC) and the University of Waterloo to carry out this research.

Most importantly, I thank my family for their unfailing support. This thesis could not have been completed without their love and encouragement.

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LIST OF ACRONYMS

2 x CO ₂	Doubled Atmospheric Carbon Dioxide
ACIA	Arctic Climate Impact Assessment
CBD	Convention on Biological Diversity
CCCSN	Canadian Climate Change Scenarios Network
CO ₂	Carbon Dioxide
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFO	Fisheries and Oceans Canada
GCM	General Circulation Model
GHG	Greenhouse Gas
GVM	Global Vegetation Model
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
NGO	Non-governmental Organization
NRCan	Natural Resources Canada
SARA	Species at Risk Act
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER 1: INTRODUCTION

1.1. Study Context

Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) (1997) states: “The ultimate objective of this convention is to achieve stabilization of greenhouse gas concentrations in the atmosphere at such a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to *allow ecosystems to adapt naturally to climate change*...[emphasis added].” However, in its Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) (2007a) projects that average global surface temperature will rise between 1.8°C and 4.0°C by 2100¹, and that warming of a minimum of 0.1°C per decade over the next several decades is now unavoidable, regardless of the success of ongoing international efforts to reduce greenhouse gas (GHG) emissions. While natural climate patterns are known to be intimately linked with the distribution and abundance of species and ecosystems across the globe (i.e., Holdridge 1947; Woodward 1987; Schwartzman 1999), the rapid rate at which future climate is projected to change will place significant stress on the resilience of species and ecosystems and climate change is projected to become a leading driver in global biodiversity loss during the 21st century (Sala *et al.* 2000; Thomas *et al.* 2004; IPCC 2007b; Thuiller 2007). Most recently, the International Union for Conservation of Nature (IUCN) indicated that climate change is acting as an accelerant to many of the threats currently influencing species across the globe and states that “Climate change is likely to figure more prominently in future IUCN Red List² updates (IUCN 2008).”

¹ According to IPCC (2007a) best estimate climate scenarios

² The IUCN Red List of Threatened Species is a register of the global conservation status of species worldwide, as assessed by the IUCN.

A growing body of literature stresses the need to create anticipatory strategies that will help to facilitate the adaptation of ecological systems to climate change (i.e., Peters & Lovejoy 1992; Halpin 1997; McCarty 2001; Hannah *et al.* 2002; Lovejoy & Hannah 2005). The implementation of anticipatory climate change measures at an early stage is expected to be more effective and less costly than reactive adaptation measures over the long term, and should be designed to provide near-term benefits as well as future benefits under climate change (Burton 1996; Smith & Lenhart 1996; Smith 1997; IPCC 2001a). More importantly, anticipatory adaptation is theorized to be the best means of preventing irreversible impacts, such as species extinction, and of capitalizing on the potential positive opportunities of climate change (Smith 1997).

In Canada, the research and implementation of climate change adaptation measures related to biodiversity have received the most attention in the context of protected areas. A number of reports have assessed the potential physical and socio-ecological impacts of climate change on protected areas in Canada (i.e., Scott & Suffling 2000; Hui 2001; Scott *et al.* 2002; Lemieux & Scott 2005; Wood 2007) and have outlined potential management and policy strategies for the adaptation of protected areas to climate change (i.e., Scott 2005; Scott & Lemieux 2005; Welch 2005; Lemieux *et al.* 2007).

While planning for climate change in protected areas has broad conservation benefits for many species across Canada, the 427 species federally designated as “at risk”³ may be among the most vulnerable of all Canadian species to climate change and are likely to have unique conservation needs. Species at risk typically occur in small and isolated populations, possess biological traits that limit their resilience to broad environmental changes and are highly threatened by one or multiple external stressors; these characteristics may limit the overall

³ Listed on Schedule 1 of the Species at Risk Act (SARA) as at March 2008

adaptability of species at risk to the projected environmental changes associated with 21st century climate change.

The Species at Risk Act (SARA) was passed in 2002 and is the primary piece of legislation guiding species at risk protection, management and recovery in Canada. The formation of SARA was driven by Canada's commitments under the United Nations Convention on Biological Diversity (CBD) and, subsequently, the Canadian Biodiversity Strategy. However, while climate change is explicitly addressed in the Canadian Biodiversity Strategy, the consideration of climate change with respect to species at risk and SARA has, to date, been very limited. Climate change has been mentioned as a potential threat within assessment and recovery documents of some species at risk⁴, but there has been no systematic assessment of the vulnerabilities of species at risk to climate change in Canada or discussion of species at risk policy in the context of future climate change. The vulnerability of all species at risk to rapid environmental change and the irreversible nature of species extinction emphasize the need for a better understanding of the potential impacts of climate change on species at risk in Canada and for strategies to address the challenges and opportunities of climate change for species at risk management and policy.

1.2. Study Objectives

The overarching goal of this thesis is to generate a broad understanding of the potential impacts, challenges and opportunities of climate change for species at risk conservation in Canada. In doing so, it is expected that this thesis will be an initial step in generating a dialogue on species at risk conservation in the era of climate change, which will inform further research needs and support management and policy decisions related to species at risk.

⁴ Some form of reference to future climate change was made in the federal documentation (status reports or recovery strategies) for 57 of the 165 endangered species assessed in this thesis.

To achieve these goals, an approach similar to Scott and Suffling's (2000) screening level assessment of the implications of climate change for national parks in Canada was adopted. Scott & Suffling's (2000) screening level assessment approach to integrating current knowledge of climate change impacts for each national park in Canada was a critical and effective first step in generating more in-depth national park impacts research (i.e., Staple & Wall 1996; Hui 2001; Scott *et al.* 2002; Lemieux & Scott 2005; Scott & Jones 2005; Jones & Scott 2006; Scott *et al.* 2007; Wood 2007) and in advancing discussions of climate change adaptation strategies suitable for implementation within Canada's national park system (i.e., Scott & Lemieux 2005; Welch 2005), which has resulted in the ongoing development of a climate change adaptation framework for national parks in Canada (Welch 2008)

The main objectives of this thesis are:

- 1) To conduct a screening level assessment of the potential impacts of climate change on endangered species in Canada by integrating current knowledge of the physical impacts of climate change with information on each of the 165 species classified as endangered in Canada under Schedule 1 of SARA as at December, 2007;
- 2) To identify and discuss management and policy issues and knowledge gaps relating to species at risk and climate change in Canada;
- 3) To assess the robustness of the Species at Risk Act in the context of future climate change.

CHAPTER 2: LITERATURE REVIEW

2.1. Species at risk management and legislation in Canada

The objectives of the United Nations CBD are “the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources... (CBD 1992, Article 1).” Canada ratified the CBD in 1992 and responded to its obligations under this convention through the creation of the Canadian Biodiversity Strategy (1995), which mimics at the national level the CBD’s goals for biodiversity conservation and outlines a framework for action to meet these goals. SARA was passed in 2002 and is a critical piece of legislation for the fulfillment of Canada’s obligations under the Canadian Biodiversity Strategy and the CBD.

The purpose of SARA (2002, s. 6) is to “prevent wildlife species from being extirpated or becoming extinct, to provide for the recovery of wildlife species that are extirpated, endangered or threatened as a result of human activity and to manage species of special concern to prevent them from becoming endangered or threatened (p.8).” Core components of this legislation are the immediate protection of individuals⁵ and residences⁶ of wildlife species that are at high risk of extinction, the development, implementation and ongoing review of recovery strategies or management plans for each listed species, and an emphasis on consultation and cooperation among concerned parties including opportunities for public input and stewardship.

The process of listing a species at risk for protection under SARA is outlined in Figure 2.1. Species assessments and classifications are carried out by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), which is an independent group of experts

⁵ An individual includes members of a wildlife species at any point during their life cycle, including larvae, embryos, eggs, sperm, seeds, pollen, spores and asexual propagules (SARA 2002, s. 2[1]).

⁶ A residence is defined as a dwelling place that is occupied by an individual during part or all of its life cycle (i.e. nest, den, etc.) (SARA 2002, s. 2[1]).

responsible for evaluating the state of wildlife species in Canada. According to COSEWIC, a species can be classified as extinct, extirpated, endangered, threatened, of special concern, data deficient or not at risk (defined in Table 2.1). The assessment of species is prioritized by COSEWIC (2007a) and each species is evaluated against quantitative and qualitative criteria relating to its population trend, distribution, biological traits and current and potential threats (Table 2.2).

Once a species has been classified as at risk and is approved for protection under SARA, it is listed on Schedule 1 of the Act; any species listed on Schedules 2 and 3 were assessed by COSEWIC prior to the establishment of SARA in 2002 and must be reassessed according to current SARA guidelines before they are officially protected under the Act. Species listed as extirpated, endangered or threatened on Schedule 1 are immediately afforded protection according to the Act's prohibitions⁷ and recovery strategies for these species are developed and implemented. Management plans are administered for species listed as special concern, but individuals and residences of these species are not protected from harm under SARA.

⁷ Immediate protection of species applies only to aquatic species, species listed under the Migratory Birds Convention Act and species on federal land. Species on provincial or territorial land are not immediately protected by SARA unless otherwise ordered by the Governor in Council (SARA 2002, s. 34 [1&2]).

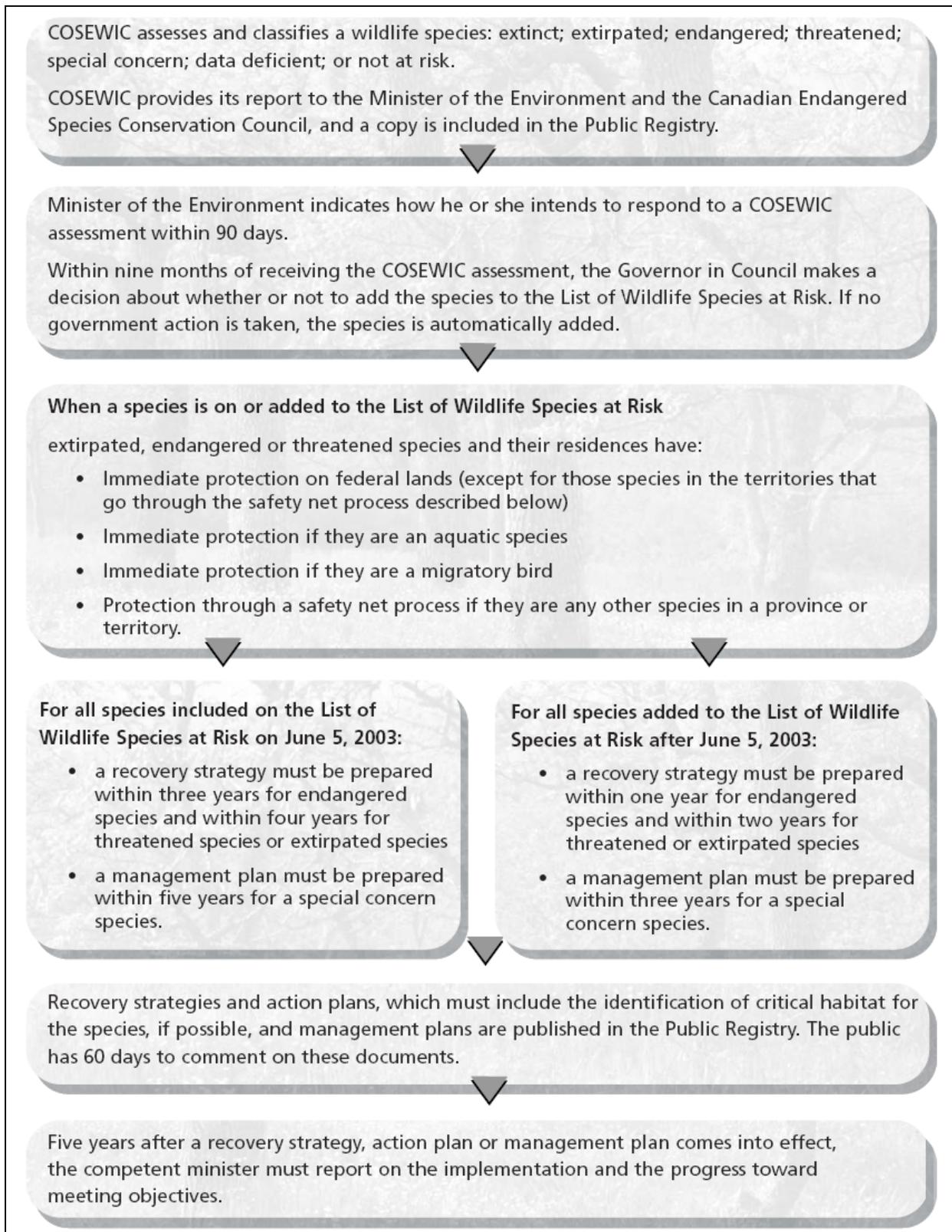


Figure 2.1. The process for protecting a species at risk under SARA (Source: Environment Canada 2003)

Table 2.1. Definitions of species classifications under SARA as assigned by COSEWIC (Adapted from SARA 2002, COSEWIC 2007a)

Classification	Definition
Extinct	A wildlife species that no longer exists
Extirpated	A wildlife species that no longer exists in the wild in Canada, but exists elsewhere
Endangered	A wildlife species that is facing imminent extirpation or extinction
Threatened	A wildlife species that is likely to become endangered if factors limiting the species' survival are not reversed
Special Concern	A wildlife species that may become threatened or endangered because of a combination of biological characteristics and identified threats
Data Deficient	Available information is insufficient to resolve a wildlife species' eligibility for assessment or to permit an assessment of the wildlife species' risk of extinction
Not at Risk	A wildlife species that has been evaluated and found to be not at risk of extinction under current circumstances

Table 2.2. Prioritization criteria for species assessment by COSEWIC (Adapted from COSEWIC 2007b)

Criteria	Description
Taxonomic Level	Species taxonomic level, where priority is given to full species, then subspecies, then populations
Portion of Global Range in Canada	The portion of the species range that occurs in Canada in consideration of species' life history and which part of its range represents the greatest conservation concern, including species endemic to Canada, species with > 50 percent of extant global range or population in Canada, or species with < 50 percent of extant global range or population in Canada,
Global conservation status	Status of species listed on the IUCN Red List of Threatened Species or species with Nature Serve G Rank of G1, G#T1, G2, G3, G#T2, or G#T3. Where an IUCN or NatureServe status rank does not exist, information from other systems may be used to assess global status.
Canadian population size and trends	Population of species in Canada, including species with very small population size and ongoing or suspected population decline, as measured over 3 generations or 10 years, whichever is longer
Threats	Threats, either ongoing or likely to occur, that are likely to affect a large percentage (>50%) of population or threats with smaller but observed impact
Small extent of occurrence or area of occupancy	Species with identified threats and very small extent of occurrence or area of occupancy, or all individuals in five or fewer populations.
Limiting biological factors	Other biological considerations (i.e., age to maturity, interspecies relationships, etc.)

2.2. Climate change in Canada

The Fourth Assessment Report by the IPCC (2007a) recently concluded that mean global temperature over the past century has warmed by 0.74°C. Moreover, the IPCC (2007a, b) has documented direct observations of the physical effects of recent climate change across the earth, including declines in sea ice and glacier extent, increases in water vapour content in the atmosphere, changes in terrestrial hydrologic patterns, and rises in global sea level, as well as climate related changes in terrestrial, freshwater and marine biological systems. The IPCC's (2007a) best estimate climate change scenarios project that mean global temperature will rise by 1.8°C to 4.0°C by the end of the 21st century and climate change related impacts are expected to intensify.

Canada, as a northern country, is expected to experience more pronounced warming from climate change than lower latitudes. According to Environment Canada (2008), mean annual temperature in Canada has warmed by 1.4°C over the past 60 years and of the 10 warmest years on record, six have occurred within the past decade. Mean annual precipitation has also increased slightly in Canada over the past several decades (Environment Canada 2008)⁸. However, the climate has not changed uniformly across the country. While all parts of Canada have experienced warming, it has been most pronounced in northwestern Canada (2.1°C over the past 60 years), while the eastern maritime provinces have experienced the least amount of warming (0.2°C warming over the past 60 years) (Environment Canada 2008). Regional precipitation trends also differ across the country and fluctuate by region more frequently from year to year (Environment Canada 2008).

Projecting future climate change is a more complex process, but, in general, trends similar to those documented in Canada over the past several decades are expected to continue.

⁸ Total annual precipitation across Canada increased by 5-35% between 1950 and 1998 (Zhang *et al.* 2000).

Mean annual temperature in Canada is projected to increase by 0.6°C to 3.9°C in the 2080s (see Appendix 1 for data); however, in general, warming will be much more pronounced in the northern regions of Canada (Figure 2.2) (Canadian Climate Change Scenarios Network [CCCSN] 2007). National precipitation projections are more variable: total annual precipitation change in the 2080s is projected to range from a decrease of 20.2% to an increase of 21.5% (see Appendix 1 for data) (CCCSN 2007). However, the majority of scenarios project slight increases in total precipitation in Canada, similar to trends observed over the past several decades (see Figure 2.3 and Appendix 1) (CCCSN 2007). Variation between seasons is also expected and many regions may experience long-term trends of decreased summer precipitation (CCCSN 2007).

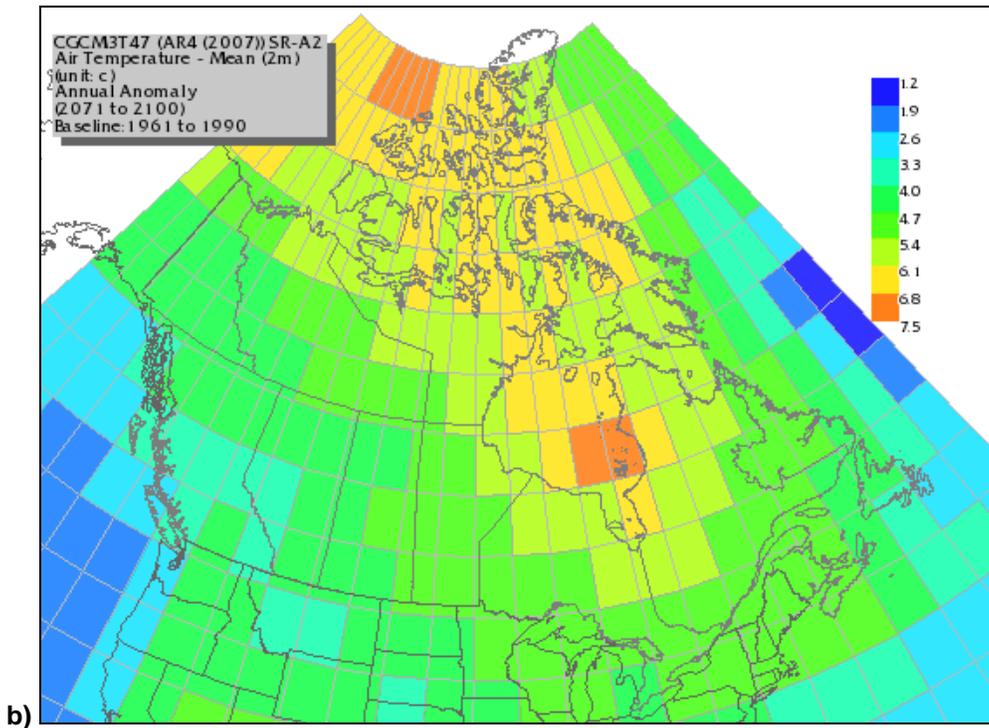
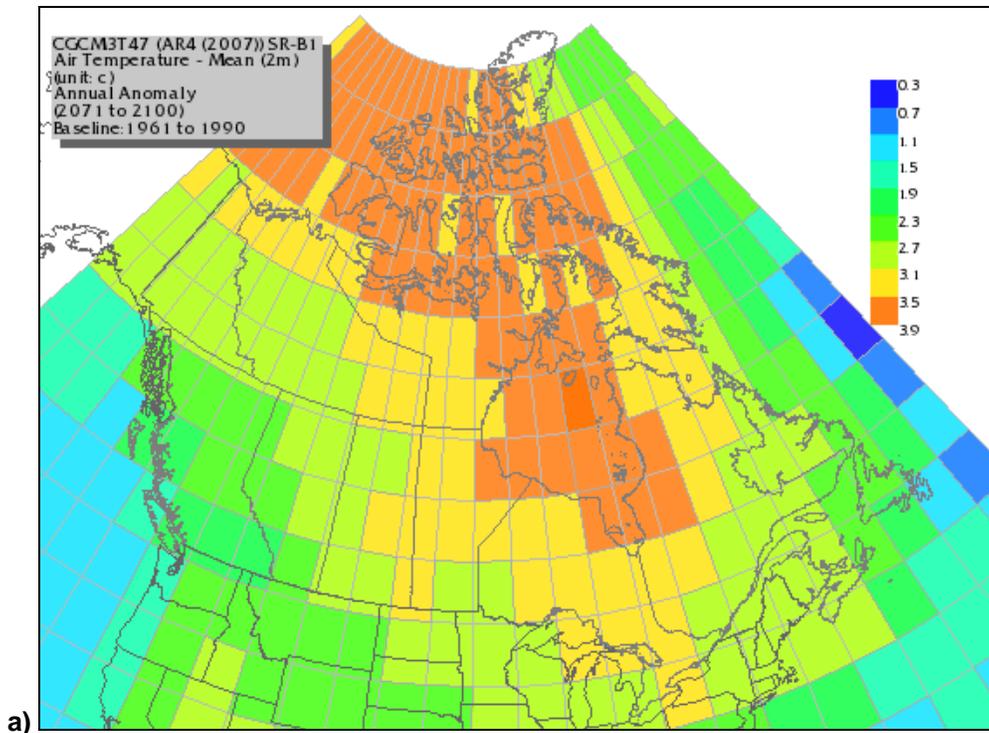


Figure 2.2. Projected mean annual temperature change ($^{\circ}\text{C}$) in Canada by 2071-2100 using the CGCM3 GCM and a) B1 climate scenarios and b) A2 climate scenario; note that scales vary between maps (Source: CCCSN 2007)

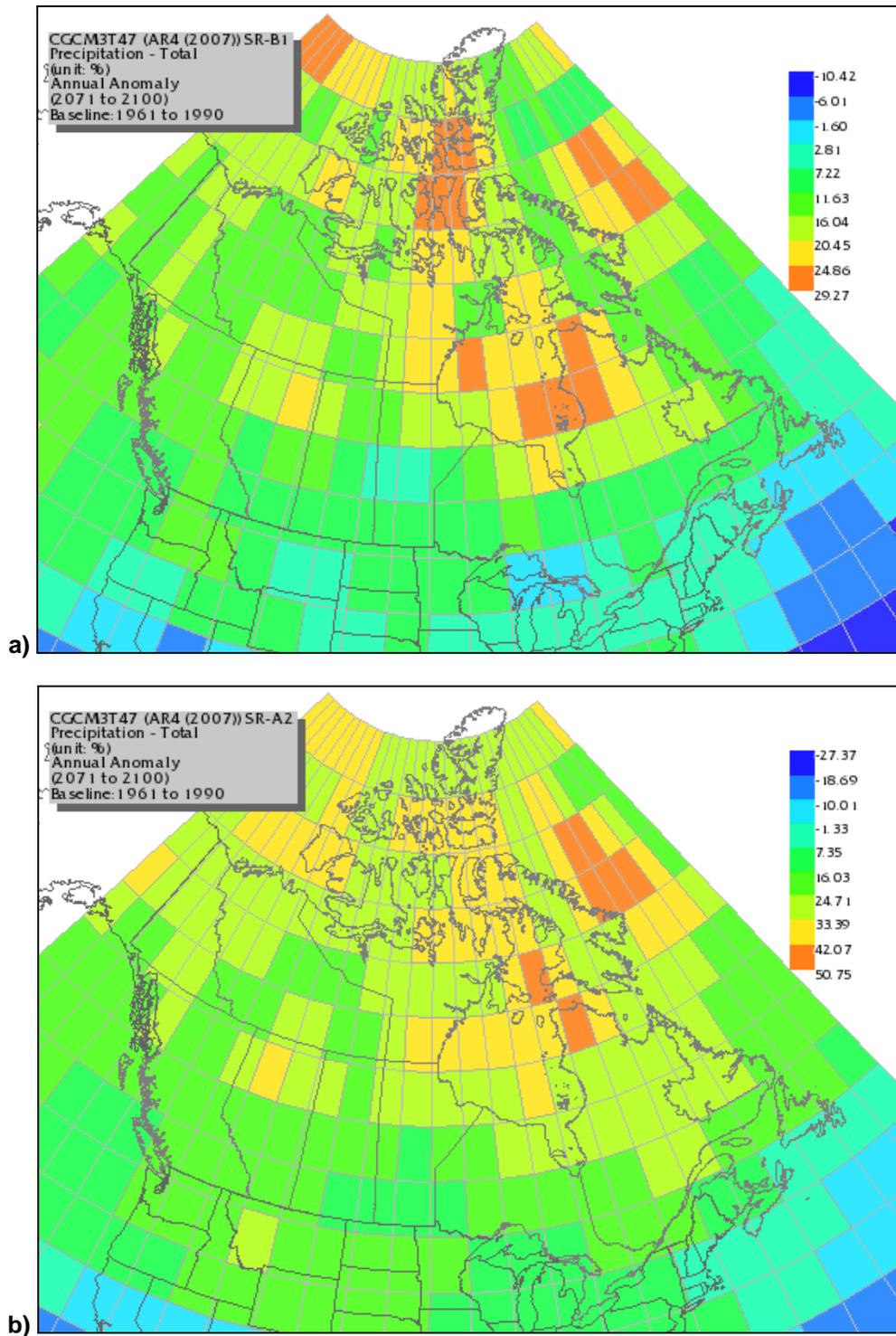


Figure 2.3. Projected total annual precipitation change (%) in Canada by 2071-2100 using the CGCM3 GCM and a) B1 climate scenarios and b) A2 climate scenario; note that scales vary between maps (Source: CCCSN 2007)

In recent years, a large number of studies and reports have utilized climate change scenarios to project the potential impacts of climate change for specific regions, systems or sectors within Canada. In an update of the *Canada Country Study* (Maxwell *et al.* 1998), Lemmen and Warren (2004) reviewed and synthesized existing knowledge of the vulnerability of Canadian sectors to climate change, including water, agriculture, forestry, fisheries, transportation, human health and the coastal zone. More recently, Lemmen *et al.* (2008) built upon the work of Lemmen and Warren (2004) to create a comprehensive and in-depth assessment of the impacts of climate change by region in Canada, including the observed and projected impacts across regional sectors and systems and ongoing and anticipated adaptation needs. Climate change impacts are currently being observed in every region across Canada assessed by Lemmen *et al.* (2008). As climate change progresses, impacts will be exacerbated and are projected to have significant social, economic and ecological consequences. However, Lemmen *et al.* (2008) indicate that Canada generally has a high adaptive capacity for climate change and that sufficient knowledge exists to begin undertaking adaptation activities now.

2.3. Ecological change and climate change

Climate plays a critical role in determining patterns of biodiversity. The occurrence and abundance of species and ecosystems is intimately linked to the climate characteristics of a given region (i.e., Holdridge 1947; Woodward 1987; Holt 1990). The response of species to climate change may take several possible forms: (i) shifts in range/geographic distribution; (ii) changes in population size and relative abundance; (iii) changes in phenological⁹ events and patterns; and (iv) changes in physiology or morphology (Holt 1990; Hughes 2000; Lovejoy & Hannah 2005).

⁹ Phenology refers to biological events during the life cycle of an organism that are triggered by environmental cues.

The following sections provide an overview of current knowledge of the impacts of climate change on species and ecosystems from historical, current and future contexts.

2.3.1. The implications of historical species response to climate change for 21st century conservation

According to Overpeck *et al.* (2005), past rates of global climate change, in some instances, parallel rates expected under anthropogenic influences in the 21st century, but regional changes projected in some areas, such as the Arctic, will exceed documented historical rates of climate change. Periods of rapid climate warming in the past have also only taken place from glacial periods and the projected rate of warming from the current interglacial period does not have a similar historical analogue. Nonetheless, the response of species to past climate change remains among the most useful tools available to provide information on how species may respond to contemporary change.

Analyses of pollen deposits and macro-fossils are the primary evidence used in the reconstruction of past ecological changes from the individual species level to the global pattern of biomes (i.e., Delacourt & Delacourt 1988; Overpeck *et al.* 1991; Overpeck *et al.* 1992; Prentice & Webb 1998; Williams *et al.* 2000; Williams *et al.* 2004). Huntley (2005) summarized documented cases of terrestrial ecological change in response to shifts in climate in northern temperate regions (north of 30°N) during the Tertiary and Quaternary periods and deduced four primary conclusions of the implications of paleoecological response to climate change for current and future biodiversity conservation. First, historical evidence suggests that the occurrence of genetic or in-situ evolutionary adaptations are relatively limited in response to rapid climate change, and occur only in populations in which sufficient genetic variance exists. Second, in cases where the persistence of an entire biome is threatened by climate change the extinction of species associated specifically with that biome are likely. Third, most species'

primary response to climate change is to shift their geographical distribution to align with new climate conditions. However, Huntley (2005) suggests that ability of species to shift their range is limited by their biological ability for dispersal, as well as the fragmentation of suitable habitat; due to human land-use, this is a more prevalent issue for present-day species than it was in the past when habitat connectivity was assumed to be limited only by natural geographic barriers. Finally, historical evidence suggests that species respond individually to climate change (via some form or combination of distribution, population or evolutionary change) and, because projected future climate conditions do not have any recent historical analogues, future species distributions and biome patterns and composition will also be without analogues in some cases.

2.3.2. Observed ecological change in response to recent climate change

A large amount of literature has identified climate as a factor in recent (~1970 – present) species and ecosystem changes and many authors have begun to synthesize these studies to present a picture of the influence that climate change is having on ecological systems across the globe. Recent research has focused on two key methods to distinguish the ecological impacts of climate change during the last several decades: (i) literature reviews that focus on recent changes at the species and community level to demonstrate that research observations point to a general trend of ecological change in response to climate change, and (ii) meta-analyses that quantitatively integrate many individual studies on species and communities to summarize the average impact of climate change on ecological change.

2.3.2.1. Literature review approach

The most comprehensive literature review on the subject of the ecological impacts of climate change was conducted by the IPCC (2001a) for the Third Assessment Report and the findings were later reiterated and supplemented with new data in the Fourth Assessment Report

(Fischlin *et al.* 2007; IPCC 2007b). For the IPCC's (2001a) Third Assessment Report, 2500 studies were assembled that addressed climate and a physical or biological property relating to plants or animals. These studies were then narrowed to meet the following criteria to ensure their viability in detecting patterns of change: (i) have at least 10 years of data measuring the phenomena, (ii) measured temperature as one of the study's variables, (iii) found a statistically significant change in a plant- or animal-related process and in temperature over time, and (iv) found a statistically significant correlation between temperature and the plant- or animal-related process in question. An in-depth review process was conducted on the 44 studies that met these criteria, which represented data on more than 500 species. Since the undertaking of the IPCC review process, several other literature reviews have been published that identify a link between recent ecological change and climate change (i.e., Hughes 2000; McCarty 2001; Peñuelas & Filella 2001; Walther *et al.* 2002; Parmesan 2006); however, the IPCC (2001a & 2007b) yielded the most transparent report in terms of study selection criteria and the most thorough review of the recent ecological impacts of climate change to date.

The IPCC (2001a) found that 80% of the species studied were changing in the expected direction in at least one of the four typical species responses to climate change (examples listed in Table 2.3). The IPCC (2001a) report concluded that there is a 'high confidence'¹⁰ that recent climate change has already contributed to ecological change. Since the undertaking of the IPCC review, all other literature reviews published on this topic have reached a similar consensus: there is a clear link between recent global changes in ecological systems and climate change (Hughes 2000; Peñuelas & Filella 2001; Walther *et al.* 2002; Secretariat of the CBD 2003; IPCC 2004; Parmesan 2005; Root & Hughes 2005; Parmesan 2006).

¹⁰ According to the IPCC (2001a), the term high confidence denotes a 67-95% confidence based upon the collective judgment of the authors using the observational evidence and theory that they examined.

Table 2.3. Selected ecological changes linked to recent climate change as summarized in literature reviews (Adapted from Hughes 2000, IPCC 2001a, Peñuelas & Filella 2001, Walther et al. 2002, IPCC 2004, Parmesan 2005, Root & Hughes 2005; Parmesan 2006)

<p>(i) Range/distribution change:</p> <ul style="list-style-type: none"> • Northward range shift of butterfly species in North America and Europe • Upward elevational shift of alpine plant species • Northward expansion of red fox range and simultaneous retreat of arctic fox range in Canada • Northward shift of treeline in the northern hemisphere
<p>(ii) Population/abundance change:</p> <ul style="list-style-type: none"> • Increase terrestrial plant abundance in Antarctica • Decline in abundance of tundra plant species and increase in shrub species in Alaska • Increased abundance of southern rocky intertidal invertebrates in California • Dieback of mountainous tree species
<p>(iii) Phenological change:</p> <ul style="list-style-type: none"> • Earlier flowering and leaf unfolding in plant species • Earlier spring migration of migratory bird species • Lengthened plant growing season in northern hemisphere • Earlier amphibian breeding • Mismatch in the timing of the breeding of bird species with their food species • End of hibernation of the yellow-bellied marmot
<p>(iv) Physiological/morphological change:</p> <ul style="list-style-type: none"> • Decline of the body weight of the North American wood rat with increasing temperatures • Faster growth of juvenile red deer species during spring • Decreased egg viability in coldwater fish species

2.3.2.2. Meta-analysis approach

Two critical studies have used meta-analyses¹¹ to determine the overall pattern of influence or ‘fingerprint’ of climate on ecological systems at a global scale. Parmesan and Yohe (2003) examined the impacts of recent climate change by conducting meta-analyses on multiple-species studies that, combined, covered more than 1700 different species representing a wide variety of taxa. They found that approximately half of the species included in their analysis have significantly changed their range and/or phenology within recent decades in the direction

¹¹ A meta-analysis is a statistical method of reviewing and integrating the results of multiple surveys to quantitatively summarize a link between two processes, such as climate change and ecological change

expected under climate change. The study's analyses showed that species ranges are shifting on average 6.1 km per decade towards the poles (or 6.1 m per decade upwards in alpine areas) and that average spring phenological events are occurring 2.3 days earlier per decade in response to climate change.

In a separate study, Root *et al.* (2003) analyzed data for 694 species from different taxonomic groups that have undergone range and/or phenological changes within the past decade or longer. They found that 80% of all species analyzed have traits shifting in the direction expected under climate change; average spring phenological events were calculated to be occurring 5.3 days earlier per decade.

The percentage of species changing in the expected direction as determined by Root *et al.* (2003) was equal to the percentage determined by the IPCC (2001a) review (80% of species), which is reasonable as Root *et al.* (2003) used the same criteria to select studies for their meta-analysis as the IPCC (2001a) (10+ years of data, a species or trait in the study showed change over time, a change in temperature was documented over time). However, Parmesan and Yohe (2003) estimated that approximately 50% of species were changing in the expected direction. The discrepancy among these studies is likely caused by the more stringent study selection criteria employed by Parmesan and Yohe (2003). For their analysis, Parmesan and Yohe (2003) required that studies have more than 20 years of data, data covering a large geographic region (or multiple sites), and data for multiple species assemblages. The stringent study selection process used by Parmesan and Yohe (2003) resulted in a more conservative estimate for the percentage of species changing in the expected direction, and, when compared with the meta-analysis by Root *et al.* (2003), a more conservative estimate of average advancement of spring phenological events.

2.3.2.3. Challenges of linking recent ecological change with climate change

Scientific studies documenting recent species and community changes tend to use a correlational rather than experimental approach. As a result, the interpretation of the link between climate change and ecological change is often inferential and indirect (Hughes 2000; Parmesan 2005). Furthermore, the identification of this link is complicated by the influence of local stressors. A key challenge in identifying the role of recent climate change on ecological systems is to distinguish the effects of climate from the effects of other local stressors, which include habitat fragmentation and loss, human land use impacts, pollution, species exploitation and competition with invasive and other native species (Kappelle *et al.* 1999; Parks Canada 2003; Venter *et al.* 2006). In some cases, when considering the magnitude of ecological changes caused by stressors such as habitat loss and land use modifications, the influence of climate change may appear relatively small in comparison. However, current research suggests that the persistent, long-term effects of climate change on ecological systems may raise climate change to a leading driver of biodiversity change in the 21st century, causing slow, but potentially irreversible impacts (i.e., species extinction) (Sala *et al.* 2000; Parmesan & Yohe 2003; Thomas *et al.* 2004; Parmesan 2005).

While local stressors can never be entirely discounted when examining recent ecological change in response to climate change, the global, long-term (10+ years) approach of literature reviews and meta-analyses currently provides the best means of filtering out other stressors to demonstrate the overall trend of climate change influence. However, the ability to synthesize the effects of climate change in literature reviews and meta-analyses is limited based on the small, short-term scale of most ecological studies (Parmesan 2005). Most studies do not meet the ideal requirement of having long-term data taken at regular intervals. Furthermore, few studies examine species across their full geographic ranges and instead infer full range shifts from

smaller scale studies using extrapolation methods that may not fully reflect the whole range trends (Parmesan 2005). These issues highlight the need for researchers to collaborate on more long-term, full-range species studies that can be integrated for synthesis reports on climate and ecological change.

Another problem affecting all integrative studies on climate and ecological change is publishing bias (Hughes 2000; Root *et al.* 2003; Parmesan 2005). There is much less incentive to study and publish phenomena that exhibit no response to climate change (or other stressors). For this reason, researchers more frequently undertake studies on species and communities that are likely to exhibit change; therefore a higher proportion of papers are published where species exhibit change in response to climatic factors, and species exhibiting no change are not accurately represented within the research synthesized by recent literature reviews and meta-analyses (Hughes 2000; Parmesan 2005; Thomas 2005).

In spite of its utility in quantitatively communicating the role of climate in ecological change, fewer studies have utilized a meta-analysis approach than a literature review approach to determine the effects of recent climate change. It has been theorized that researchers may be reluctant to conduct meta-analyses because of their inability to control for bias within the individual studies they analyze, as well as for the publishing bias of studies in this area as discussed above (Root *et al.* 2003; Parmesan 2005). Unlike the literature review approach, in which no quantitative data are further synthesized, a meta-analysis based on biased, non-representative studies will result in inaccurate statistical outputs regardless of the quality of the meta-analysis calculations. However, meta-analyses can be designed to compensate for potential bias within their methodologies. For example, Root *et al.* (2003) noted that they could not control whether the authors of the studies they analyzed reported all of the species they observed

or if they biased their studies by reporting only species that experienced change; nonetheless, Root *et al.* (2003) claim that even if such biases exist, it would have no influence on their claim of a discernable link between climate and ecological change because they examined what fraction of species that have experienced change were changing in the expected direction. To control for bias in their meta-analysis, Parmesan and Yohe (2003) used only studies that surveyed multiple species and reported neutral and negative linkages with climate change as well as positive.

A concluding point that was common to all studies examining the ecological impacts of recent climate change was concern for the rapid rate at which climate is projected to warm throughout the 21st century and the further impact it may have on ecological systems (Hughes 2000; McCarty 2001; Peñuelas & Filella 2001; Walther *et al.* 2002; Root *et al.* 2003; Root & Hughes 2005). This conclusion is best summarized by Root *et al.* (2003) who state, “Clearly, if such climatic and ecological changes are now being detected when the globe has warmed by an estimated average of only 0.6 °C, many more far-reaching effects on species and ecosystems will probably occur in response to changes in temperature to levels predicted by IPCC(p.59).”

2.3.3. Projected ecological change in response to future climate change

The recent ecological consequences of climate change emphasize the need for accurate, detailed models capable of projecting future climate change impacts on species and ecosystems. Trends in the overall influence of climate change on biodiversity may become more immediately apparent at the global scale. However, because climate is expected to warm differentially around the world, researchers have attempted to focus projections at the national or regional level to provide a more comprehensive understanding of the potential impacts of climate change to policymakers and resource managers, in order to prevent irreversible consequences.

2.3.3.1. Projected ecological change at the global scale

Many authors and international organizations have highlighted the potential role that climate change may play in threatening global biodiversity (i.e., Peters & Lovejoy 1992; IUCN 1994; Green *et al.* 2003; Lovejoy & Hannah 2005; Secretariat of the Convention on Biological Diversity 2007; UNESCO World Heritage Centre 2007) and a significant amount of research has been conducted worldwide on the potential future impact of climate change on individual species and ecosystems. However, only recently has such information been summarized in a quantitative way to provide estimates of the potential impact of future climate change on biodiversity at the global scale, and more specifically on species extinction rate.

Sala *et al.* (2000) explored how global biodiversity will change by 2100 by projecting the abundance and distribution of terrestrial biomes under the influence of major global change drivers, including climate change, land-use change, nitrogen deposition, biotic exchange (deliberate or accidental introduction of organisms into an ecosystem), and changes in atmospheric carbon dioxide (CO₂). They found that land-use change and climate change are expected to be the first and second largest drivers of biodiversity change over the next century, although variation exists among biome types and climate change is expected to play a larger role in northern biomes, such as the boreal forest and the arctic (Figure 2.4). However, given that climate change operates on a larger and longer time-scale than more localized threats like land-use change, more recent reports have indicated that climate change may prove to have an overall greater influence on biodiversity in the long-term than other stressors (Thomas *et al.* 2004; Thuiller 2007).

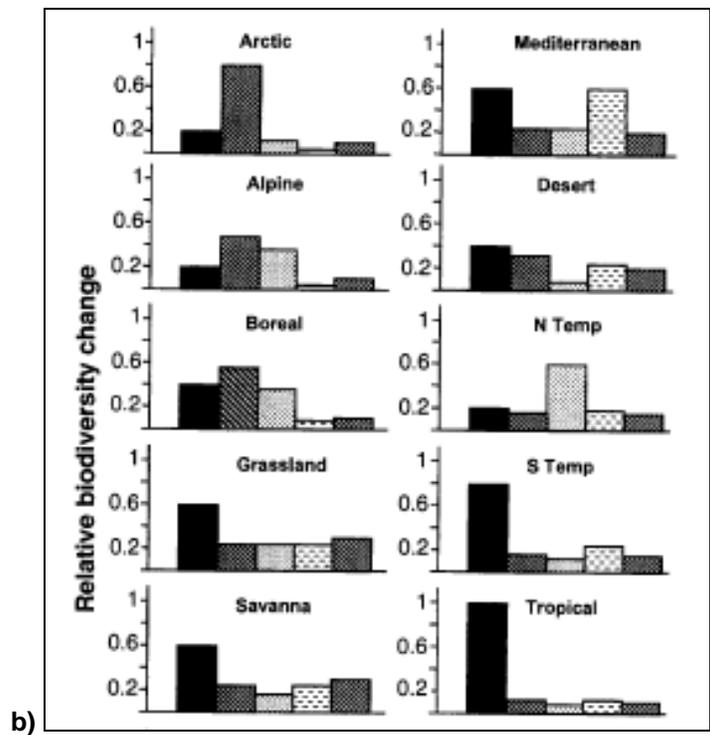
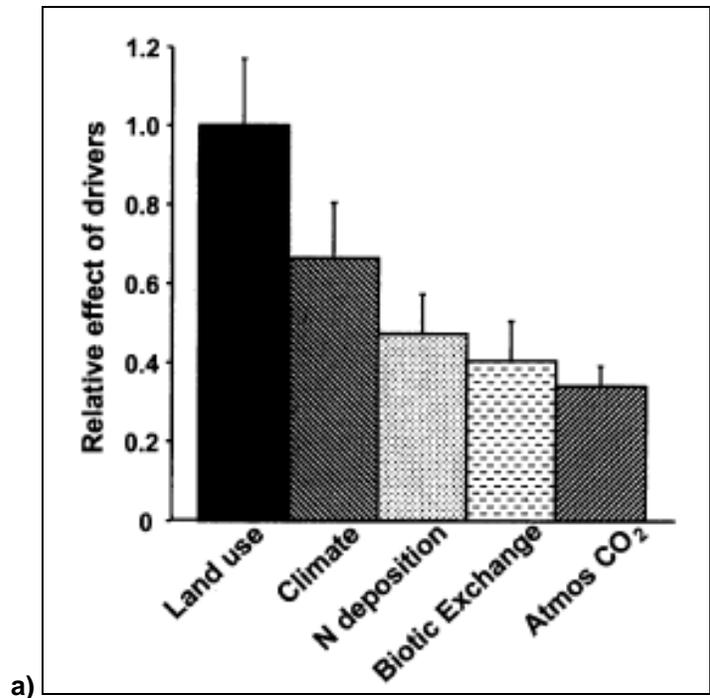


Figure 2.4. Projected relative effect of major global change drivers on a) global biodiversity change, and b) biodiversity change in individual terrestrial biomes. Thin bars in Fig. 2.4a are standard errors and represent variability among biomes. (Source: Sala *et al.* 2000)

Thomas *et al.* (2004) were the first to quantitatively assess the global extinction risk of species from climate change. They assembled projected distributions for over 1000 species by 2050 (from a variety of taxa and regions found across 20% of the earth's terrestrial surface) to calculate the number of species that will become extinct based on the availability of suitable growing conditions within their future distribution. They found that under mid-range warming scenarios, 15% to 37% of the species assessed would be "committed to extinction" by 2050, meaning that suitable habitat areas for those species are projected to no longer exist, but lags in habitat and species change in response to climate change prevent the prediction of exact extinction dates.

The IPCC's Fourth Assessment Report evaluation of the ecological impacts of climate change focused primarily on reviewing and integrating projections of the potential future impact of climate change on different biomes across the globe (Fischlin *et al.* 2007). The IPCC concluded that significant changes in the structure and function of both terrestrial and marine ecosystems are very likely to occur if mean global temperature reaches 2°C to 3°C above pre-industrial values by 2100 (Fischlin *et al.* 2007). Similar to Thomas *et al.* (2004), the IPCC also assessed the potential extinction risk from climate change and arrived at a comparable, although slightly more conservative conclusion. The IPCC determined that 20% to 30% of the plant and animal species that had been assessed so far were likely to be at an increasingly high risk of extinction if mean global temperatures reach 2°C to 3°C above pre-industrial values by 2100 (which is projected under mid-range scenarios) (Fischlin *et al.* 2007).

2.3.3.2. Projected ecological change in Canada

In order to generate more useful projections to inform management and policy decisions, models on the ecological impacts of climate change are more frequently focused at the national

scale and at regional scales as suitable data and modeling capacity becomes available. In Canada, most modeling studies have focused on projecting the landscape scale impacts of climate change at a future equilibrium¹² state in order to project broad changes in ecological diversity.

Rizzo and Wiken (1992) were the first to use equilibrium modeling to project the ecological impacts of climate change in Canada. They created a classification-based model that integrated the ecoclimatic province classification scheme with future climate scenarios under doubled atmospheric CO₂ conditions (2 x CO₂) (generally expected by 2100). Ecoclimatic provinces are amalgamations of ecoclimatic regions – broad terrestrial surface areas characterized by distinct ecological responses to climate as expressed by vegetation and reflected in soils, wildlife and water (Rizzo & Wiken 1992). The 72 individual ecoclimatic regions in Canada were amalgamated into 10 ecoclimatic provinces for this study in order to best reflect landscape vegetation patterns (Figure 2.5a) (Rizzo & Wiken 1992). Rizzo and Wiken (1992) found that large spatial changes are expected among the ecoclimatic provinces under climate change including a decline in area of the arctic and subarctic provinces, an almost 50% decline in the boreal forest province, an expansion of grasslands throughout central Canada and the emergence of two new ecoclimatic provinces, the semi-desert province in southern Alberta and Saskatchewan and the transitional grasslands province, which represents areas of unhomogenized mixing of two or three different ecoclimatic provinces, generally along the borders of the boreal, cool temperate forest and grasslands provinces (Figure 2.5b).

¹² Equilibrium modeling simulates the potential future distribution of ecosystem types at a given point in time, but does not consider how ecosystems will change from one state to another

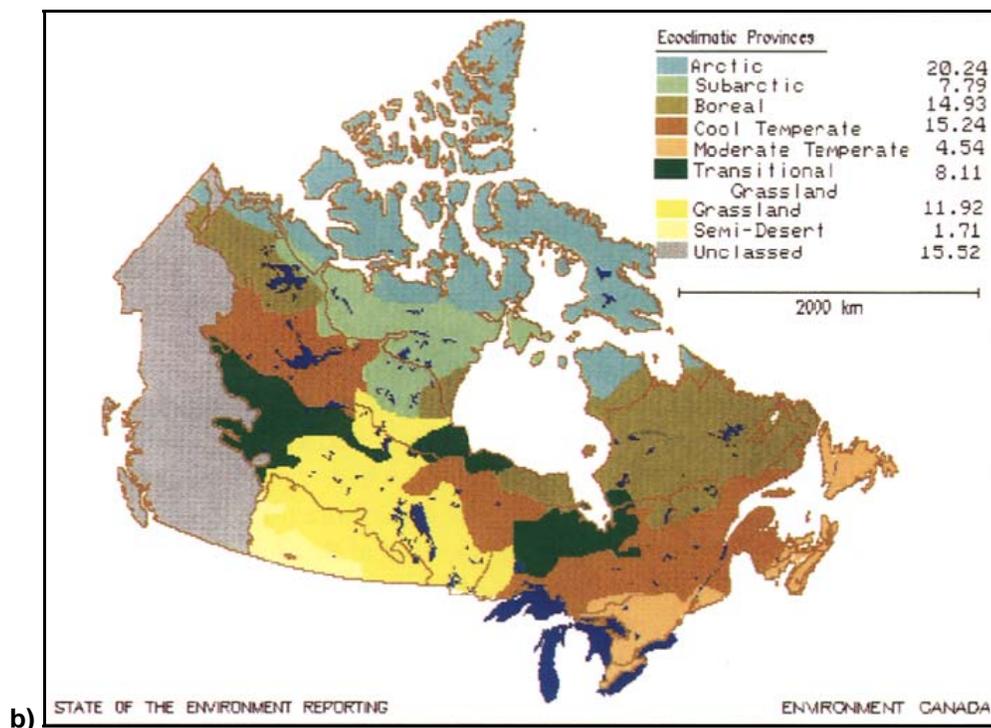
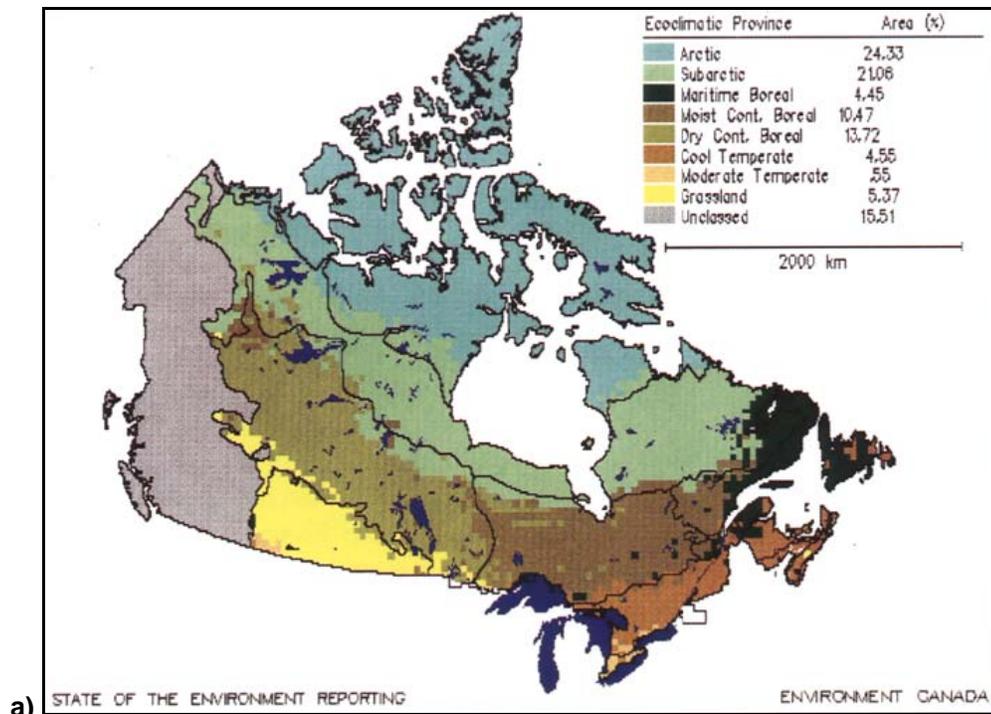


Figure 2.5. a) Current ecoclimatic provinces of Canada; b) Projected ecoclimatic provinces under 2 x CO₂ climate conditions (Source: Rizzo & Wiken 1992)

Lenihan and Neilson (1995) also modeled the effects of climate change on terrestrial vegetation in Canada. However, in contrast to Rizzo and Wiken's (1992) classification model, where temperature and precipitation variables were the primary model drivers, Lenihan and Neilson (1995) employed a process-based¹³ model that simulates vegetative patterns using parameters related to the growth, reproduction and survival of vegetation. Lenihan and Neilson (1995) combined future climate scenarios under double atmospheric CO₂ conditions with the Canadian Climate-Vegetation Model, which uses five parameters as model drivers: number of degree days, absolute minimum temperature, snowpack depth, actual evapotranspiration and soil moisture deficit. Similar to the results of Rizzo and Wiken (1992), Lenihan and Neilson (1995) project declines in the extent of the tundra (arctic) and subarctic woodland vegetation formations and expansion of grassland formations across the prairie regions of Canada. However, contrary to the Rizzo and Wiken (1992) study, Lenihan and Neilson (1995) project an expansion of the boreal forest formation.

Less attention has been paid to the issue of faunal diversity under climate change in Canada, partially because of the theory that dominant vegetation patterns can infer the general composition of ecosystems at all trophic levels. However, one study by Kerr and Packer (1998) modeled the potential impact of climate change on mammalian diversity in Canada by calculating mammalian species richness¹⁴ after a 75-year period of climate warming assuming annual 1% increases in atmospheric CO₂. Kerr and Packer (1998) found that there is considerable geographic variability in the projected response of mammalian diversity across Canada (Figure 2.6). Mammalian diversity is expected to increase by as much as 111% in the

¹³ Equilibrium process-based models simulate the potential distribution of generalized types of natural vegetation on the basis of factors such as the physiological properties of plants, average seasonal climate and hydrological conditions (Scott & Lemieux 2005)

¹⁴ Mammalian species richness refers to the number of distinct mammalian species within a given region; in this study, 154 quadrats dividing mainland Canada were assessed (Kerr & Packer 1998)

arctic while diversity in southern areas of Canada, where projected temperature changes are smallest, is expected to remain relatively unchanged. However, the composition of mammal species in Canada will change: the study determined that 25 mammal species currently located near the northernmost boundaries of mainland Canada will be susceptible to extinction because of limited potential for northward dispersal and competition with an influx of new species.

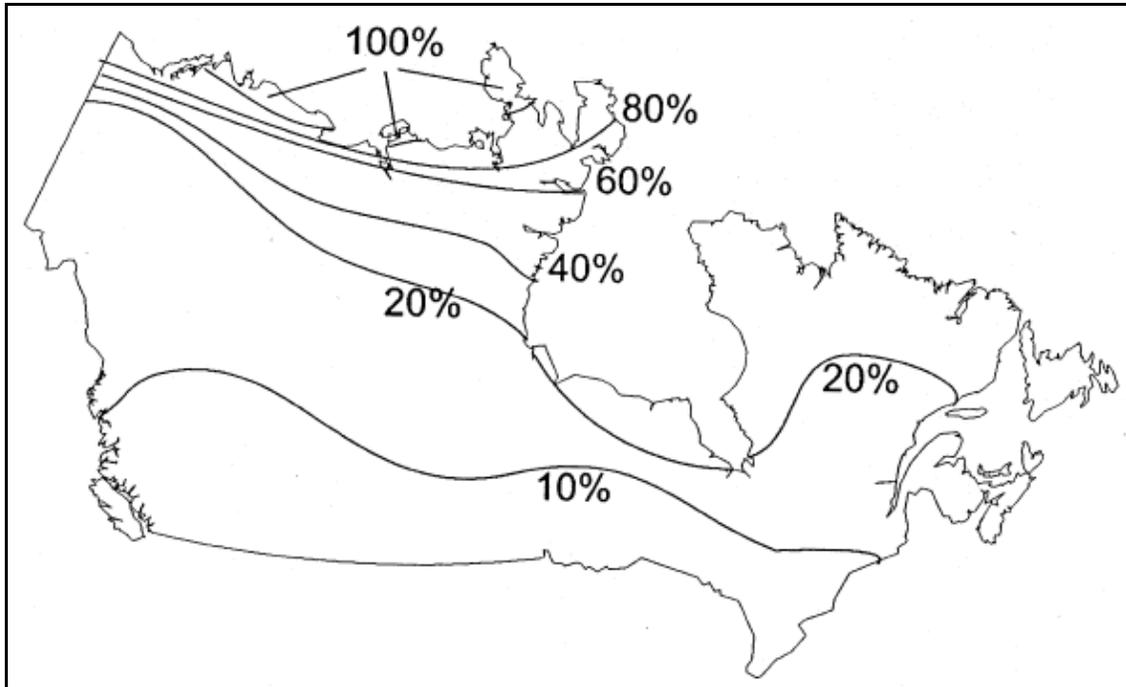


Figure 2.6. Contour map showing percent increases in mammal diversity under climate change assuming no barriers to species migration (Source: Kerr & Packer 1998)

2.3.3.2.1. Projected ecological change in Canada's national park system

Publications by Parks Canada staff first acknowledged climate change as a potential ecological stressor to Canada's national parks system almost 20 years ago (Rowe 1989, Lopoukhine 1990 & 1991 as cited in Scott & Suffling 2000), and the official recognition of climate change as a stressor to park ecosystems in 1997 (Parks Canada 2003) spurred Canadian researchers to begin projecting the future impacts of climate change on Canada's national parks both for park ecology (Scott & Suffling 2000; Hui 2001; Scott *et al.* 2002; Lemieux & Scott

2005; Wood 2007) and tourism and recreation (Staple & Wall 1996; Scott & Suffling 2000; Scott & Jones 2006; Scott *et al.* 2007).

Four studies have explicitly addressed the projection of the ecological impacts of climate change across the national parks system. Scott and Suffling (2000) conducted an initial screening level assessment of the impact of climate change on Canada's national parks system by integrating and assessing projected future climate change (compiled from the results of four doubled atmospheric CO₂ GCM climate scenarios) with current knowledge of national park features. The 38 national parks (as of 2000) were subdivided into six geographic regions where the range of climate change impacts would be relatively similar; selected potential ecological impacts predicted by this study are summarized by region in Table 2.4. Scott and Suffling (2000) concluded that "Climate change simultaneously represents a threat and opportunity to different species and ecological communities across Canada" (p.127) and that climate change will be a dominant factor in the practice of 21st century ecological conservation in Canada. The "screening" approach used by this study to assess the potential impacts of climate change was integral in generating further, more detailed studies relating to national parks and climate change and in raising the profile of this issue within the Parks Canada Agency, as demonstrated through recent workshops, individual national park assessments and the ongoing development of a climate change adaptation framework (Welch 2005; Welch 2008).

Table 2.4. Selected ecological impacts of climate change projected in Canada’s national parks by region (Adapted from Scott & Suffling 2000; Suffling & Scott 2002)

<p>Atlantic Parks:</p> <ul style="list-style-type: none"> • Increased mixed and deciduous forest types, less boreal forest • Increased storm, fire and pest disturbance (yielding more early successional ecosystems) • Reduction, isolation and extirpation of arctic-alpine species and communities
<p>Great Lakes – St. Lawrence Basin Parks:</p> <ul style="list-style-type: none"> • Altered fish spawning and migration patterns • More early successional forest ecosystems from increased fire occurrence and intensity • Expansion of southern exotic species • Increased mixed and deciduous forest types, less boreal forest
<p>Prairie Parks:</p> <ul style="list-style-type: none"> • Altered waterfowl breeding and migration patterns • Loss of boreal forest to grassland and temperate forest • Increased forest disease outbreak and insect infestations • Expansion of southern exotic species and warm water fish species
<p>Western Cordillera Parks:</p> <ul style="list-style-type: none"> • Latitudinal and altitudinal migration of ecozones • Loss of some alpine species assemblages from mountain peaks • Increased forest disease outbreak and insect infestation • Increased ungulate wintering zone land use pressures and impaired migration
<p>Pacific Parks:</p> <ul style="list-style-type: none"> • Altered fish spawning and migration patterns • Loss of higher elevation alpine species • Increased forest disease outbreak and insect infestation
<p>Arctic Parks:</p> <ul style="list-style-type: none"> • Extended plant growing season • Northward expansion of treeline • Altered predator-prey relationships • Greater severity and length of insect seasons • Altered migration patterns and diminished genetic exchange among Arctic islands

In a more quantitative study, Scott *et al.* (2002) used equilibrium process-based modeling to project biome change within Canada’s national parks. They combined two global vegetation models (GVMs) with several GCM scenarios to assess potential biome distribution change within national parks under doubled atmospheric CO₂ climate conditions. Similar to the results

of Rizzo & Wiken (1992) and Lenihan & Neilson (1995), Scott *et al.* (2002) found that the proportional representation of tundra and taiga/tundra biomes (arctic and subarctic) within national parks declined in each scenario, while the savanna/woodland and temperate forest biomes increased. The percent change in boreal forest was variable; some scenarios projected increases in boreal forest biome representation while others projected declines. These results coincide with the disagreement among Rizzo and Wiken (1992), who projected a decrease in boreal forest, and Lenihan and Neilson (1995), who projected an increase in boreal forest, and suggest that the projection of boreal forest under climate change is dependent on the type of climate-vegetation modeling approach used. Scott *et al.* (2002) also found that five out of six scenarios projected the appearance of a novel biome type in more than half of all national parks under climate change; moreover, greater than 50% of all vegetation grid cells across national park land area are projected to experience a change in biome type.

Lemieux and Scott (2005) repeated the methods used by Scott *et al.* (2002), but extended the analysis to Canada's entire protected areas network (including national parks, Ramsar sites, migratory bird sanctuaries, national wildlife areas, ecological reserves, provincial parks and wilderness areas). Lemieux and Scott (2005) project that 39% to 61% of national park land will experience a change in biome-type under climate change, while the whole protected areas network is projected to experience a biome change in the range of 37% to 48% based on the six climate-vegetation scenarios (Figure 2.7). These results are in agreement with the findings of Scott *et al.* (2002) and indicate that national parks are similarly vulnerable to climate change-induced ecological change as other protected area types.

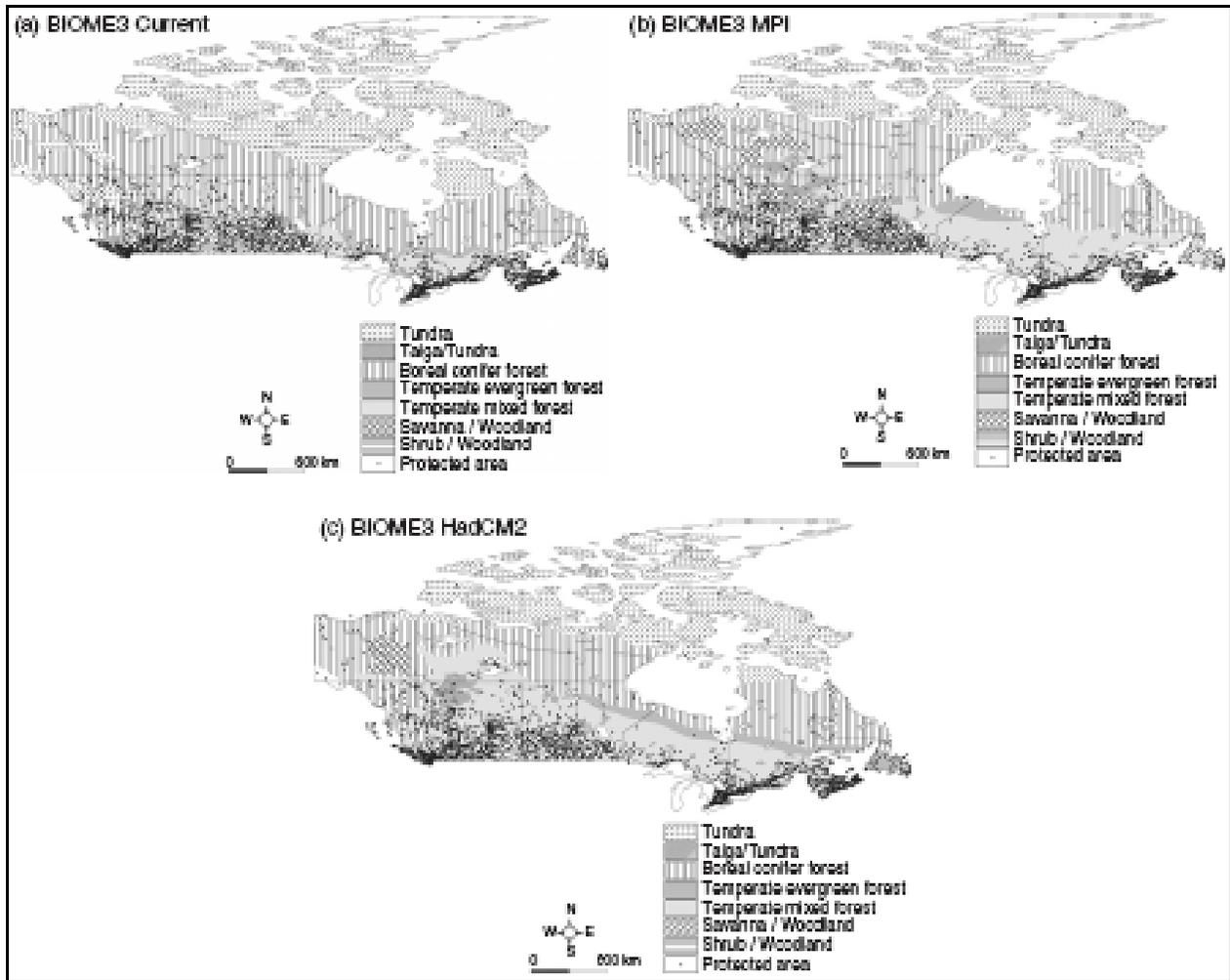


Figure 2.7. Canada's protected areas network under current and future ($2 \times \text{CO}_2$) climate scenarios using BIOME3 GVM (Source: Lemieux & Scott 2005)

Most recently, Wood (2007) examined the potential for biome change in both Canadian and American national parks, but utilized the results of a new generation of dynamic GVM that incorporates biogeographical, biogeochemical and disturbance processes into its projections. Wood's (2007) findings agreed with Scott *et al.* (2002) and Lemieux and Scott (2005): at least 50% of biomes currently represented in parks across Canada and the United States are expected to change by 2080 under all three climate change scenarios analyzed in this study. Similar trends in biome patterns were also projected. The proportional representation of tundra and taiga biomes in national parks was projected to decline while savannah/woodland and temperate forest

biomes were projected to expand. The potential impact of climate change on the boreal forest biome was variable, but in general Wood (2007) projected an overall loss of boreal forest biome representation in national parks.

No studies to date have modeled faunal diversity change specifically in Canada's national parks under climate change. However, Burns *et al.* (2003) modeled the potential change in mammalian diversity in the U.S national park system by combining data on mammalian species currently found in U.S. national parks with the results of an equilibrium process-based model that projected changes in associated vegetation type to predict the presence or loss of species based on the availability of suitable habitat. They found that up to 20% of species found within park borders may shift out of U.S. national parks under future climate change (2 x CO₂ conditions) and that parks will experience influxes of new species not currently protected. As a result, Burns *et al.* (2003) state that climate change will have important implications for U.S. park conservation policies and suggest that parks may have difficulty meeting their mandates to protect current biodiversity.

2.3.3.3. Projecting the impacts of climate change at the individual species level

Although landscape scale vegetation projections are useful in projecting large changes in ecological patterns, they do not provide specific information on how individual species will respond to climate change. Climate envelope modeling (or ecological niche modeling) is the most common approach used to project changes at the individual species level and has recently been used more frequently as a result of increased knowledge of species distributions and the availability of finer scale climate data (Guisan & Thuiller 2005; Peterson *et al.* 2005; Fischlin *et al.* 2007). Climate envelope models apply the climatic and/or ecological conditions of the

present distribution of a species to climate change scenarios in order to project the future distribution of the species at a given point in time (Peterson *et al.* 2005).

While numerous climate envelope models have been run for individual species and species assemblages in various regions across North America (i.e., Crumpacker *et al.* 2001; Peterson *et al.* 2002; Peterson 2003; Matthews *et al.* 2004), a relatively large body of research has focused on the projected distributions of North American tree species. A series of studies have modeled distributional changes of trees specifically within the eastern United States (i.e., Iverson & Prasad 1998; Iverson *et al.* 1999; Iverson & Prasad 2002; Iverson *et al.* 2004), but more recently, McKenney *et al.* (2007) modeled the projected distributions of North American tree species across the full extent of their current and potential ranges in the United States and Canada. Species were modeled under two separate assumptions. First, using scenarios that assume species have no barriers to dispersal, McKenney *et al.* (2007) project that species ranges will decrease by an average of 12% and that species will shift northward by 700km. Second, using scenarios that assume species will be unable to disperse beyond regions that overlap with their current climatic range, McKenney *et al.* (2007) project that species ranges will decrease by an average of 58% and that species will shift northward by 330km. In both cases, it is clear that significant redistribution of tree species in North America is likely under future climate change.

Specifically in Canada, Malcolm *et al.* (2004) modeled the distributions of 134 tree species in Ontario under climate change scenarios for 2100. They project that nearly all species will shift northward and, in many cases, species will experience increases in the size of their distributions due to either the proportionally larger land areas in northern Ontario relative to southern Ontario or the appearance of a tree species in Ontario for the first time. While the relative dominance of species in Ontario is projected to change under climate change, in general,

the overall richness of tree species in Ontario is projected to increase, particularly in southern Ontario.

Although climate envelope modeling is currently the best means of quantitatively projecting the response of individual species to climate change, it is not possible to model every species. The selection of species for climate envelope modeling must therefore take into consideration the suitability of the species for modeling, the data available on the species' current distribution and habitat needs, the potential benefits of modeling for both the species and its associated ecological community, and the relative priority of the species for conservation.

2.3.3.4. Challenges of projecting the future ecological impacts of climate change

Uncertainty is an inherent problem in any model that attempts to predict the future impacts of climate change and presents a significant challenge to researchers. No model can create a definitive forecast of future conditions and, instead, researchers must strive to create the most plausible future scenario based on existing knowledge and modeling techniques.

Uncertainty is introduced into the GCMs used for climate-vegetation modeling primarily through the projected future levels of greenhouse gas emissions used in climate change scenarios and differences in the ways in which physical earth processes and feedbacks are simulated (IPCC 2001b; Raper & Giorgi 2005). Although the IPCC (2001b) concluded that GCMs provide credible simulations of climate down to (at least) the sub-continental scale, IPCC guidelines still strongly recommend that scenarios from multiple GCMs be applied to climate change impact studies to reduce the uncertainties inherent in using GCMs (IPCC 2001b). More recent studies examining the ecological impacts of climate change in Canada have conformed to this international standard (i.e., Scott & Suffling 2000; Scott *et al.* 2002; Lemieux & Scott 2005;

Wood 2007), but some older studies base their projections on only one climate scenario, thereby decreasing the reliability of their results (i.e., Rizzo & Wiken 1992; Kerr & Packer 1998).

Uncertainty also enters into climate-vegetation modeling through the reconciliation of the different scales at which climate (global scale) and ecological (local to regional to landscape scales) processes operate. Recent studies have used process-based vegetation models to project broad ecosystem changes across Canada (Scott *et al.* 2002; Lemieux & Scott 2005; Wood 2007); however, the coarse resolution of ecological change projected using this technique has been criticized as failing to recognize the complexity of ecological interactions and as being incapable of predicting new types of interactions that may evolve under climate change (Schneider & Root 1996; Schmitz *et al.* 2003). Current literature stresses that the ecosystem simulation models that have been cited as capable of inferring biodiversity change in Canada should be considered a first-cut approximation as biodiversity models because their prognosis is dependent on two assumptions that are unlikely to be met in reality (Schmitz *et al.* 2003; IPCC 2004). First, this type of predictive modeling assumes that ecosystems can be fully conceptualized in a bottom-up manner based on their dominant vegetation pattern and ignores the effects of animals at higher trophic levels on ecosystem structure and function (Schmitz *et al.* 2003). Second, climate-vegetation models assume that ecosystems will move as discrete units in response to climate change (Scott & Suffling 2000; Schmitz *et al.* 2003; IPCC 2004; Peterson *et al.* 2005). This type of cohesive movement is unlikely: as reviewed in Section 2.3.1., species and communities respond to climate change individually and, “it is unrealistic to expect that current ecological communities will simply ‘march northward’ in unison (Scott & Suffling 2000, p.3).” Equilibrium climate-vegetation models also ignore the potential geographic barriers to ecosystem migration, such as mountains and fragmented habitats. Because of the inability of current models to

account for these issues, it has been suggested that many of the ecological interactions and formations that develop under climate change will be a “surprise”, detected only through ecosystem monitoring (Schneider & Root 1996).

The large scale at which equilibrium process-based models project change has also caused a gap in knowledge regarding the interaction of future climate change with other more local stressors to biodiversity (i.e., habitat fragmentation, human land use) (Kappelle *et al.* 1999; McCarty 2001; Root *et al.* 2003; Thomas *et al.* 2004; Lemieux & Scott 2005). While the methodology used to detect the *recent* ecological impacts of climate change was faced with the challenge of filtering out other stressors to detect the climate change-influence, the models used to predict *future* ecological change are challenged with integrating the potential effects of local, ongoing stressors.

While the smaller scale of single-species climate envelope models may be better able to address these issues, they have also been criticized for their variability and the high level of uncertainty in their predictions (Pearson & Dawson 2003; Araújo *et al.* 2005a; Araújo *et al.* 2005b; Guison & Thuiller 2005; Peterson *et al.* 2005; Araújo & Luoto 2007). Furthermore, similar to biome models, individual species models project a future distribution at a given point in time, but do not simulate the dispersal process and often ignore the influence of interactions with other species and the potential for individualistic species responses to climate change that may not involve a poleward shift in range in accordance with new climate conditions (Davis *et al.* 1998; Guison & Thuiller 2005; Peterson *et al.* 2005; Fischlin *et al.* 2007). Schmitz *et al.* (2003) have recommended the integration of top-down processes into climate-ecological models as a supplementary means of presenting future ecological scenarios in a more holistic manner. They stress that the integration of top-down processes (examining ecosystem linkages from the

highest trophic level downwards) is critical to accurately forecasting more complicated ecological interactions that may take place under climate change.

2.4. Climate change and species at risk management and policy in Canada

Substantial changes in species and ecosystems are expected under future climate change and paleoecological evidence suggests that species' primary response to climate change will be to shift their distributions in attempt to accommodate new climates and associated ecological conditions. Species designated as at risk are therefore likely to be highly vulnerable to climate change, as they have small and isolated populations, restrictive distributions and biological traits and are threatened by external stressors, which will limit their ability to disperse to more suitable habitat as growing conditions change; low genetic diversity among some species at risk populations will also limit their ability for in-situ genetic adaptation. Moreover, future projections indicate that species that are not currently at risk may become endangered at an increasing rate under climate change (Thomas *et al.* 2004; IPCC 2007b).

Attention from international organizations has raised significant awareness of the need for action to prevent the loss of biodiversity from climate change (i.e., IUCN 1994; Green *et al.* 2003; Secretariat of the CBD 2007; UNESCO World Heritage Centre 2007). Most recently, the IUCN indicated that climate change is acting as an accelerant to many of the threats currently influencing species across the globe and states that "Climate change is likely to figure more prominently in future IUCN Red List updates (IUCN 2008)."

While climate change mitigation is clearly crucial to preventing biodiversity loss, the IPCC (2007a) has already declared that some future climate change will occur in spite of current international mitigation efforts. Climate change adaptation theory stresses that the implementation of anticipatory measures is the best means of facilitating the long-term

adaptation of systems to future climate change, preventing irreversible impacts such as species extinctions and capitalizing on the potential benefits of climate change (i.e., Smith *et al.* 1996; Smith 1997; IPCC 2001a). Due to the large influence climate exerts on ecological systems and the susceptibility of species at risk to extinction, the potential implications of climate change for the effectiveness of species at risk management and policy requires evaluation.

Bloomgarden (1995) was the first to draw attention to the challenge climate change poses specifically to species at risk management and policy by assessing the ability of the United States Endangered Species Act to function efficiently under future climate change. She determined that the U.S. Endangered Species Act will fail to keep pace with the number of species needing protection and recommends that the Act take a more holistic and dynamic approach to conservation that incorporates climate change into long-term conservation planning and considers the interaction of climate change with other stressors.

In Canada, no cohesive efforts have emerged to understand the potential challenges and opportunities of climate change for species at risk management or the effectiveness of species at risk policy in the era of climate change. Parks Canada has made significant strides to understand and manage the role that climate change may play for park ecosystems via research and national park assessments (i.e., Scott & Suffling 2000; Hui 2001; Scott *et al.* 2002; Parks Canada 2003; Lemieux & Scott 2005; Wood 2007), the integration of climate change into park management plans, and the development of a climate change adaptation framework (Welch 2005; Welch 2008), but issues specific to species at risk have not been systematically assessed. Many of the more recently produced COSEWIC assessment and status reports and federal recovery strategies consider the potential influence of anthropogenic climate change on individual species, but this is not uniform across all species at risk and species that have not been recently assessed are less

likely to have been evaluated in the context of future climate change. Of the 165 endangered species examined in this thesis, reference was made to the influence of anthropogenic climate change in the federal documentation of 57 species, with the earliest references occurring in 2000 and becoming more common in 2006 onwards.

The Canadian Biodiversity Strategy states: “The current climate, with its variability and extremes, directly affects all ecosystems. Future global atmospheric changes resulting from human activities may exert the greatest influence on biodiversity... It is not known how ecosystems and species will adjust or fail to adjust to these stresses, or what the potential effect on genetic diversity will be (Canadian Biodiversity Strategy 1995, Goal 1 [F]).” The Strategy goes on to outline several strategic directions designed to address the influence of climate change on biodiversity in Canada (Table 2.5), referring to the need to understand the impacts of climate change for biodiversity and to implement measures to address such impacts. Given that the threat of climate change is explicitly addressed in the Canadian Biodiversity Strategy and that SARA is a critical piece of legislation developed to meet the goals of this Strategy, a better understanding of the potential impacts of climate change on species at risk is needed to assess the robustness of Canadian species at risk protection for the course of the 21st century.

Table 2.5. Strategic directions of the Canadian Biodiversity Strategy relating to climate change (Adapted from Canadian Biodiversity Strategy 1995, Goal 1[F])

	Strategic Direction
1	Develop linkages in the implementation processes for the Conventions on Biological Diversity and Climate Change and other atmospheric agreements and programs
2	Maintain and enhance bioclimatic monitoring to track the effects of atmospheric changes on ecosystems, species and genetic diversity
3	Increase coordination among national programs to determine potential impacts on biodiversity from past, present and future atmospheric changes
4	Apply multi-disciplinary research to investigate relationships between atmospheric changes and changes in biodiversity
5	Implement measures to eliminate or reduce human-caused atmospheric changes that adversely affect biodiversity

CHAPTER 3: STUDY APPROACH AND METHODOLOGY

3.1. Screening level assessment approach to evaluate the potential impacts of climate change on endangered species in Canada

The approach for this study is similar to Scott and Suffling's (2000) screening level assessment of the implications of climate change for Canada's national park system, where projected climate change scenarios and current knowledge of climate change impacts were used to make an initial evaluation of the implications of climate change for each national park in Canada. In this study, a screening level assessment is used to evaluate the potential impact of climate change on individual species at risk in Canada. Due to time constraints for this project, only the 165 species classified as endangered on Schedule 1 of SARA as of December 2007 were assessed.

For each endangered species, information was compiled on population size, distribution, habitat and biology, primarily using COSEWIC status reports and recovery strategies from the respective federal departments under which the jurisdiction of the species falls (i.e., Environment Canada, Fisheries and Oceans Canada [DFO], Parks Canada). Where applicable and available, other federal and provincial government, non-governmental organization (NGO) and academic reports were used to supplement this information. Based on these species' profiles, each endangered species was then assessed in the context of future climate change. Climate change projections and best available information on relevant climate change impacts were integrated with the species profile information to understand how climate change may influence each species during the 21st century. This included temperature and precipitation projections generated by CCCSN (2007) and biome projections by Wood (2007); information on other types of potential climate change impacts across Canada were taken from a wide variety of

government, NGO and academic reports. The climate change impact criteria considered for each species are listed in Table 3.1.

Table 3.1. Criteria considered in the assessment of the potential impact of climate change on endangered species in Canada.

Criteria	Description
<i>Physical climate change impacts</i>	
Temperature change	The potential impact of projected temperature change in the 2080s across species' distributions. Annual or seasonal projections may be considered where applicable for a given species. All temperature change scenarios are derived from CCCSN's (2007) range of scenarios in accordance with the IPCC's Fourth Assessment Report using the CGCM3, CSIRO, GFDL, GISS, HADCM3 and NCAR GCMs. In general, trends in projected temperature change are discussed rather than the exact projected range of future temperature change.
Precipitation change	The potential impact of projected total precipitation change in the 2080s across species' distributions. Annual or seasonal projections may be considered where applicable for a given species. All precipitation change scenarios are derived from CCCSN's (2007) range of scenarios in accordance with the IPCC's Fourth Assessment Report using the CGCM3, CSIRO, GFDL, GISS, HADCM3 and NCAR GCMs. In general, trends in projected precipitation change are discussed rather than the exact projected range of future precipitation change.
Sea level rise	The potential impact of climate change related sea level rise on coastal species. National scale projections of the sensitivity of coastal areas to sea level rise (Lemmen & Warren 2004) are applied to species' distributions unless more regional sea level rise impact studies are available.
Hydrologic regime	The potential impact of projected long-term changes in the level/flow of lakes, wetlands and rivers, as well as changes in flow timing and magnitude. Climate change related impacts on snow, glaciers or groundwater are considered independently where applicable. Changes in water temperature and quality are considered for terrestrial hydrologic systems and oceans.
Extreme events	The potential impact of climate change related changes in the rate, pattern or magnitude of extreme weather or environmental events such as storms, flooding or drought. This includes the potential for regional or local extreme events, but also large scale extreme events, such as hurricanes in coastal areas. Rapid, extreme geomorphic events related to climate change factors are also considered where applicable and where suitable information exists. The connection of extreme events to other physical changes listed above is acknowledged and the importance of species at risk characteristics (i.e., population size) relative to the impact of extreme events is discussed further in section 5.1.1.
<i>Climate change-induced ecological impacts</i>	
Biome change	The potential impact of climate change related biome change in the 2080s across species' distributions as derived by Wood (2007). Although biome scale data is too coarse to provide detailed information on ecological change at the scale of individual species, biome projections are considered to be a broad indicator of the availability of suitable habitat conditions known for a given species.

Ecological disturbance	The potential impact of climate change related ecosystem disturbances, such as fire, pests and disease, is considered from a species context; however, much of the available information on future disturbance lacks the detail needed for integration at the individual species level and does not consider complex relationships among species and natural disturbance regimes or the artificial suppression of disturbances (discussed further in section 5.1.1.).
Species-to-species interactions	The potential impact of climate change on inter-species relationships, such as predation, herbivory and mutualistic relationships. These relationships cannot be assessed within the scope of this project, but are discussed where research exists.
Competition with invasive species	The potential role of climate change in facilitating competition with species not endemic to a particular region based on knowledge of current/historic species assemblages. This factor is only sparsely considered throughout the endangered species assessments, as competition with non-native species is likely to influence most endangered species under climate change (discussed further in section 5.1.1.1.).
<i>Climate change-induced socio-economic impacts</i>	
Tourism/recreation	The potential impact of changes in tourism and recreation patterns in response to climate change. This factor is primarily considered for species in which tourism and recreation activities already threaten the species' survival.
<i>Factors relating to species' response to climate change</i>	
Ability for shifts in range/distribution	The ability of a species to migrate/shift its distribution in response to climate change. This also considers barriers to dispersal, the availability of suitable habitat within its new growing range (as related to physical and socioecological climate change impacts), and the loss/gain of protection from protected areas.
Population size	The influence of population size as it relates to the ability of species to recover in Canada under climate change. This also considers connectivity among individual populations and current trends in populations.
Phenological change	The influence of climate change related changes in phenological events on inter-species interactions and the availability of suitable habitat.

Summaries of the available information on the potential impacts of climate change were written for each endangered species; note that in order to make reviews concise, only the relevant criteria from Table 3.1 were discussed for each species. Based on the information outlined in these assessments, the potential overall impact of climate change on each species was inferred as positive, neutral, or negative, or that there was insufficient information to classify the species (terms described in Table 3.2). In general, the classification of each species was determined based on the balance of potential impacts from the criteria in Table 3.1, meaning that species with a greater number of negative or positive potential impacts were classified into these

categories, while species with equal division of impacts between positive and negative were classified as insufficient information and species in which potential climate change impacts were expected to be negligible were classified as neutral. However, given that not all criteria have equal weight in terms of their relevance to the survival of each species, the author’s discretion was applied in cases where relevant criteria differed largely in terms of priority. The limitations associated with this methodology are discussed further in section 3.2.

The results of the classification of endangered species were summed and analyzed to compare the potential impact of climate change among taxonomic groups and provinces/territories and are used as a basis for discussion of the implications of climate change for species at risk management and legislation (Chapter 4).

Table 3.2. Classifications of the potential overall impact of climate change on individual endangered species

Potential Overall Climate Change Impact	Description
Positive	Potential climate change impacts dominantly indicate that climate change will be beneficial to the survival of this species in Canada
Neutral	Potential climate change impacts on this species appear negligible and unlikely to play a significant role in the survival of the species in Canada
Negative	Potential climate change impacts dominantly indicate that climate change will be detrimental to the survival of this species in Canada
Insufficient Information	Information is insufficient to generate a decision on the potential overall impact of climate change on this species OR potential climate change impacts identified in scientific literature are contradictory in terms of their influence on this species and the overall impact of climate change remains uncertain

3.2. Challenges of the screening level assessment approach

As discussed throughout section 2.3.3, modeling the future ecological impacts of climate change is a complex and data intensive process at both the landscape and individual species scales. The challenges prevalent in modeling future climate and ecological change (section

2.3.3.4) also apply to this screening level assessment of the potential impacts of climate change on endangered species in Canada.

The spatial scale at which future climate change is projected is much larger than the scale at which individual species operate; projected climate conditions may not prevail in regions with distinct local and micro climates and species' responses to climate change in these regions may be individualistic and irregular. Although the approach taken by this screening level assessment of integrating information on climate change impacts with species' characteristics allows for more consideration of unique species' responses to climate change than typically found in climate envelope studies, the lack of data on future climate change at the spatial scale of most species' populations makes precise predictions of climate change impacts impossible.

Similarly, assessing the potential impact of climate change on individual species allows for consideration of both anthropogenic stressors and natural factors (such as community-scale interactions like competition, herbivory or predation) that currently limit endangered species in Canada, as well as consideration of landscape barriers that could prevent the dispersal of species to new regions. However, these factors and their relative influence on endangered species may vary over the course of the 21st century, both independently of climate change (e.g., restoration of habitat modified by anthropogenic land-use) and in direct response to climate change (e.g., different rates of climate change-related distributional change of species in a competitive relationship). If the factors currently limiting endangered species are reduced, species may become more resilient to the impacts of climate change; alternately, the intensification of these factors may cause species to become more vulnerable to the impacts of climate change. For the purposes of this assessment, it was assumed that unless research indicated otherwise the current

threats to endangered species in Canada would remain relatively constant under future climate change.

As identified in section 2.3.3.4, uncertainty is a critical issue in the projection of future climate change and is best minimized by the use of multiple GCMs and climate scenarios. The temperature and precipitation trends across species distributions generated by CCCSN (2007) were depicted by a range of GCMs and climate scenarios in compliance with guidelines set out in the IPCC's Fourth Assessment Report. However, a large variety of other climate change impacts studies were taken into consideration for each species assessment and these studies do not all conform to IPCC guidelines for climate change impact projections. As a result, comparison and interrelation among sources used is generally not feasible and the levels of uncertainty in climate change impact projections among separate studies are noted to differ.

When compared to species modeling studies, the screening level assessment approach is a faster and less cost- and data-intensive means of evaluating the potential impact of climate change on an array of individual species. However, a main limitation in the use of a screening level assessment approach instead of quantitatively modeling species' responses to climate change is the subjectivity associated with formulating decisions on the potential overall impact of climate change on each endangered species. As stated in section 3.1 above, classifications of the potential overall impact of climate change for each species were based on the author's interpretation of the best available information. These classifications may be interpreted differently by other scientists, particularly those with greater expertise on an individual species. Consequently, one of the recommendations of this work is that an expert panel be commissioned to further consider the available scientific evidence as part of a broader initiative to consider

climate change adaptation in SARA (see Recommendation 6.2.2). Importantly, the interpretations offered here are also subject to change as new information becomes available.

Given these limitations, as well as the challenges associated with projecting future climate change impacts discussed above, it should be made very clear that this assessment is not intended as a definitive prognosis of the fate of endangered species under climate change. Rather, it is intended as a first analysis of the possible implications of climate change for endangered species in Canada, which can be used to stimulate further research and modeling activities and inform species at risk policy and management practices.

CHAPTER 4: SCREENING LEVEL ASSESSMENT OF THE IMPACTS OF CLIMATE CHANGE ON ENDANGERED SPECIES IN CANADA

This chapter presents the results of the screening level assessment of the impacts of climate change on endangered species in Canada. Section 4.1 provides an overview of key findings and trends among the 165 species assessed. Section 4.2 provides detailed assessments on an individual species basis. In this section, the relevant impacts of climate change are summarized for each species, and species are classified according to the potential overall impact of climate change based on the best available information as interpreted by the author (positive, negative, neutral or insufficient information [refer to Table 3.2 above for definitions]).

4.1. Overview of results

The potential impact of climate change was assessed for a total of 165 endangered species listed on Schedule 1 of SARA (as at December 2007) (Table 4.1). Based on available scientific evidence, just over half of all endangered species in Canada (51%) are anticipated to be negatively impacted by future climate change. The potential climate change impact was assessed to be neutral for 8% of species and positive for only 4% of species. For a considerable portion of species (37%) there was insufficient scientific information to make a robust determination of the overall impact of future climate change; in many of these cases, climate change had the potential to benefit aspects of the growth/habitat of these species in Canada (refer also to section 5.1.2), but factors related to current threats, limitations of endangered species to capitalize on such opportunities and insufficient data applicable to the species scale prevented a clear conclusion about overall climate change impact. As new information at a more detailed scale becomes available and/or if current threats to species are successfully mitigated, it is possible, particularly

via management and planning, for at least some of these species to be positively impacted by climate change in Canada.

As presented in Table 4.2, all amphibian species in Canada and the majority of freshwater fish and mollusk species are expected to respond negatively to climate change, which is due to the dependence of these species on the abundance, temperature and quality of aquatic habitats and the high potential for climate change to affect these variables. Similarly, marine mammals and fish will generally be negatively affected by climate change due to the influence of warmer water temperature on the marine food web and on the suitability of spawning habitat. Other taxonomic groups were largely split between the negative and insufficient information categories and can only be considered on a case by case basis. Common trends among species projected to respond negatively to future climate change are small total range size, restrictive habitat preferences and biologic or population-related traits that may limit the species' adaptability to climate change (i.e., poor ability for dispersal, specific thermal tolerances, dependence on interspecies relationships, isolated populations). Common trends among species that have the potential to respond positively to climate change are occurrence of the northern extent of the species' range in southern Canada, evidence that the core climatic growing range of the species may shift in favour of current Canadian populations, and biological or population-related traits that make the species well-adapted to future climate change conditions and impacts (i.e., non-specificity/adaptability in habitat and diet preferences, summer drought-tolerant, continuous populations).

In terms of regional distribution, the majority of endangered species in Canada are found in British Columbia and Ontario (Table 4.3). These species largely occur in biodiversity "hotspots" in southwestern British Columbia and southern Ontario, which experience warmer

climate conditions due to the moderating influence of large bodies of water but also coincide with areas of intense human land-use. Many of the endangered species in these regions are at the northern extent of their range in Canada and are thought to be partially limited by cold climatic conditions. While most of these species were classified as having insufficient information to determine overall climate change impact, it is possible that species within these biodiversity hotspots may be among the most likely to experience at least some benefits from climate change in Canada (discussed further in section 5.1.2.). A similar opportunity may exist for species that exist at the northern limit of their range in the southern prairie regions of Canada. Species in the maritime provinces of Canada are largely projected to respond negatively to climate change, which is a function of the restricted potential for geographic dispersal in this region, the higher risk of sea level rise, and substantial biome change projected across northern maritime regions. Relatively few endangered species in Canada are inhabitants of the territories and other northern regions of Canada; those that are (i.e., Whooping Crane, Eskimo Curlew), as well as species that inhabit alpine and sub-alpine regions (i.e., Vancouver Island Marmot, Atlantic-Gaspésie population of Woodland Caribou), are expected to be negatively impacted by climate change due to the substantial climate and ecological changes projected in these regions and/or their wintering grounds. Species or subspecies endemic to Canada occur sporadically across the country (i.e., Banff Springs Snail, Red Crossbill *percna* subspecies, Seaside Centipede Lichen) and in most cases are likely to respond negatively to climate change due to restrictive habitat preferences and range area.

Table 4.1. Potential impacts of climate change on endangered species in Canada

	Name	Scientific Name	Taxonomic Group	Province	Potential Climate Change Impact
1	Acadian Flycatcher	<i>Empidonax virescens</i>	Birds	ON	Insufficient Information
2	Allegheny Mountain Dusky Salamander	<i>Desmognathus ochrophaeus</i>	Amphibians	ON	Negative
3	American Badger jacksoni subspecies	<i>Taxidea taxus jacksoni</i>	Mammals (Terrestrial)	ON	Neutral
4	American Badger jeffersonii subspecies	<i>Taxidea taxus jeffersonii</i>	Mammals (Terrestrial)	BC	Neutral
5	American Chestnut	<i>Castanea dentata</i>	Vascular Plants	ON	Neutral
6	American Ginseng	<i>Panax quinquefolius</i>	Vascular Plants	ON, QC	Negative
7	American Marten (Newfoundland Population)	<i>Martes americana atrata</i>	Mammals (Terrestrial)	NL	Insufficient Information
8	Atlantic Salmon (Inner Bay of Fundy populations)	<i>Salmo salar</i>	Fishes (Marine)	NB, NS, Atlantic Ocean	Negative
9	Atlantic Whitefish	<i>Coregonus huntsmani</i>	Fishes (Freshwater)	NS	Negative
10	Aurora Trout	<i>Salvelinus fontinalis timagamiensis</i>	Fishes (Freshwater)	ON	Negative
11	Banff Springs Snail	<i>Physella johnsoni</i>	Molluscs	AB	Negative
12	Barn Owl (Eastern Population)	<i>Tyto alba</i>	Birds	ON, QC	Positive
13	Barrens Willow	<i>Salix jejuna</i>	Vascular Plants	NL	Negative
14	Bashful Bulrush	<i>Trichophorum planifolium</i>	Vascular Plants	ON	Insufficient Information
15	Bearded Owl-clover	<i>Triphysaria versicolor versicolor</i>	Vascular Plants	BC	Insufficient Information
16	Bear's-foot Sanicle	<i>Sanicula arctopoides</i>	Vascular Plants	BC	Insufficient Information
17	Benthic & Limnetic Enos Lake Stickleback	<i>Gasterosteus</i> sp.	Fishes (Freshwater)	BC	Negative
18	Benthic & Limnetic Paxton Lake Stickleback	<i>Gasterosteus</i> sp.	Fishes (Freshwater)	BC	Negative
19	Benthic & Limnetic Vananda Creek Stickleback	<i>Gasterosteus</i> sp.	Fishes (Freshwater)	BC	Negative
20	Bird's-foot Violet	<i>Viola pedata</i>	Vascular Plants	ON	Insufficient Information
21	Blanding's Turtle (Nova Scotia Population)	<i>Emydoidea blandingii</i>	Reptiles	NS	Negative
22	Blue Racer	<i>Coluber constrictor foxii</i>	Reptiles	ON	Negative
23	Blue Whale (Atlantic Ocean)	<i>Balaenoptera musculus</i>	Mammals (Marine)	Atlantic Ocean	Negative

24	Blue Whale (Pacific Ocean)	<i>Balaenoptera musculus</i>	Mammals (Marine)	Pacific Ocean	Negative
25	Bluehearts	<i>Buchnera americana</i>	Vascular Plants	ON	Negative
26	Blunt-lobed Woodsia	<i>Woodsia obtusa</i>	Vascular Plants	ON, QC	Insufficient Information
27	Bog Bird's-foot Trefoil	<i>Lotus pinnatus</i>	Vascular Plants	BC	Negative
28	Boreal Felt Lichen (Atlantic Population)	<i>Erioderma pedicellatum</i>	Lichens	NB, NS	Negative
29	Branched Phacelia	<i>Phacelia ramosissima</i>	Vascular Plants	BC	Neutral
30	Burrowing Owl	<i>Athene cunicularia</i>	Birds	BC, AB, SK, MB	Insufficient Information
31	Butternut	<i>Juglans cinerea</i>	Vascular Plants	ON, QC, NB	Neutral
32	Coastal Scouler's Catchfly	<i>Silene scouleri grandis</i>	Vascular Plants	BC	Insufficient Information
33	Cucumber Tree	<i>Magnolia acuminata</i>	Vascular Plants	ON	Negative
34	Deltoid Balsamroot	<i>Balsamorhiza deltoidea</i>	Vascular Plants	BC	Neutral
35	Dense Spike-primrose	<i>Epilobium densiflorum</i>	Vascular Plants	BC	Neutral
36	Dense-flowered Lupine	<i>Lupinus densiflorus</i>	Vascular Plants	BC	Negative
37	Drooping Trillium	<i>Trillium flexipes</i>	Vascular Plants	ON	Neutral
38	Dwarf Sandwort	<i>Minuartia pusilla</i>	Vascular Plants	BC	Negative
39	Eastern Mountain Avens	<i>Geum peckii</i>	Vascular Plants	NS	Negative
40	Eastern Prairie Fringed-orchid	<i>Platanthera leucophaea</i>	Vascular Plants	ON	Negative
41	Eastern Prickly Pear Cactus	<i>Opuntia humifusa</i>	Vascular Plants	ON	Negative
42	Engelmann's Quillwort	<i>Isoetes engelmannii</i>	Vascular Plants	ON	Negative
43	Eskimo Curlew	<i>Numenius borealis</i>	Birds	NT, NU, AB, SK, MB, ON, QC, NB, PE, NS, NL	Negative
44	False Hop Sedge	<i>Carex lupuliformis</i>	Vascular Plants	ON, QC	Insufficient Information
45	Forked Three-awned Grass	<i>Aristida basiramea</i>	Vascular Plants	ON, QC	Positive
46	Furbish's Lousewort	<i>Pedicularis furbishiae</i>	Vascular Plants	NB	Negative
47	Gattinger's Agalinis	<i>Agalinis gattingeri</i>	Vascular Plants	ON	Insufficient Information
48	Golden Paintbrush	<i>Castilleja levisecta</i>	Vascular Plants	BC	Insufficient Information

49	Grand Coulee Owl-clover	<i>Orthocarpus barbatus</i>	Vascular Plants	BC	Insufficient Information
50	Greater Sage-Grouse urophasianus subspecies	<i>Centrocercus urophasianus urophasianus</i>	Birds	AB, SK	Negative
51	Heart-leaved Plantain	<i>Plantago cordata</i>	Vascular Plants	ON	Negative
52	Henslow's Sparrow	<i>Ammodramus henslowii</i>	Birds	ON	Negative
53	Hoary Mountain-mint	<i>Pycnanthemum incanum</i>	Vascular Plants	ON	Insufficient Information
54	Horned Lark strigata subspecies	<i>Eremophila alpestris strigata</i>	Birds	BC	Neutral
55	Horsetail Spike-rush	<i>Eleocharis equisetoides</i>	Vascular Plants	ON	Negative
56	Hotwater Physa	<i>Physella wrighti</i>	Molluscs	BC	Insufficient Information
57	Howell's Triteleia	<i>Triteleia howellii</i>	Vascular Plants	BC	Insufficient Information
58	Island Blue	<i>Plebejus saepiolus insulanus</i>	Arthropods	BC	Negative
59	Juniper Sedge	<i>Carex juniperorum</i>	Vascular Plants	ON	Insufficient Information
60	Kellogg's Rush	<i>Juncus kelloggii</i>	Vascular Plants	BC	Negative
61	Kidneyshell	<i>Ptychobranthus fasciolaris</i>	Molluscs	ON	Negative
62	Killer Whale (Northeast Pacifica Southern Resident Population)	<i>Orcinus orca</i>	Mammals (Marine)	Pacific Ocean	Insufficient Information
63	King Rail	<i>Rallus elegans</i>	Birds	ON	Negative
64	Kirtland's Warbler	<i>Dendroica kirtlandii</i>	Birds	ON	Negative
65	Large Whorled Pogonia	<i>Isotria verticillata</i>	Vascular Plants	ON	Insufficient Information
66	Leatherback Seaturtle	<i>Dermochelys coriacea</i>	Reptiles	Pacific Ocean, Atlantic Ocean	Negative
67	Loggerhead Shrike migrans subspecies	<i>Lanius ludovicianus migrans</i>	Birds	MB, ON, QC	Insufficient Information
68	Long's Braya	<i>Braya longii</i>	Vascular Plants	NL	Negative
69	Margined Streamside Moss	<i>Scouleria marginata</i>	Mosses	BC	Negative
70	Maritime Ringlet	<i>Coenonympha nipisiquit</i>	Arthropods	QC, NB	Negative
71	Mormon Metalmark (Southern Mountain Population)	<i>Apodemia mormo</i>	Arthropods	BC	Insufficient Information
72	Morrison Creek Lamprey	<i>Lampetra richardsoni</i>	Fishes (Freshwater)	BC	Insufficient Information
73	Mountain Plover	<i>Charadrius montanus</i>	Birds	AB, SK	Insufficient Information

74	Mudpuppy Mussel	<i>Simpsonaias ambigua</i>	Molluscs	ON	Negative
75	Night Snake	<i>Hypsiglena torquata</i>	Reptiles	BC	Positive
76	Nodding Pogonia	<i>Triphora trianthophora</i>	Vascular Plants	ON	Insufficient Information
77	Nooksack Dace	<i>Rhinichthys cataractae</i> ssp.	Fishes (Freshwater)	BC	Negative
78	North Atlantic Right Whale	<i>Eubalaena glacialis</i>	Mammals (Marine)	Atlantic Ocean	Negative
79	North Pacific Right Whale	<i>Eubalaena glacialis</i>	Mammals (Marine)	Pacific Ocean	Negative
80	Northern Bobwhite	<i>Colinus virginianus</i>	Birds	ON	Positive
81	Northern Bottlenose Whale (Scotian Shelf Population)	<i>Hyperoodon ampullatus</i>	Mammals (Marine)	Atlantic Ocean	Negative
82	Northern Cricket Frog	<i>Acris crepitans</i>	Amphibians	ON	Negative
83	Northern Leopard Frog (Southern Mountain Population)	<i>Rana pipiens</i>	Amphibians	BC	Negative
84	Northern Madtom	<i>Noturus stigmosus</i>	Fishes (Freshwater)	ON	Insufficient Information
85	Northern Riffleshell	<i>Epioblasma torulosa rangiana</i>	Molluscs	ON	Negative
86	Oregon Forestsnail	<i>Allogona townsendiana</i>	Molluscs	BC	Insufficient Information
87	Oregon Spotted Frog	<i>Rana pretiosa</i>	Amphibians	BC	Negative
88	Ottoo Skipper	<i>Hesperia ottoe</i>	Arthropods	MB	Insufficient Information
89	Pink Coreopsis	<i>Coreopsis rosea</i>	Vascular Plants	NS	Negative
90	Pink Milkwort	<i>Polygala incarnata</i>	Vascular Plants	ON	Insufficient Information
91	Pink Sand-verbena	<i>Abronia umbellata</i>	Vascular Plants	BC	Negative
92	Piping Plover circumcinctus subspecies	<i>Charadrius melodus circumcinctus</i>	Birds	AB, SK, MB, ON	Negative
93	Piping Plover melodus subspecies	<i>Charadrius melodus melodus</i>	Birds	QC, NB, PE, NS, NL	Negative
94	Pitcher's Thistle	<i>Cirsium pitcheri</i>	Vascular Plants	ON	Negative
95	Poor Pocket Moss	<i>Fissidens pauperculus</i>	Mosses	BC	Negative
96	Prairie Lupine	<i>Lupinus lepidus</i> var. <i>lepidus</i>	Vascular Plants	BC	Insufficient Information
97	Prairie Skink	<i>Eumeces septentrionalis</i>	Reptiles	MB	Insufficient Information
98	Prothonotary Warbler	<i>Protonotaria citrea</i>	Birds	ON	Negative
99	Pugnose Shiner	<i>Notropis anogenus</i>	Fishes (Freshwater)	ON	Insufficient Information

100	Purple Twayblade	<i>Liparis liliifolia</i>	Vascular Plants	ON	Insufficient Information
101	Rayed Bean	<i>Villosa fabalis</i>	Molluscs	ON	Negative
102	Red Crossbill perca subspecies	<i>Loxia curvirostra perca</i>	Birds	NL	Negative
103	Red Mulberry	<i>Morus rubra</i>	Vascular Plants	ON	Insufficient Information
104	Rigid Apple Moss	<i>Bartramia stricta</i>	Mosses	BC	Insufficient Information
105	Rocky Mountain Tailed Frog	<i>Ascaphus montanus</i>	Amphibians	BC	Negative
106	Roseate Tern	<i>Sterna dougallii</i>	Birds	QC, NB, NS	Negative
107	Rosy Owl-clover	<i>Orthocarpus bracteosus</i>	Vascular Plants	BC	Negative
108	Round Hickorynut	<i>Obovaria subrotunda</i>	Molluscs	ON	Negative
109	Round Pigtoe	<i>Pleurobema sintoxia</i>	Molluscs	ON	Negative
110	Rusty Cord Moss	<i>Entosthodon rubiginosus</i>	Mosses	BC	Negative
111	Sage Thrasher	<i>Oreoscoptes montanus</i>	Birds	BC, AB, SK	Negative
112	Salish Sucker	<i>Catostomus catostomus</i> ssp.	Fishes (Freshwater)	BC	Insufficient Information
113	Sand-verbena moth	<i>Copablepharon fuscum</i>	Arthropods	BC	Negative
114	Scarlet Ammannia	<i>Ammannia robusta</i>	Vascular Plants	BC, ON	Insufficient Information
115	Seaside Birds-foot Lotus	<i>Lotus formosissimus</i>	Vascular Plants	BC	Insufficient Information
116	Seaside Centipede Lichen	<i>Heterodermia sitchensis</i>	Lichens	BC	Negative
117	Sei Whale (Pacific Population)	<i>Balaenoptera borealis</i>	Mammals (Marine)	Pacific Ocean	Negative
118	Sharp-tailed Snake	<i>Contia tenuis</i>	Reptiles	BC	Insufficient Information
119	Showy Goldenrod	<i>Solidago speciosa</i>	Vascular Plants	ON	Insufficient Information
120	Silver Hair Moss	<i>Fabronia pusilla</i>	Mosses	BC	Positive
121	Skinner's Agalinis	<i>Agalinis skinneriana</i>	Vascular Plants	ON	Insufficient Information
122	Slender Bush-clover	<i>Lespedeza virginica</i>	Vascular Plants	ON	Insufficient Information
123	Slender Collomia	<i>Collomia tenella</i>	Vascular Plants	BC	Neutral
124	Small White Lady's-slipper	<i>Cypripedium candidum</i>	Vascular Plants	MB, ON	Insufficient Information
125	Small Whorled Pogonia	<i>Isotria medeoloides</i>	Vascular Plants	ON	Insufficient Information

126	Small-flowered Lipocarpha	<i>Lipocarpha micrantha</i>	Vascular Plants	BC, ON	Negative
127	Small-flowered Sand-verbena	<i>Tripterocalyx micranthus</i>	Vascular Plants	AB, SK	Positive
128	Small-flowered Tonella	<i>Tonella tenella</i>	Vascular Plants	BC	Insufficient Information
129	Small-mouthed Salamander	<i>Ambystoma texanum</i>	Amphibians	ON	Negative
130	Snuffbox	<i>Epioblasma triquetra</i>	Molluscs	ON	Negative
131	Southern Maidenhair Fern	<i>Adiantum capillus-veneris</i>	Vascular Plants	BC	Neutral
132	Spalding's Campion	<i>Silene spaldingii</i>	Vascular Plants	BC	Negative
133	Spoon-leaved Moss	<i>Bryoandersonia illecebra</i>	Mosses	ON	Insufficient Information
134	Spotted Owl caurina subspecies	<i>Strix occidentalis caurina</i>	Birds	BC	Negative
135	Spotted Turtle	<i>Clemmys guttata</i>	Reptiles	ON, QC	Negative
136	Spotted Wintergreen	<i>Chimaphila maculata</i>	Vascular Plants	ON, QC	Neutral
137	Stoloniferous Pussytoes	<i>Antennaria flagellaris</i>	Vascular Plants	BC	Insufficient Information
138	Streambank Lupine	<i>Lupinus rivularis</i>	Vascular Plants	BC	Negative
139	Swift Fox	<i>Vulpes velox</i>	Mammals (Terrestrial)	AB, SK	Insufficient Information
140	Tall Bugbane	<i>Actaea elata</i>	Vascular Plants	BC	Insufficient Information
141	Tall Woolly-heads	<i>Psilocarphus elatior</i>	Vascular Plants	BC	Negative
142	Taylor's Checkerspot	<i>Euphydryas editha taylori</i>	Arthropods	BC	Insufficient Information
143	Thread-leaved Sundew	<i>Drosera filiformis</i>	Vascular Plants	NS	Insufficient Information
144	Tiger Salamander (Southern Mountain Population)	<i>Ambystoma tigrinum</i>	Amphibians	BC	Negative
145	Tiny Cryptanthe	<i>Cryptantha minima</i>	Vascular Plants	AB, SK	Positive
146	Toothcup	<i>Rotala ramosior</i>	Vascular Plants	BC, ON	Insufficient Information
147	Townsend's Mole	<i>Scapanus townsendii</i>	Mammals (Terrestrial)	BC	Insufficient Information
148	Vancouver Island Marmot	<i>Marmota vancouverensis</i>	Mammals (Terrestrial)	BC	Negative
149	Virginia Goat's-rue	<i>Tephrosia virginiana</i>	Vascular Plants	ON	Insufficient Information
150	Water-plantain Buttercup	<i>Ranunculus alismifolius</i> var. <i>alismifolius</i>	Vascular Plants	BC	Negative
151	Wavy-rayed Lampmussel	<i>Lampsilis fasciola</i>	Molluscs	ON	Negative

152	Western Prairie Fringed-orchid	<i>Platanthera praeclara</i>	Vascular Plants	MB	Insufficient Information
153	Western Screech-Owl macfarlanei subspecies	<i>Megascops kennicottii macfarlanei</i>	Birds	BC	Insufficient Information
154	White Flower Moth	<i>Schinia bimatrix</i>	Arthropods	MB	Insufficient Information
155	White Meconella	<i>Meconella oregana</i>	Vascular Plants	BC	Negative
156	White Prairie Gentian	<i>Gentiana alba</i>	Vascular Plants	ON	Neutral
157	White Sturgeon	<i>Acipenser transmontanus</i>	Fishes (Freshwater)	BC	Negative
158	White-headed Woodpecker	<i>Picoides albolarvatus</i>	Birds	BC	Insufficient Information
159	Whooping Crane	<i>Grus americana</i>	Birds	NT, AB	Negative
160	Williamson's Sapsucker	<i>Sphyrapicus thyroideus</i>	Birds	BC	Insufficient Information
161	Wolverine (Eastern Population)	<i>Gulo gulo</i>	Mammals (Terrestrial)	QC, NL	Negative
162	Woodland Caribou (Atlantic-Gaspésie population)	<i>Rangifer tarandus caribou</i>	Mammals (Terrestrial)	QC	Negative
163	Wood-poppy	<i>Stylophorum diphyllum</i>	Vascular Plants	ON	Insufficient Information
164	Yellow-breasted Chat auricollis subspecies (BC Population)	<i>Icteria virens auricollis</i>	Birds	BC	Insufficient Information
165	Yucca Moth	<i>Tegeticula yuccasella</i>	Arthropods	AB	Insufficient Information

Table 4.2. Summary of potential climate change impacts on endangered species by taxonomic group

Taxonomic Group	Potential Climate Change Impact				
	Negative	Neutral	Positive	Insufficient Information	Total
Amphibians	7	0	0	0	7
Arthropods	3	0	0	5	8
Birds	13	1	2	8	24
Fishes (Freshwater)	7	0	0	4	11
Fishes (Marine)	1	0	0	0	1
Lichens	2	0	0	0	2
Mammals (Marine)	6	0	0	1	7
Mammals (Terrestrial)	3	2	0	3	8
Molluscs	9	0	0	2	11
Mosses	3	0	1	2	6
Reptiles	4	0	1	2	7
Vascular Plants	26	10	3	34	73
Total	84	13	7	61	165

Table 4.3. Summary of potential climate change impacts on endangered species by occurrence in Canadian provinces and territories

Province	Potential Climate Change Impact				
	Negative	Neutral	Positive	Insufficient Information	Total
British Columbia	30	7	2	27	66
Alberta	6	0	2	4	12
Saskatchewan	4	0	2	3	9
Manitoba	2	0	0	7	9
Ontario	30	5	3	26	64
Quebec	8	2	2	3	15
New Brunswick	7	1	0	0	8
Prince Edward Island	2	0	0	0	2
Nova Scotia	9	0	0	1	10
Newfoundland	6	0	0	1	7
Yukon	0	0	0	0	0
Northwest Territories	2	0	0	0	2
Nunuvut	1	0	0	0	1
Oceans	8	0	0	1	9

4.2. Endangered species screening assessments

Acadian Flycatcher (*Empidonax virescens*)

Taxonomic Group: Birds

Province: Ontario

Climate Change Impact: Insufficient Information

The Acadian Flycatcher is a migratory songbird that reaches the northern extent of its summer range in the Carolinian zone of southern Ontario, and most recent estimates indicate that the Canadian population consists of only 20 to 30 pairs of birds (SARA Public Registry 2008a). This species is currently more widespread and common across its core breeding range in the eastern United States; however, according to Matthews *et al.* (2004), the American population of the Acadian Flycatcher is projected to decrease in abundance under climate change (2 x CO₂ conditions) and shift northward in range, potentially resulting in a relative increase of the Canadian population. Research suggests that Carolinian-type forest systems may have the opportunity to expand northward under climate change (Malcolm *et al.* 2004; AMEC Earth & Environmental 2006), and landscape scale biome projections indicate that the occurrence of the temperate mixed forest biome will increase in Ontario by the 2080s (Wood 2007). However, the Acadian Flycatcher only nests in the interior of large expanses (>40ha) of mature, undisturbed forest, and forest habitat across southern Ontario has been severely diminished and fragmented by development (SARA Public Registry 2008a). Canadian populations of this species may stand to benefit from climate change, but only if sufficiently large forest areas are restored and preserved within its current and future range.

Allegheny Mountain Dusky Salamander (Carolinian Population) (*Desmognathus ochrophaeus*)

Taxonomic Group: Amphibians

Province: Ontario

Climate Change Impact: Negative

The Allegheny Mountain Dusky Salamander occurs throughout the Appalachian Mountain range in the eastern United States and in southern Quebec along the U.S. border, where the species has been classified as threatened; however, another small population of this species (the Carolinian population) was recently discovered in the Niagara Gorge area of southern Ontario and is classified as endangered (COSEWIC 2007c). This salamander has a secretive lifestyle and the size of the Ontario population is unknown, but is likely very small (COSEWIC 2007c). This population exists across a very small area (~0.53ha) and has specific habitat requirements: it is restricted to moist, seep habitat in the deciduous forest of the Carolinian zone in southern Ontario, with some shallow water in close proximity for the egg and larval stage of this species development (COSEWIC 2007c). Climate change is already thought to be playing a role in the global decline of amphibians (i.e., Seburn & Seburn 2000; McCarty 2001; Walther *et al.* 2002; Carey & Alexander 2003) and, while it is unknown if climate change has already impacted the Allegheny Mountain Dusky Salamander, it is likely that projected warmer temperatures and slight declines in summer precipitation in southern Ontario may result in some drying of this species habitat, particularly during periods of drought (AMEC Earth & Environmental 2001; CCCSN 2007; Lemmen *et al.* 2008). Furthermore, the small and seemingly isolated population of this species, as well as the intense dependence on external temperature and environment

common to all amphibians, suggest that even small perturbations under climate change may have a negative impact on the Carolinian population of Alleghany Mountain Dusky Salamanders.

American Badger *jacksoni* subspecies (*Taxidea taxus jacksoni*)

Taxonomic Group: Mammals (Terrestrial)

Province: Ontario

Climate Change Impact: Neutral

The American Badger *jacksoni* subspecies occurs in the Great Lakes region of both the United States and Canada. The estimated population of the American Badger *jacksoni* subspecies in Canada is less than 200 individuals and the Canadian range of this species is primarily restricted to southwestern Ontario along the borders of Lake Erie and Lake Huron (SARA Public Registry 2008b). While climate change could influence the breeding time and duration of torpor (state of decreased physiological activity) of the American Badger *jacksoni* subspecies, these phenological traits are already known to be somewhat variable across individuals of this species (SARA Public Registry 2008b). Some scenarios project that climate change may favour the growth of grassland type landscapes in southern Ontario (Wood 2007), but any potential impacts to the American Badger are likely to be insignificant compared to the influence of habitat loss and fragmentation due to development in this region. Furthermore, the American Badger is an opportunistic feeder and the adaptability of this animal's diet may ensure relatively steady sources of food even if local plant and animal communities change under climate change (SARA Public Registry 2008b).

American Badger *jeffersonii* subspecies (*Taxidea taxus jeffersonii*)

Taxonomic Group: Mammals (Terrestrial)

Province: British Columbia

Climate Change Impact: Neutral

The American Badger *jeffersonii* subspecies occurs across western North America, as far south as California and as far north as the interior of southern British Columbia (SARA Public Registry 2008c). The American Badger *jeffersonii* subspecies lives in a variety of open habitats (primarily grassland, but also deserts, forest clearings, agricultural land, among others), and, although more detailed models are needed, landscape scale biome projections indicate that it not likely climate change will have a significant impact on the general availability of habitat for this species across its current range (SARA Public Registry 2008c; Wood 2007). Furthermore, the American Badger is an opportunistic feeder and is therefore better equipped to adapt to changes in biological communities within its range under climate change (SARA Public Registry 2008c). Finally, similar to its eastern counterpart (the *jacksoni* subspecies, above), the breeding time and duration of torpor of the American Badger *jeffersonii* subspecies is likely to be affected to some degree by climate change, but these phenological traits are already known to be variable among individuals in any given year and potential alterations of these patterns under climate change seem unlikely to have significant implications for the overall survival of the species.

American Chestnut (*Castanea dentata*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Neutral

The American Chestnut is a tall deciduous tree that occurs across the eastern United States and in the Carolinian zone of southern Ontario (COSEWIC 2004a). The American Chestnut used to be a dominant tree species across much of the eastern United States, but the introduction of the chestnut blight, a fungus imported with Japanese chestnut trees, eliminated most of the American Chestnut populations across North America during the 20th century (Anderson *et al.* 2004; COSEWIC 2004a). The chestnut blight often kills new American Chestnut trees before they become sexually mature; as a result, few mature American Chestnut trees exist in Canada (or the United States), and larger groups of trees are mostly affected by chestnut blight (COSEWIC 2004a). Carolinian-type forest systems may have the opportunity to expand their growing range in Canada under climate change if they are not limited by anthropogenic development (Malcolm *et al.* 2004; AMEC Earth & Environmental 2006). However, the inability of the American Chestnut to reproduce at a large scale is likely to prevent the natural establishment of trees in more northern regions and the aggressive nature of the chestnut blight and its history of rapid transference across large distances suggest that the blight could migrate with the American Chestnut under climate change. Potential recovery options may exist for the American Chestnut as research continues on the identification and use of natural resistance mechanisms to the chestnut blight (COSEWIC 2004a; Milgroom & Cortesi 2004). If a successful form of defense against the chestnut blight is realized for the American Chestnut, potential range changes under climate change should be considered in the restoration/reintroduction of this tree.

American Ginseng (*Panax quinquefolius*)

Taxonomic Group: Vascular Plants

Province: Ontario, Quebec

Climate Change Impact: Negative

In Canada, American Ginseng can be found in southern Ontario and southwestern Quebec, but it is considered naturally rare across its whole North American range (extending as far south as Louisiana and Georgia) (Nault & White 1999). The small, isolated and slow-to-mature populations of American Ginseng are known to be vulnerable to stochastic weather events (i.e., drought, ice storms), which are likely to become more frequent under climate change (Francis & Hengeveld 1998; Nault & White 1999; Gagnon *et al.* 2005; Lemmen *et al.* 2008). In a study by Gagnon *et al.* (2005), increased dormancy in adult American Ginseng plants, declining seed production and low growth rates were observed between 1998 and 2001 in American Ginseng populations in Tennessee and North Carolina and were attributed to drought events that occurred during the study period. Warmer temperatures and slight declines in summer precipitation projected across this species' range may increase the threat of drought during the American Ginseng growing season (CCCSN 2007; Lemmen *et al.* 2008). Furthermore, in an experimental greenhouse-based study by Jochum *et al.* (2007), a 5°C increase in the growing temperature of American Ginseng caused decreased photosynthesis, stomatal conductance and total plant biomass compared to plants grown at lower temperatures. In the range of projections by Lemmen *et al.* (2008) for eastern Ontario, the median change in average annual temperature was slightly greater than 5°C; this generally corresponds with CCCSN (2007) projections of mean summer temperature change across the southern Ontario – southwestern Quebec growing range of American Ginseng. It is therefore possible that wild American Ginseng plants may

experience the diminished growth trends associated with higher temperatures as demonstrated in Jochum *et al.*'s (2007) controlled study.

American Marten (Newfoundland Population (*Martes americana atrata*))

Taxonomic Group: Mammals (Terrestrial)

Province: Newfoundland

Climate Change Impact: Insufficient Information

The American Marten has a fairly wide range in North America, but the Newfoundland population is restricted to the island of Newfoundland and is one of few mammal species considered native to this region (COSEWIC 2007d). The status of the American Marten in Newfoundland was recently downgraded by COSEWIC (2007d) to threatened, but the species is still listed as endangered on Schedule 1 of SARA. Given that the American Marten is restricted to a limited geographic area and that a considerable portion of its current range occurs in protected areas, it may be vulnerable to shifts in its climatic range. Significant loss of the boreal forest biome is projected across the island of Newfoundland under climate change, but the American Marten is known to live in both coniferous and mixed wood forests and therefore may be adaptable to the temperate mixed forest biome that is projected to expand in this region (COSEWIC 2007d; Wood 2007). However, this species prefers mature forest areas, and is known to be sensitive to forest disturbances such as insect outbreaks that may become more frequent under climate change in the Atlantic region of Canada (COSEWIC 2007d; Lemmen *et al.* 2008). More information is also needed on the potential impact of climate change on populations of the American Marten's predator and prey species.

Atlantic Salmon (Inner Bay of Fundy populations) (*Salmo salar*)

Taxonomic Group: Fishes (Marine)

Province: New Brunswick, Nova Scotia, Atlantic Ocean

Climate Change Impact: Negative

The only population of salmon that is classified as endangered on Schedule 1 of SARA is the inner Bay of Fundy population of the Atlantic Salmon. This population spawns in rivers in Nova Scotia and New Brunswick, and moves into the Bay of Fundy in the late summer and remains until late autumn, but it is unknown where these fish spend their winters (COSEWIC 2006a). The Atlantic Salmon is a cool-water adapted species that requires clear aquatic habitats within specific temperatures ranges (COSEWIC 2006a). Under climate change, the Atlantic Salmon will be threatened by the loss of suitable habitat conditions and increased parasitism due to warmer water temperatures (Marcogliese 2001; Schindler 2001; El-Jabi *et al.* 2004; COSEWIC 2006a; Lemmen *et al.* 2008). El-Jabi *et al.* (2004) predict that Atlantic Salmon will be particularly affected by climate change during its spawning period in freshwater rivers. Lower-flowing rivers, which are projected to occur in Nova Scotia and New Brunswick over the next century, will affect the time at which the Atlantic salmon return to rivers to spawn and the accessibility of spawning habitat will be reduced (El-Jabi *et al.* 2004); another study of river flow regimes and Atlantic Salmon in England reached similar conclusions (Walsh & Kilsby 2007). There is evidence that Atlantic Salmon populations have already begun to be negatively impacted by climate change that has occurred over the last several decades (Swansburg *et al.* 2002; Beaugrand & Reid 2003; COSEWIC 2006a). Swansburg *et al.* (2002) found that increases

in air and water temperature were linked to decreases in the mean annual size of juvenile Atlantic Salmon between 1971 and 1999. More broadly, a study by Beaugrand & Reid (2003) found that climate change since the 1970s is linked to long-term decreases Atlantic Salmon populations in the northeast Atlantic Ocean, as well as significant changes in the phytoplankton and zooplankton populations, causing disruption to the equilibrium of northeast Atlantic pelagic ecosystem as a whole.

Atlantic Whitefish (*Coregonus huntsmani*)

Taxonomic Group: Fishes (Freshwater)

Province: Nova Scotia

Climate Change Impact: Negative

The Atlantic Whitefish is a species endemic to the eastern coast of Nova Scotia, moving inland into freshwater systems during the spawning period and returning to the open Atlantic Ocean during the spring (DFO 2006). However, the Atlantic Whitefish population has declined significantly over the past several decades and may currently be restricted to several small land-locked lakes in Nova Scotia, but exact population size is unknown (DFO 2006). Relatively little is known about the biology of this species, but it is likely that the Atlantic Whitefish will be threatened by climate change in a similar manner to the Atlantic Salmon (above). While more specific studies are needed, alterations in seasonal river flow and lake levels and increased water temperatures will likely affect the timing and success of Atlantic Whitefish spawning in Nova Scotia. If any individuals are still capable of migrating into the open ocean, alterations to the northern Atlantic trophic structure as a result of increased temperatures may also negatively affect the survival of the Atlantic Whitefish (as projected for northeast Atlantic Salmon populations by Beaugrand & Reid 2003).

Aurora Trout (*Salvelinus fontinalis timagamiensis*)

Taxonomic Group: Fishes (Freshwater)

Province: Ontario

Climate Change Impact: Negative

The Aurora Trout naturally occurs only in two small lakes in northeastern Ontario, but wild populations disappeared following lake acidification in the 1960s and have since been reintroduced into these two lakes and twelve others in the same region (Snucins & Gunn 2000; Aurora Trout Recovery Team 2006). While lake acidification remains a current threat to the Aurora Trout, climate change has been acknowledged as a significant concern for this species (Snucins & Gunn 2000; Aurora Trout Recovery Team 2006). Aurora Trout favour cold-water conditions, and, while no direct link with this species has been noted in existing research, other fish species in northern Ontario are currently experiencing increased mortality associated with warmer water temperatures (Aurora Trout Recovery Team 2006). Furthermore, it has been suggested that climate change could contribute to the re-acidification of lakes containing Aurora Trout depending on the abundance of sulphur in the lakes' watersheds (Aurora Trout Recovery Team 2006). This agrees with Yan *et al.* (1996), who found that a 1986-7 drought at Swan Lake in northern Ontario lowered water levels and exposed sulphur-containing sediment that was reoxidized, transported into the lake and contributed to acidification. Other preliminary studies on boreal lakes in northern Ontario have suggested that climate change-related declines in

dissolved organic carbon may influence the ability of lakes to buffer acidity, as well as affect the abundance and composition benthic communities and therefore the trophic structure as a whole (Schindler *et al.* 1997; Turner *et al.* 2001; Baulch *et al.* 2005).

Banff Springs Snail (*Physella johnsoni*)

Taxonomic Group: Mollusks

Province: Alberta

Climate Change Impact: Negative

The Banff Springs Snail is known to occur only in thermal springs in Banff National Park and is limited within each spring to very specific water temperature, quality and flow conditions (Lepitzki & Pacas 2007). The specialization of the Banff Springs Snail means that it is extremely sensitive to environmental change (Lepitzki 2002; Lepitzki & Pacas 2007). Water flow stoppages have been linked to the extirpation of the Banff Springs Snail from four thermal springs, and the influence of climate change threatens to alter water flow in remaining Banff Springs Snail habitat (Scott & Suffling 2000; Lepitzki 2002; Lepitzki & Pacas 2007). Precipitation in Banff National Park is expected to increase in the winter and spring, but decrease in summer and autumn, and Scott and Suffling (2000) project that these changes will cause thermal spring flow in the park to remain constant or decrease slightly. However, Grasby and Lepitzki (2002) have linked unusual seasonal flow stoppages to low precipitation years, and this variability may become more frequent under climate change. Furthermore, Scott and Jones (2005) project that climate change will increase tourism in Banff National Park and increased visitation at thermal springs could negatively impact the Banff Spring Snail by increasing the likelihood of human disturbance and contamination.

Barn Owl (Eastern Population) (*Tyto alba*)

Taxonomic Group: Birds

Province: Ontario, Quebec

Climate Change Impact: Positive

The eastern population of the Barn Owl is known to breed only in southern Ontario and possibly in southern Quebec (SARA Public Registry 2008d). The Barn Owl is at the northern limit of its range in Canada and populations are relatively sparse compared to U.S. populations (Solymár & McCracken 2002); while further study is needed on the potential range changes of this species under climate change, it is possible that the northward migration of individual birds from the U.S. under climate change could help to facilitate the repopulation of this species in Canada. Climate change may also positively impact the Canadian Barn Owl population by reducing the frequency of cold, severe winters, which is known to increase this species' mortality rate (SARA Public Registry 2008d). Although current threats to habitat availability in Canada require mitigation, in general, the open, vegetated areas preferred by the Barn Owl (i.e., pasture, grassland) are not projected to be significantly altered by climate change and some biome distribution scenarios project that climate change will favour the growth of open savannah type landscapes in southern Ontario (SARA Public Registry 2008d; Wood 2007). Furthermore, Gedir *et al.* (2004) suggest that the Barn Owl demonstrates significant promise for successful assisted reintroduction in Canada; this potential may be enhanced by the inclusion of climate change into the reintroduction process.

Barrens Willow (*Salix jejuna*)

Taxonomic Group: Vascular Plants

Province: Newfoundland

Climate Change Impact: Negative

The Barrens Willow is a dwarf, woody shrub that is endemic to a small coastal area in the northwest corner of Newfoundland (Djan-Chékar 2003). This species is adapted to a narrow range of environmental conditions, living in an arctic-like habitat with little vegetation that experiences harsh winters and variable summer temperatures (Djan-Chékar 2003). This species does not naturally exist in large numbers, but it is endangered by habitat loss and degradation, and the small population size of this species, its restricted distribution at the northern coast of its range and its preference for a cold climate suggest that this species will be negatively influenced by climate change (Djan-Chékar 2003). Warmer temperature projected across Newfoundland under climate change may negatively influence growing conditions, as well as increased competition from fast-colonizing vegetative species and herbivory by animals that were previously restricted to warmer southern areas of Newfoundland (CCCSN 2007; Lemmen *et al.* 2008). This species lives along the coastal zone of northwest Newfoundland, which is classified as low to moderately sensitive to sea level rise (Lemmen *et al.* 2008); while more localized information is needed, the potential for increased storm activity and related storm surge in Atlantic Canada may negatively impact the Barrens Willow.

Bashful Bulrush (*Trichophorum planifolium*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient information

According to White (2000), Canadian populations of the Bashful Bulrush is confined to the northwestern shore of Lake Ontario (near Toronto and Hamilton) and are currently in decline. This plant dwells only in the warmest, and most urbanized areas of Ontario, often on steep slopes where gentle to moderate natural disturbances occur. However, the environmental requirements throughout the full life cycle of this plant are not well-researched and it is unclear why the Bashful Bulrush does not occupy areas adjacent to its current locations that have been deemed suitable habitat (SARA Public Registry 2008e). Further information is required on the growing conditions of the Bashful Bulrush and the potential impact of climate change on them. This species is at the northern extent of its range in Canada, and may stand to benefit from warmer temperatures across its current Canadian range, but potential climate change benefits may be relatively negligible compared to the availability of suitable habitat and the isolation of current populations (Smith & Rothfels 2007).

Bearded Owl-clover (*Triphysaria versicolor versicolor*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Insufficient Information

The Bearded Owl-clover occurs along the western coast of the United States from California to Oregon, and an isolated population occurs at the southeastern corner of Vancouver Island in the Garry Oaks Maritime Meadows system (see also Bear's-foot Sanicle, Coastal Scouler's Catchfly, Golden Paintbrush, Prairie Lupine and Seaside Birds-foot Lotus) (Penny & Douglas 1999; Parks Canada Agency 2006a). The location of this species on southeastern Vancouver Island is subject to a rainshadow effect from nearby mountains and experiences wet, mild winters and warm, dry summers (Penny & Douglas 1999; Parks Canada Agency 2006a). This species exists at the northern extent of its range in Canada, but its small and isolated population combined with geographic limitations on dispersal makes it naturally vulnerable to climatic change. This species is tolerant of a range of moisture conditions, and soils in which it grows are prone to drought and usually approach the permanent wilting point by late summer (Parks Canada Agency 2006a). It is unknown how the Bearded Owl-Clover may respond to changes in hydrologic patterns, particularly during the summer when projected decreases in precipitation and warmer temperatures may increase soil moisture loss (Parks Canada Agency 2006a; CCCSN 2007; Lemmen *et al.* 2008). This species occurs in close proximity to coastal areas; however, while most of the coasts of southeastern Vancouver Island are considered low to moderately sensitive to sea level rise, the rocky nature of coasts in this region may counter some effects of sea level rise with respect to the Bearded Owl-clover (Neil 2001; Lemmen & Warren 2004; Lemmen *et al.* 2008). Furthermore, salt spray from the ocean and the tendency for summer drought are important to the maintenance of the open, meadow habitat in this region and prevent the establishment of other, less specialized vegetative competition that could threaten the Bearded Owl-clover (Parks Canada Agency 2006a).

Bear's-foot Sanicle (*Sanicula arctopoides*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Insufficient Information

The Bear's-foot Sanicle occurs along the western coast of the United States, extending south as far as central California and reaches its northern limit on the southeast corner of Vancouver Island and smaller nearby island in British Columbia (Parks Canada Agency 2006a). Similar to other endangered plant species in the Garry Oaks Maritime Meadows region, potential climate change impacts on the Bear's-foot Sanicle do not yield a clear overall pattern and require further research (see also Bearded Owl-clover, Coastal Scouler's Catchfly, Golden Paintbrush, Prairie Lupine and Seaside Birds-foot Lotus) (Parks Canada Agency 2006a). Although the Canadian populations of Bear's-foot Sanicle occur at the northern extent of the species North American range, the ability of this species to disperse is limited by lack of suitable connective habitat and geographic barriers. The region in which the Bear's-foot Sanicle grows is prone to summer drought and salt spray, which are also critical in the maintenance of maritime meadows habitat, but the potential effects of changes to soil moisture pattern and low to moderate sea level rise require further examination (Lemmen & Warren 2004; Parks Canada Agency 2006a; CCCSN 2007; Lemmen *et al.* 2008).

Benthic & Limnetic Enos Lake Stickleback (*Gasterosteus sp.*)

Taxonomic Group: Fishes (Freshwater)

Province: British Columbia

Climate Change Impact: Negative

Stickleback are freshwater fishes that occur in three separate locations in southern, coastal British Columbia; each species has evolved independently to become behaviourally, morphologically and genetically distinct from the others and all are endemic to Canada. Within each location, two species exist as “stickleback pairs” that have distinct benthic and limnetic lifestyles, although some hybridization of these species is known to occur (see also Benthic & Limnetic Paxton Lake and Vandana Creek Stickleback pairs below) (National Recovery Team for Stickleback Species Pairs 2007). The Benthic and Limnetic Enos Lake Stickleback occur only in Enos Lake, a small body of water near the southeastern coast of Vancouver Island, and are the most critically endangered, as the fish in this lake are more prone to hybridization than other species (COSEWIC 2002a). Possible negative impacts to these species under climate change include warmer water temperatures and lower water flow (particularly in the late summer) and associated effects, such as decreased water quality via increased concentrations of pollutants and sediments and lower dissolved oxygen levels (Taylor & Taylor 1997; Lemmen & Warren 2004; Lemmen *et al.* 2008). Moreover, because these fish are isolated in a single lake, their ability to migrate to new areas is limited if their habitat becomes unsuitable (Taylor & Taylor 1997). Competition with exotic fish species, which is a current threat to Stickleback populations, is also predicted to increase under climate change (Taylor & Taylor 1997).

Benthic & Limnetic Paxton Lake Stickleback (*Gasterosteus sp.*)

Taxonomic Group: Fishes (Freshwater)

Province: British Columbia

Climate Change Impact: Negative

The Benthic and Limnetic Paxton Lake Stickleback pair occur in Paxton Lake on Texada Island, located in between Vancouver Island and mainland British Columbia (see Benthic & Limnetic Enos Lake Stickleback, above, for more information on Stickleback pairs) (SARA Public Registry 2008f & g). Populations of both these species are believed to be stable (SARA Public Registry 2008f & g), but climate change is likely to impact them in the same manner as the Enos Lake (above) and Vandana Creek (below) Stickleback. Climate change impacts such as warmer water temperatures, lower water flows, decreased water quality and increased competition with exotic species are all likely to negatively influence these species, and their isolated nature and limited ability for dispersal mean that migration to new habitat is unlikely if current Paxton Lake habitat becomes unsuitable (Taylor & Taylor 1997; Lemmen & Warren 2004; Lemmen *et al.* 2008).

Benthic & Limnetic Vananda Creek Stickleback (*Gasterosteus sp.*)

Taxonomic Group: Fishes (Freshwater)

Province: British Columbia

Climate Change Impact: Negative

The Benthic and Limnetic Vananda Lake Stickleback pair are known to occur in Balkwill, Emily and Priest Lakes, located in the Vananda Creek watershed on Texada Island (see Benthic & Limnetic Enos Lake Stickleback, above, for more information on Stickleback pairs) (SARA Public Registry 2008h & i). Populations of both these species are believed to be stable in the

Vananda Creek watershed (SARA Public Registry 2008h&i), but climate change is likely to impact them in the same manner as the Enos and Paxton Lake Stickleback (above). Climate change impacts such as warmer water temperatures, lower water flows, decreased water quality and increased competition with exotic species are all likely to negatively influence these species, and their isolated nature and limited ability for dispersal mean that migration to new habitat is unlikely if current lake habitat in the Vandana Creek watershed becomes unsuitable (Taylor & Taylor 1997; Lemmen & Warren 2004; Lemmen *et al.* 2008).

Bird's-foot Violet (*Viola pedata*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

In Canada, the Bird's-foot Violet is found only as small, isolated populations in southern Ontario that are separate from the main population found in the eastern United States (COSEWIC 2002b). Four of six plant growing range projections by NRCan (2007) indicate that the core range of the Bird's-foot Violet will shift northward into southern Ontario and other parts of southern Canada by 2071-2100. However, while these growing range projections suggest that climate change has the potential to further support Canadian populations of this species, the Bird's-foot Violet is known to grow only in certain habitats, primarily open, black oak savannah forests that are subject to periodic disturbance (COSEWIC 2002b). This type of habitat currently occurs in developed areas of southern Ontario and the influence of climate change on the future distribution of this type of habitat requires more detailed information (COSEWIC 2002b).

Blanding's Turtle (Nova Scotia Population) (*Emydoidea blandingii*)

Taxonomic Group: Reptiles

Province: Nova Scotia

Climate Change Impact: Negative

Blanding's Turtle is a freshwater species, that is classified as threatened in Ontario and Quebec and endangered in Nova Scotia, where a population of less than 250 individuals resides (mostly in Kejimikujic National Park) and is thought to be particularly vulnerable to climate change (Scott & Suffling 2000; Blanding's Turtle Recovery Team 2002; COSEWIC 2005a). The Nova Scotia population is small and isolated, and recent research by Mockford *et al.* (2004) suggests that several sub-populations of Blanding's Turtle exist in Nova Scotia that exchange less genetic material than previously thought, which may further limit the survival of the Nova Scotia population. Blanding's Turtle has very specific habitat needs in terms of water quality, water level, local vegetation and substrate that are likely to be altered under climate change, and the strong-site affinity demonstrated by this species may hinder natural survival as habitat conditions change (Herman & Scott 1994 as cited in Scott & Suffling 2000; Blanding's Turtle Recovery Team 2002). The Blanding's Turtle Recovery Team (2002) also suggests that the current primary threats to this species could all potentially be exacerbated under climate change: predation levels may increase as a result of decreased winter mortality in predators (i.e., raccoons); altered water levels and patterns could increase nest flooding; and, reduced ice-scour

and overgrowth of vegetation on nesting beaches may affect the availability and success of nesting substrate during the egg incubation period.

Blue Racer (*Coluber constrictor foxii*)

Taxonomic Group: Reptiles

Province: Ontario

Climate Change Impact: Negative

While considered relatively common in its range across the northern United States Great Lakes region, the Canadian population of the Blue Racer is currently restricted to Pelee Island at the tip of southern Ontario in Lake Erie (Wilson & Rouse 2002). Although the Blue Racer is at the northern limit of its range in Canada and Canadian populations of this species may benefit somewhat from warmer conditions if the core climatic range of this species shifts northward, the potential for dispersal of the Pelee Island populations is limited by habitat availability and geographic isolation, and repopulation of this species in southern Ontario from American populations will likely be limited by the high degree of development across this region. Furthermore, climate change is generally considered to be of particular concern for reptiles: in Canada, more frequent winter thaws may disrupt reptile hibernation periods and studies of North American turtles has shown that climate change may influence sex determination of hatchlings, although similar evidence has not been demonstrated for snakes (Janzen 1994; Seburn & Seburn 2000; Walther *et al.* 2002). More information is needed on how future projections of declining water levels in Lake Erie may influence the habitat of the Blue Racer, but impacts may be relatively negligible compared to the current threat of habitat loss from continuing development on the island (Wilson & Rouse 2002; AMEC Earth & Environmental 2006). Climate change will likely play a role in exacerbating the current threat of human disturbance to the Blue Racer, as the recreational season (during which this species is active) may lengthen and intensify, increasing the rate of accidental killings and disruption of Blue Racer habitat (Wilson & Rouse 2002; Scott & Jones 2006).

Blue Whale (Atlantic Ocean) (*Balaenoptera musculus*)

Taxonomic Group: Mammals (Marine)

Province: Atlantic Ocean

Climate Change Impact: Negative

The Atlantic population of the Blue Whale is known to occur in the Gulf of the St. Lawrence and off eastern Nova Scotia during the spring, summer and autumn, and off the southern coast of Newfoundland and in the Davis Strait during the summer (Sears & Calambokidis 2002). While the Blue Whale became endangered primarily because of commercial whaling, current threats to the continued survival of the species include human disturbance and pollution, and climate change has also been identified as a negative threat to this species because of its relation to the abundance of the zooplankton, the primary food source of the Blue Whale (Sears & Calambokidis 2002; Gregr *et al.* 2006). Recent research suggests that sea surface warming in the northeast Atlantic is already linked to changes in its marine food web and future warming is likely produce impacts throughout the whole ecological system (Beaugrand & Reid 2003; Richardson & Schoeman 2004; Hays *et al.* 2005; Learmonth *et al.* 2006). Other research specific to Antarctic populations of the Blue Whale indicates that zooplankton populations will

decline as a result of sea ice loss, which will adversely affect Blue Whale populations in this region (WWF 2001; Walther *et al.* 2002).

Blue Whale (Pacific Ocean) (*Balaenoptera musculus*)

Taxonomic Group: Mammals (Marine)

Province: Pacific Ocean

Climate Change Impact: Negative

The Pacific population of the Blue Whale is known to occur off the coast of British Columbia during its spring and fall migrations (Sears & Calambokidis 2002). Pacific populations of the Blue Whale are known to be responsive to climate variability and, although the Pacific Blue Whale food web is less studied than that of the Atlantic Blue Whale (above), under long-term climate change similar changes in abundance of the zooplankton prey are inferred for the Pacific population (Gregar *et al.* 2006).

Bluehearts (*Buchnera americana*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Negative

In Canada, Bluehearts exist only along a 10km stretch of the southeastern shore of Lake Huron and annual monitoring data suggest that the population has been decreasing over the past several decades (Brownell 1998). Although this species is at the northern limit of its range, its small, isolated population and the specialized nature of its habitat limits its ability to disperse and makes it vulnerable to environmental change. Bluehearts live near wet areas, often in depressions between sand dunes, and require fluctuating water level for survival (Brownell 1998). Lake Huron water levels are expected to decrease by up to 1.4m by the end of this century, meaning that Bluehearts could be increasingly threatened by potential losses of wet, interdunal areas and competition from successive vegetation capitalizing on the receding shoreline (AMEC Earth & Environmental 2006). Periods of drought are known to reduce Bluehearts populations and increased risk of drought is predicted for several regions along the Lake Huron shoreline in Ontario under climate change (Brownell 1998; AMEC Earth & Environmental 2006). This species is also threatened by cottage development and human recreational activities and climate change-related increases in tourism and recreation may intensify this threat during the summer (Brownell 1998; Scott & Jones 2006).

Blunt-lobed Woodsia (*Woodsia obtusa*)

Taxonomic Group: Vascular Plants

Province: Ontario, Quebec

Climate Change Impact: Insufficient Information

The Blunt-lobed Woodsia occurs across the eastern United States and in southeastern Ontario and southern Quebec (COSEWIC 2006b). Given that this species is at the northern extent of its range and shows signs of recovery in Canada, it may benefit from a northward shift in its climatic growing range. However, this species is known to be naturally limited by the availability of its habitat (forested slopes with shallows soils overlaying calcareous rock), and it

is unknown if suitable, connective habitat exists to facilitate the dispersal of this species (COSEWIC 2006b). COSEWIC (2006b) lists water availability as another limiting factor for the Blunt-lobed Woodsia and suggests that lack of water limits the establishment of individual plants in the current habitat of this species. Climate change-related changes in precipitation and temperature are also likely to impact the local hydrologic regime of this species' habitat. Evidence suggests that this species benefits from a higher input of water but, while annual precipitation rate across its current Canadian range is projected to increase slightly, more information is needed on the potential impacts of seasonal changes in precipitation patterns, particularly during the summer when precipitation is expected to experience declines (CCCSN 2007; Lemmen *et al.* 2008).

Bog Bird's-foot Trefoil (*Lotus pinnatus*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Negative

The Bog Bird's-foot Trefoil is a perennial herb that grows along the western coast of North America, from central California to the southeastern coast of Vancouver Island and nearby islands of British Columbia, where it is at the northernmost extent of its range and exists in isolation of southern plants (Donovan 2004). This species is known to grow in ephemeral wet areas in the Garry Oak ecosystems in this region, which is also home to several other endangered species dependent on ephemeral wet areas (see also Dwarf Sandwort, Kellogg's Rush, Rosy Owl Clover, Tall Woolly-heads and Water Plantain Buttercup) (Parks Canada Agency 2006b). The dynamic nature of ephemeral wet areas is closely linked to temperature and precipitation patterns and they are likely to be greatly affected by climate variability and long-term climate change (Graham 2004 as cited in Parks Canada Agency 2006b). Higher temperatures and decreased summer precipitation projected for southern Vancouver Island over the next century will likely result in earlier and more rapid drying of vernal pool/seep habitat, which can result in a shortened growing season and lower seed production (M. Fairbarns, pers. comm., 2005 as cited in Parks Canada Agency 2006b; CCCSN 2007). Although the impacts of projected precipitation and temperature change during the autumn and winter wetting periods of vernal pool/seep habitat on the Bog Bird's-foot Trefoil is unknown, Graham (2004 as cited in Parks Canada Agency 2006b) suggests that any shift in wetting and drying patterns is likely to change the relative composition of ecological communities in the system, and the small and isolated populations of this species are more likely to be vulnerable to such changes. Furthermore, many ephemeral wet areas on Vancouver Island are located just above the coastal intertidal zone and are believed to be threatened by marine pollution transported by salt spray during storm events (Parks Canada Agency 2006b); southern Vancouver Island is classified as having a low to moderate sensitivity to sea level rise and it is possible that sea level rise and more frequent storm events may increase the transport of marine pollution to vernal pool habitat (Lemmen & Warren 2004). Climate change may also play a role in exacerbating current threats of human disturbance from recreation activities during warmer spring and summer recreational seasons (Parks Canada Agency 2006b; Scott & Jones 2006).

Boreal Felt Lichen (Atlantic Population) (*Erioderma pedicellatum*)

Taxonomic Group: Lichens

Province: New Brunswick, Nova Scotia
Climate Change Impact: Negative

Canada is believed to be host to the only remaining populations of Boreal Felt Lichen. The Atlantic population of this species has experienced significant declines and only 13 individuals exist at three sites of cool, moist forest habitat in eastern Nova Scotia (Maass & Yetman 2002). The Boreal Felt Lichen is particularly sensitive to climate and is considered a useful indicator species for monitoring overall ecosystem change in response to climate change (Maass & Yetman 2002; Cameron 2004). Its small population, limited distribution and affinity for boreal/northern host trees make the Boreal Felt Lichen naturally vulnerable to climate change; it is thought that climate change has and will continue to be a negative influence on the survival of this species because of changes in the abundance of host tree species and changes in local climate conditions (Maass & Yetman 2002; Cameron 2004; Environment Canada 2007). Furthermore, current threats to the Boreal Felt Lichen from forest fire, drought and destruction by hurricanes are likely to be exacerbated by climate change (Maass & Yetman 2002; Environment Canada 2007a; Lemmen *et al.* 2008).

Branched Phacelia (*Phacelia ramosissima*)

Taxonomic Group: Vascular Plants
Province: British Columbia
Climate Change Impact: Neutral

Branched Phacelia is at the northern extent of its range in the Okanagan Valley in south-central British Columbia and is restricted to a relatively small total population that occurs on the slopes of Mount Kruger, where it is known to live only on dry talus slopes near the base of rocky outcrops (COSEWIC 2005b). This species is thought to have always occurred rarely in Canada because it is at the northern extent of its range and exists in specialized and naturally limited habitat (COSEWIC 2005b). While this specialization and the small Canadian population of Branched Phacelia make it inherently vulnerable to any environmental changes, long-term climate change is unlikely to have a significant impact on the overall survival of this species in its current location. Although increased annual temperatures and changes to precipitation patterns are expected in south-central British Columbia under climate change, Branched Phacelia is known to be drought-tolerant during dry summer conditions, is accustomed to some land-slope disturbances that might be increasingly associated with wetter conditions projected during the winter and early spring (COSEWIC 2005b; CCCSN 2007; Lemmen *et al.* 2008). Since the species is at the northernmost extent of its range in Canada, increased annual temperatures may expand the growing range of this species in Canada, but its ability to disperse will likely be limited by lack of suitable, connective habitat

Burrowing Owl (*Athene cunicularia*)

Taxonomic Group: Birds
Province: British Columbia, Alberta, Saskatchewan, Manitoba
Climate Change Impact: Insufficient Information

The Burrowing Owl's current breeding range extends across much of the western United States and into southern Alberta and Quebec in Canada, but the species has declined significantly in

recent decades in terms of both population and range and is now extirpated from British Columbia and Manitoba, where it historically occurred (COSEWIC 2006c). Burrowing Owls live in grassland areas with mixed types of short vegetation that can support a variety of prey species (COSEWIC 2006c). Although such vegetation may increase in area in the prairie regions under climate change according to biome projections (Wood 2007), more information is needed on how climate change will affect the prey of Burrowing Owl and its habitat in its overwintering sites. The species has also been in rapid decline in Canada and the United States, and, while this decline has been attributed to a variety of stressors, especially habitat loss, it is unclear why some apparently suitable habitat areas are unoccupied by the Burrowing Owl or why more owls emigrate out of Canada to the United States than immigrate in (COSEWIC 2006c).

Butternut (*Juglans cinerea*)

Taxonomic Group: Vascular Plants

Province: Ontario, Quebec, New Brunswick

Climate Change Impact: Neutral

The range of the Butternut tree extends across the northwestern United States, southern Ontario and Quebec and parts of New Brunswick (Nielson *et al.* 2003). The primary threat to the Butternut is the butternut canker, which is an invasive fungus that has spread from the United States to all three Canadian provinces in which the Butternut is found (Nielson *et al.* 2003). In a total of six scenarios by NRCAN (2007), the growing range of the Butternut is projected to shift northward into Canada under climate change by 2071-2100 and in four of these six scenarios, the core population of this species is projected to expand in Canada. However, given that there are currently no successful means of controlling the butternut canker, this threat can be expected to shift its growing range with the Butternut tree. Moreover, the disjunctive nature in which the Butternut grows and the degree of habitat fragmentation across its current range means that this species will have difficulty dispersing to new regions, particularly if currently suitable habitat becomes altered due to climate change (Columbo *et al.* 1998; Nielson *et al.* 2003).

Coastal Scouler's Catchfly (*Silene scouleri grandis*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Insufficient Information

The range of Coastal Scouler's Catchfly extends from central California north to three small islands off the southeast corner of Vancouver Island in British Columbia (Fairbanks & Wilkinson 2003). Coastal Scouler's Catchfly is an endangered flowering plant of the Garry Oaks Maritime Meadows landscape and, similar to other endangered species in this region, the potential climate change impacts on Coastal Scouler's Catchfly do not yield a clear overall pattern (see also Bearded Owl-clover, Bear's-foot Sanicle, Golden Paintbrush, Prairie Lupine and Seaside Birds-foot Lotus) (Parks Canada Agency 2006a). Although the Canadian populations of Coastal Scouler's Catchfly occur at the northern extent of its North American range, the ability of this species to disperse is limited by lack of suitable connective habitat and broader geographic barriers. The region in which Coastal Scouler's Catchfly grows is prone to summer drought and salt spray, which are important in the maintenance of maritime meadows

habitat, but the potential effect of changes to soil moisture patterns and low to moderate sea level rise and storm activity requires further examination (Lemmen & Warren 2004; Parks Canada Agency 2006a; CCCSN 2007; Lemmen *et al.* 2008). Coastal Scouler's Catchfly reproduction is particularly dependent on seasonal weather cues and climate change may play a significant role in this species' reproductive success (Parks Canada Agency 2006a). The locations in which this species resides are also active sites for human recreation activities, and lengthened recreational season due to climate change may exacerbate current threats from human disturbance (Fairbanks & Wilkinson 2003; Scott & Jones 2006).

Cucumber Tree (*Magnolia acuminata*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Negative

The Cucumber Tree is a rare species that occurs in southwestern Ontario along the shores of Lakes Erie and Ontario and across the eastern United States (Ambrose & Kirk 2007). Although this species is at the northern limit of its range in Canada, the small, isolated populations of the Cucumber Tree and its highly fragmented habitat will limit this species ability to disperse or adapt should current suitable habitat conditions be altered as a result of climate change (Ambrose & Kirk 2007). In southern Ontario, decreased summer precipitation and warmer temperatures will lead to higher risk of drought periods (AMEC Earth & Environmental 2006; CCCSN 2007; Lemmen *et al.* 2008). The Cucumber Tree lives in moist, open forest area and does not grow well in overly wet or dry soil (Ambrose & Kirk 2007); therefore, climate change-related alterations in seasonal soil moisture regimes can be regarded as a potential threat to this species in southern Ontario.

Deltoid Balsamroot (*Balsamorhiza deltoidea*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Neutral

The Deltoid Balsamroot occurs along the western coast of North America and reaches its northernmost extent in Canada, where it is restricted to the southeastern corner of Vancouver Island in British Columbia (Ryan & Douglas 1999; Parks Canada Agency 2006c). The Deltoid Balsamroot lives in Garry Oak woodland ecosystem in open or partially shaded areas with shallow soils (see also Howell's Triteleia and Small-flowered Tonella) (Ryan & Douglas 1999; Parks Canada Agency 2006c). Although this species is at the northern limit of its range in Canada, the currently small and isolated populations of this species in Canada, the intense threat of habitat loss and fragmentation in its current location and the species' limited ability for dispersal will make it difficult for the species to capitalize on possibly ameliorated growing conditions (Parks Canada Agency 2006c). The Deltoid Balsamroot is well-adapted to and in fact prefers extreme drought-like conditions during the summer; this means that it will not likely be significantly affected by projected warmer and drier summers and may have a competitive edge with respect to some other species in its current habitat as climate change progresses, although threats from invasive species may increase (Parks Canada Agency 2006c; CCCSN 2007; Lemmen *et al.* 2008).

Dense Spike-primrose (*Epilobium densiflorum*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Neutral

The range of the Dense Spike-primrose occurs in western North America from California to as far north as the southeastern corner of Vancouver Island, where four small and isolated populations remain, as the majority of suitable Garry Oak habitat for this species has been lost or become very fragmented due to human activities (COSEWIC 2005c). The climatic features of this species' habitat include mild, wet winters and warm, dry summers, and the Dense Spike-primrose is capable of surviving in this extreme range of conditions: plants continue to mature during very dry conditions in the summer and seeds are known to be tolerant of submergence during periods of winter or spring flooding (COSEWIC 2005c). Climate change projections suggest that these conditions may be exacerbated in the future, with winters becoming warmer and slightly wetter and summers becoming hotter and drier (CCCSN 2007). Although the small population and fragmented remaining habitat of this species make it vulnerable to any environmental changes or stochastic events, this species' tolerance for a wider range of climatic conditions and its situation at the northern periphery of its range suggests that it may be better adapted than other species in this region to cope with long-term climate change. However, geographic isolation of the Dense Spike-primrose in Canada and the limitations of suitable, available habitat suggest that possible dispersal of current populations is unlikely even if its climatic growing range expands in Canada.

Dense-flowered Lupine (*Lupinus densiflorus*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Negative

In Canada, the Dense-flowered Lupine exists only at the southern coastal tip of Vancouver Island, British Columbia where it is isolated from the rest of its range in Washington and along the coast of California (COSEWIC 2005d). Although the species is at the northern limit of its range in Canada and biome composition is not projected to change significantly on Vancouver Island, the small and isolated populations of Dense-flowered Lupine have limited ability to disperse due to habitat fragmentation if the already restricted locations of become unsuitable (COSEWIC 2005d). Impacts from higher temperatures and altered precipitation patterns on current populations of this species are unknown, but increased risk of drought due to drier and warmer summers may threaten current populations that already grow in less-than-ideal soil conditions (CCCSN 2007). Furthermore, this plant is currently considered sensitive to marine pollution due to the close proximity of populations to the coast; this threat will become increasingly relevant as sea level rises and the risk from severe storms intensifies (Lemmen & Warren 2004; COSEWIC 2005d; Lemmen *et al.* 2008). The current, identified threat of human disturbance due to recreational land-use is also likely to be exacerbated by climate change during the growing period of the Dense-flowered Lupine as recreational periods become warmer and lengthen (COSEWIC 2005d; Scott & Jones 2006).

Drooping Trillium (*Trillium flexipes*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Neutral

The range of the Drooping Trillium extends across the eastern United States, but in Canada, the species exists only in the Carolinian Zone of southern Ontario; extant populations have been confirmed in only two areas (Strathroy and Dunwich) and other populations in southern Ontario are believed to be extirpated (SARA Public Registry 2008j). The survival of this species in Canada is very immediately threatened by habitat loss, and continued modification to its remaining habitat and threats from disease and pests indicate that the natural recovery of this species is unlikely in Ontario without managerial assistance (SARA Public Registry 2008j). Although this species exists at the northern extent of its range in Canada and has the potential to experience some benefits under a warmer climate, overall climate change impacts are likely to be negligible for this species relative to current threats. However, climate change should be factored into any reintroduction initiatives for this species in Canada.

Dwarf Sandwort (*Minuartia pusilla*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Negative

The Dwarf Sandwort occurs in isolated areas along the western coast of North America, from northern California to southern Vancouver Island in British Columbia, where it occurs as a single population located in a vernal seep in part of the larger Garry Oak ecosystem (see also Bog Bird's-foot Trefoil, Kellogg's Rush, Rosy Owl Clover, Tall Woolly-heads and Water Plantain Buttercup) (Penny & Costanzo 2004; Parks Canada Agency 2006b). The hydrologic regime of the vernal seep habitat of the Dwarf Sandwort is closely linked to temperature and precipitation patterns, and year-to-year changes in these patterns are known to cause fluctuations of the Dwarf Sandwort population (Penny & Costanzo 2004). The projected shift towards warmer temperatures and drier summer conditions over the next century will likely cause earlier and more rapid drying of vernal seep habitat, which can result in a shortened growing season and lower seed production (M. Fairbarns, pers. comm., 2005 as cited in Parks Canada Agency 2006b; CCCSN 2007). Penny and Costanzo (2004) suggest that the remaining Canadian population of Dwarf Sandwort is unlikely to be sufficiently adaptable to survive the impacts of climate change on the hydrologic regime of its habitat. Furthermore, as with other endangered species inhabiting ephemeral wet areas in this region, current threats from marine pollution and human disturbance due to recreation activities may be exacerbated by climate change related sea level rise and warmer and lengthened recreation periods (Lemmen & Warren 2004; Parks Canada Agency 2006b; Scott & Jones 2006; Lemmen *et al.* 2008).

Eastern Mountain Avens (*Geum peckii*)

Taxonomic Group: Vascular Plants

Province: Nova Scotia

Climate Change Impact: Insufficient Information

The Eastern Mountain Avens is a perennial herb that occurs only in the White Mountains of New Hampshire and on Brier Island and Digby Neck at the southwest coast of Nova Scotia (SARA Public Registry 2008k). Canadian populations of Eastern Mountain Avens occur in wet, boggy areas with shrub-like vegetation (SARA Public Registry 2008k). Both annual and summer precipitation are projected to slightly increase in this region by the 2080s, which may help to counteract the drying effect of higher temperatures that could threaten Eastern Mountain Avens habitat (CCCSN 2007; Lemmen *et al.* 2008). This species occurs in close (but not direct) proximity to the coast, and more specific information is needed on the potential of sea level rise to alter Eastern Mountain Avens habitat, as well as influence current threats from nearby gull colonies.

Eastern Prairie Fringed-orchid (*Platanthera leucophaea*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Negative

The Eastern Prairie Fringed-orchid has a scattered distribution across southern and eastern Ontario, living in remnant wetland and wet prairie habitat (COSEWIC 2003a). Although this species possesses adaptations to survive periodic seasons of drought, more frequent years of warmer and drier conditions projected for the summer growing season of this region may have a negative impact on this species, particularly when combined with the current threat of changes in water table level from agricultural water use (COSEWIC 2003a; CCCSN 2007; Lemmen *et al.* 2008). Successive dry growing seasons will also exacerbate threats from vegetation succession and competition with other species less dependent on wet conditions (COSEWIC 2003a). Pollination of the Eastern Prairie Fringed-orchid occurs specifically by hawkmoths (COSEWIC 2003a). Although the specific impact of climate change on the hawkmoth and the pollination of Eastern Prairie Fringed-orchids requires further investigation, other studies have demonstrated that the range, abundance and migration time of moths in other parts of the world have already begun to respond to climate change (i.e., Roy & Sparks 2000; Sparks *et al.* 2005).

Eastern Prickly Pear Cactus (*Opuntia humifusa*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Negative

In Canada, the Eastern Prickly Pear Cactus exists at the northern edge of its range on Pelee Island and in Point Pelee National Park in southern Ontario, where it lives on dry, sand spits that jut into Lake Erie (White 1998a). In four of six climate change growing range projections, the core range of the Eastern Prickly Pear Cactus was expected to shift further into southern Ontario by 2071-2100 (NRCAN 2007). However, while the growth of this species in Canada may benefit from warmer temperatures, the required habitat of the Eastern Prickly Pear Cactus occurs rarely in southern Ontario and current habitat of the two extant populations is relatively isolated, limited and vulnerable to climate change impacts (White 1998a). More intense storm activity will increase threats of periodic habitat erosion. Over the long-term, declines in Lake Erie water levels will increase the rate of encroachment of successional vegetation that will compete with and shade out the Eastern Prickly Pear Cactus, which is unlikely to be capable of dispersing to

new habitat (White 1998a; AMEC Earth & Environmental 2006). Current threats of human disturbance due to tourism and recreation may also be exacerbated by climate change as summer recreational periods warmer and lengthen (White 1998a; Scott & Jones 2006).

Engelmann's Quillwort (*Isoetes engelmannii*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Negative

Engelmann's Quillwort is an aquatic plant that is rare in southern Ontario, occurring in only two regions that are disjunct from American populations of the species (Engelmann's Quillwort Recovery Team 2007). Engelmann's Quillwort grows as a submergent (or occasionally emergent in late summer) plant along shallow shorelines. The Engelmann's Quillwort Recovery Team (2007) identified long-term changes in water levels as a result of both flow control and climate change as a potential threat to this species. Changes in river water flow are expected in terms of both timing and flow rate in southern Ontario: increased variability during spring melt and decreased river flow during the late summer may be of particular concern to the habitat of this species (AMEC Earth & Environmental 2006; Lemmen *et al.* 2008).

Eskimo Curlew (*Numenius borealis*)

Taxonomic Group: Birds

Province: Northwest Territories, Nunavut, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, Prince Edward Island, Nova Scotia, Newfoundland

Climate Change Impact: Negative

The Eskimo Curlew was formerly abundant and widespread in Canada; it bred most commonly in the Mackenzie District of the Northwest Territories, but during its migration from its overwintering sites in South America, it could be found in all provinces except British Columbia (Environment Canada 2007b). However, extensive hunting and, more recently, habitat change resulted in dramatic declines of the species (Environment Canada 2007b). The Eskimo Curlew may currently be extinct and recovery activities for the species (aside from continued monitoring) were suspended in 1995 pending verification of the species' existence (Environment Canada 2007b). Climate change has been suggested as a potential contributing factor to the more recent decline of this species and if the Eskimo Curlew is still in existence in Canada, projected northward shifts and alterations to its breeding habitat in the transition zone between tundra/taiga and woodland areas and warming of the northern coastal and freshwater ecosystems used during breeding will negatively affect this species (Schindler 2001; Prowse *et al.* 2006; Wood 2007).

False Hop Sedge (*Carex lupuliformis*)

Taxonomic Group: Vascular Plants

Province: Ontario, Quebec

Climate Change Impact: Insufficient Information

False Hop Sedge occurs sporadically across the eastern United States and in southern Ontario and southern Quebec (SARA Public Registry 2008l). This species is currently thought to be

partially limited in Canada partially by climatic factors and therefore may benefit from warmer conditions under climate change (SARA Public Registry 2008l). Five of eight climate change growing range projections for the closely related, albeit less rare species Hop Sedge (*Carex lupulina*) demonstrated a shift in its core growing range further into southern and central Ontario and other parts of eastern Canada (NRCan 2007). Similar shifts in potential growing range of False Hop Sedge may be expected under climate change. However, False Hop Sedge usually grows in ephemeral wet areas and the habitat at the five locations where this species still exists in Canada is likely to be sensitive to changes in local hydrologic regime and may be threatened by drier summer periods, particularly during more extreme conditions (SARA Public Registry 2008l; CCCSN 2007; Lemmen *et al.* 2008). Small and isolated populations and fragmentation of available habitat will limit this species ability to disperse to new areas should current locations become unsuitable.

Forked Three-awned Grass (*Aristida basiramea*)

Taxonomic Group: Vascular Plants

Province: Ontario, Quebec

Climate Change Impact: Positive

Forked Three-awned Grass is abundant in areas of the midwestern United States, but this species is at its northern most limit in Canada and is known to grown only in localized populations in central Ontario and southern Quebec (COSEWIC 2002c). Forked Three-awned Grass is a late maturing plant and is thought to be partially limited in Canada due to the shorter length of the growing season relative to the core range of this species (Jones 2007). Projected increased temperatures (especially during summer and autumn) across the current Canadian range of the Forked Three-awned Grass will lengthen growing season, thereby reducing the climatic restrictions on the growth of this species in Canada (CCCSN 2007; Lemmen *et al.* 2008). Forked Three-awned Grass lives on open, barren, sandy habitat, which is rare in Canada and threatened by succession (due to suppression of disturbances and natural landscape dynamics), and habitat loss/modification (COSEWIC 2002c; Jones 2007). However, if the quality and quantity of current habitat is maintained (or improved) it is likely possible for climate change to have a positive net impact on Canadian populations of Forked Three-awned Grass.

Furbish's Lousewort (*Pedicularis furbishiae*)

Taxonomic Group: Vascular Plants

Province: New Brunswick

Climate Change Impact: Negative

Furbish's Lousewort is a perennial herb that is known to exist only along the shoreline of the St. John River, occurring at 18 individual sites in Maine and three sites in New Brunswick (SARA Public Registry 2008m). Plants are known to grow on the slopes of river banks, in areas where they are subject to some disturbance from ice scouring and flooding, which is thought to help distribute seeds and remove competing vegetation (U.S. Fish & Wildlife Service 2005). The dynamic habitat needs of Furbish's Lousewort means that it will be affected by changes in river flow amount and timing under climate change. According to Bruce *et al.* (2003), both annual and maximum river flow in the St. John River has declined since 1970 and continued long-term declines may result in the encroachment of successional vegetation. However, this river may

also be at increased risk of severe flooding as more intense, short-term rainfalls have begun to coincide more closely with periods of snowmelt (Bruce *et al.* 2003). The low number of individual plants, specific habitat needs, limited distribution and low genetic variation of current populations of Furbish's Lousewort make it vulnerable to extreme events, like severe floods, that cause more damage than benefit (Waller *et al.* 1987; U.S. Fish & Wildlife Service 2005).

Gattinger's Agalinis (*Agalinis gattingeri*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

In Canada, Gattinger's Agalinis exists at the northern extent of its range in isolated sites near the eastern shore of Lake Huron (in Manitoulin and Bruce Counties, bordering Georgian Bay) and on Squirrel and Walpole Islands in the Lake St. Clair region (SARA Public Registry 2008n). Gattinger's Agalinis lives primarily in dry prairie and open woodland habitat. Increased soil moisture has been cited as a possible cause of recent declines of the species and a contributing factor may be the moderate increase in annual precipitation that has been observed since the 1890s in the Lake St. Clair and Georgian Bay regions (AMEC Earth & Environmental 2006; SARA Public Registry 2008n). However, while total annual precipitation is projected to continue to increase slightly as climate change progresses, more information is needed on how warmer temperatures and seasonal variation in precipitation may influence the growth of Gattinger's Agalinis in Canada (AMEC Earth & Environmental 2006; CCCSN 2007).

Golden Paintbrush (*Castilleja levisecta*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Insufficient Information

The Golden Paintbrush is a Garry Oaks Maritime Meadows herb species that currently occurs only on the southeast corner of Vancouver Island and other offshore islands in southwestern British Columbia and in northwest Washington in the United States (see also see also Bearded Owl-clover, Bear's-foot Sanicle, Coastal Scouler's Catchfly, Prairie Lupine and Seaside Birds-foot Lotus) (Parks Canada Agency 2006a). Similar to other endangered plant species that occur in this habitat area, potential climate change impacts on the Golden Paintbrush do not yield a clear overall pattern. Although this species is at the northern extent of its range on Vancouver Island, its ability to disperse is limited by lack of suitable connective habitat and isolation due to geographic barriers. The region in which the Golden Paintbrush grows is prone to summer drought and salt spray, which are critical in the maintenance of open maritime meadows habitat, but the potential effect of changes to soil moisture pattern and low to moderate sea level rise requires further examination (Lemmen & Warren 2004; Parks Canada Agency 2006a; CCCSN 2007; Lemmen *et al.* 2008). The reproductive success of the Golden Paintbrush is also very dependent on favourable seasonal weather conditions; this species will not germinate if conditions are unfavourable, but it is unknown how climate change will affect these reproductive cues (Parks Canada Agency 2006a).

Grand Coulee Owl-clover (*Orthocarpus barbatus*)

Taxonomic Group: Vascular Plants
Province: British Columbia
Climate Change Impact: Insufficient Information

The Grand Coulee Owl-clover is endemic to central Washington and south-central British Columbia, where it lives in grass and shrub dominated habitats (COSEWIC 2005e). The range of this species is restricted, but the Grand Coulee Owl-clover lives in arid regions and may be adaptable to warmer and drier growing summer conditions projected for this region under climate change. However, as an annual herb species prone to population fluctuations, it will be sensitive to climate change-related extreme events (COSEWIC 2005e). Large scale shifts in biome type across the current Grand Coulee Owl-Clover range will also influence this species, but more detailed information at the species level is needed (Wood 2007).

Greater Sage-Grouse *urophasianus* subspecies (*Centrocercus urophasianus urophasianus*)

Taxonomic Group: Vascular Plants
Province: Alberta, Saskatchewan
Climate Change Impact: Negative

The Greater Sage-Grouse exists across areas of western North America; the *urophasianus* subspecies is at the northern limit of the species range in southeastern Alberta and southwestern Saskatchewan and is considered distinct from the *phaios* subspecies, which is classified as extirpated in British Columbia (Hyslop 1998). The Greater Sage-Grouse is known to coexist closely with the sagebrush plant, which is the primary food source and nesting habitat for this species (Hyslop 1998). Climate change is projected to favour the expansion of grassland and savannah biomes associated with the sagebrush plant in Canada (Wood 2007), although current limitations on the sagebrush in Canada from anthropogenic pressures may restrict possible opportunities (Hyslop 1998). Furthermore, periods of drought are projected to become more frequent in the prairie region of Canada under climate change (Lemmen & Warren 2004; Lemmen *et al.* 2008), which may decrease the abundance of sagebrush and other plant species used for food and nesting by the Greater Sage-Grouse (by changing growing conditions and potentially increasing competition with species better adapted to dry conditions) and, at the same time, increase pressure and competition for the use of sagebrush vegetation with grazing animals (Connelly *et al.* 2004; Lungle & Pruss 2008). Connelly *et al.* (2004) and McKenzie *et al.* (2004) also suggest that climate change-related increases in natural-area fires could accelerate the loss of sagebrush habitat, and consequently the Greater Sage-Grouse.

Heart-leaved Plantain (*Plantago cordata*)

Taxonomic Group: Vascular Plants
Province: Ontario
Climate Change Impact: Negative

The Heart-leaved Plantain is a semi-aquatic plant that has a widespread distribution across eastern North America, but individual populations tend to be localized and isolated and only two populations exist in Canada in the Carolinian zone of southwestern Ontario (SARA Public Registry 2008o). The Heart-leaved Plantain lives in wet areas of mature woodlands in close proximity to clear streams and is often seasonally submerged (SARA Public Registry 2008o).

Although Carolinian species may have opportunities to expand their range northward under climate change, existing threats from development and the small, isolated nature of Heart-leaved Plantain populations may prevent dispersal (AMEC Earth & Environmental 2006). Furthermore, reduced streamflow (and associated declines in water quality) in late spring through to early fall may alter and degrade Heart-leaved Plantain habitat in southern Ontario (Lemmen & Warren 2004; Lemmen *et al.* 2008).

Henslow's Sparrow (*Ammodramus henslowii*)

Taxonomic Group: Birds

Province: Ontario

Climate Change Impact: Negative

Henslow's Sparrow lives in southern Ontario during the summer season; it currently is known to breed only in southern Ontario and the northeastern United States and spends its winters in the southeastern and south-central United States (Environment Canada 2006a). The total population of this species is considered to be critically small, primarily as a result of habitat loss in both its summer and winter domains (Environment Canada 2006a). Studies and assessments of Henslow's Sparrow in the United States suggest that the species is likely vulnerable to climate change. Butler (2003) studied the first spring arrival dates of migratory birds in North America and found that Henslow's Sparrows arriving in Massachusetts demonstrate a significant linear trend towards earlier spring arrival since the early 1900s and Cooper (2007) suggests that climate change is likely to alter the distribution of both the summer and winter ranges of Henslow's Sparrow. Although the species exists at the northern extent of its range in Canada, habitat availability and the very low population of this species will likely place limitations on further range expansion in Canada. Climate change alone may not have landscape scale implications on the availability of the open, undisturbed grassland habitat preferred by Henslow's Sparrow in Ontario (Wood 2007), but suitable habitat is already very restricted due anthropogenic factors and climate change-related impacts may affect remaining habitat. Environment Canada (2006a) indicates that seasonal flooding of Henslow's Sparrow habitat is important in maintaining the open habitat preferred by this species, but Henslow's Sparrow will avoid areas that are too wet or too dry. Warmer temperatures and changes to precipitation will likely alter current habitat over the long-term and extreme hydrologic events (i.e. floods, drought) are likely to have punctuated negative impacts on vulnerable Canadian populations.

Hoary Mountain-mint (*Pycnanthemum incanum*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

The Hoary Mountain-mint is a perennial herb that, in Canada, occurs only in the Burlington/Hamilton area of southern Ontario and tends to live on warm slopes in open, dry deciduous woods (White 1998b). This species is considered common and secure across its range in the eastern United States (Thompson & Rothfels 2006); warmer temperatures under climate change may benefit the growth of the Hoary Mountain Mint in southern Ontario if suitable habitat is available and other threats to the species are mitigated. This species is particularly threatened by competition with invasive species, and, as with most other endangered plant

species, this threat is likely to be exacerbated by climate change. More information is needed on how changes in precipitation patterns may play a role in the rate of slumping on the slopes where the Hoary Mountain Mint grows. Trampling of individual plants due to nearby trail use is and will remain a minimal disturbance to this species, but warmer temperatures and longer recreation periods may aggravate this threat (Scott & Jones 2006; Thompson & Rothfels 2006).

Horned Lark *strigata* subspecies (*Eremophila alpestris strigata*)

Taxonomic Group: Birds

Province: British Columbia

Climate Change Impact: Neutral

The Horned Lark *strigata* subspecies occurs on coastal plains in western Oregon and Washington and the southwestern corner of British Columbia, including southern Vancouver Island (COSEWIC 2003b). Over the past 50 years the species has significantly declined across its whole range and is believed to be close to extirpation in Canada due to loss of its naturally rare prairie & other open, sparsely vegetated habitat (COSEWIC 2003b). The availability of this type of habitat is unlikely to change significantly at the landscape scale in British Columbia as a result of climate change, but will remain threatened by increasing pressure for development and artificial fire suppression (Environment Canada 2007c; Wood 2007). Furthermore, COSEWIC (2003b) suggests that large population declines in Washington and Oregon mean that these regions are unlikely to be a source of birds that could re-establish Canadian populations; unless current limitations are mitigated, this is likely to hold true even if the species' climatic range shifts northward under climate change.

Horsetail Spike-rush (*Eleocharis equisetoides*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Negative

The Horsetail Spike-rush is an aquatic plant that occurs (often rarely) in more than 20 U.S. states, but in Canada is known to occur only in the Long Point National Wildlife Area in southern Ontario (Environment Canada 2006). Only a single plant of Horsetail Spike-rush exists in a localized area of shallow water along the shoreline of a pond (Environment Canada 2006). This species may be naturally limited in Canada due to the colder climate and more severe winters (Environment Canada 2006). However, the low genetic diversity and narrow habitat requirements of the remaining population of this species make it extremely vulnerable to environmental change and will likely limit its ability to survive even if the growth of this species becomes climatically more favourable in southern Ontario. This species is vulnerable to climate-related stochastic events such as severe storms, flooding or drought that could very easily destroy the remaining plant (Environment Canada 2006). Annual precipitation is expected to increase by 1-14% in the Long Point region, but both extreme precipitation and summer drought events are expected to occur more frequently here (AMEC Earth & Environmental 2006). Long term changes in the Long Point wetland community due to climate change are also likely to influence the Horsetail Spike-rush, but more specific information is needed on the single pond that the remaining plant depends on (Mortsch *et al.* 2006).

Hotwater Physa (*Physella wrighti*)

Taxonomic Group: Mollusks

Province: British Columbia

Climate Change Impact: Insufficient Information

The Hotwater Physa is an extremely specialized species that has a limited distribution in streams and pools within the Liard River Hotsprings system near the northern border of British Columbia (Heron 2007). The specific physical and biological needs of the Hotwater Physa have not been thoroughly studied, but the species is known to be responsive to variables such as water temperature, flow rate, and water composition and quality, among others (Heron 2007). The isolated and specialized habitat of the Hotwater Physa makes it very vulnerable to changes in environmental conditions: climate change could potentially affect temperature and especially flow regime in the habitat of this species, but specific changes on this type of habitat and their resultant impacts on the Hotwater Physa are unknown.

Howell's Triteleia (*Triteleia howellii*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Insufficient Information

Howell's Triteleia occurs in the northwestern United States and is found as far north as southeastern Vancouver Island in British Columbia, where several small and isolated populations occur within the Garry Oak woodlands (see also Deltoid Balsamroot and Small-flowered Tonella) (Douglas & Penny 2003a; Parks Canada Agency 2006c). Habitat loss and fragmentation and the small, isolated nature of Howell's Triteleia populations makes this species vulnerable to environmental change. However, Howell's Triteleia is not a well-studied species and little is known about its biology and potential adaptability to climate change and associated impacts.

Island Blue (*Plebejus saepiolus insulanus*)

Taxonomic Group: Arthropods

Province: British Columbia

Climate Change Impact: Negative

The Island Blue is endemic to eastern Vancouver Island in British Columbia. The biology and habitat preferences of the Island Blue are not well studied and the species has not been located on Vancouver Island since 1979 and is likely extirpated (Parks Canada Agency 2008). Current recovery efforts for the Island Blue are focused on surveying for remaining populations of the species (Parks Canada Agency 2008). However, if the Island Blue is found to still exist in Canada, it is likely that climate change will impede the recovery of the species across its historical range (Parks Canada Agency 2008). Although more information is needed on the biology of the Island Blue to understand how it will react to climate change, the restricted and geographically isolated distribution of this species makes it vulnerable to any shifts in its climatic growing range, which are already occurring among other butterfly species in North America and Europe (Parmesan 1996; Parmesan *et al.* 1999).

Juniper Sedge (*Carex juniperorum*)

Taxonomic Group: Vascular Plants
Province: Ontario
Climate Change Impact: Insufficient information

The distribution of Juniper Sedge is limited globally to the southern Ohio to northern Kentucky region, and to a single Canadian population that exists in Lennox and Addington County in eastern Ontario. In its Canadian location, Juniper Sedge grows in an alvar (an area with shallow soils, overlying calcareous bedrock) covered dominantly by red cedar in an open woodland (SARA Public Registry 2008p). More information is needed about the biology of this plant and the specific reasons for its very localized habitat requirements, but it is thought that drought may play a role in the success of this species and therefore impacts from climate change-related changes in the local hydrologic regime may be influential (SARA Public Registry 2008p; McCartney & Goodwin 2003).

Kellogg's Rush (*Juncus kelloggii*)
Taxonomic Group: Vascular Plants
Province: British Columbia
Climate Change Impact: Negative

Kellogg's Rush is an annual herb that occurs rarely throughout its range along the western United States and occurs as only one small and isolated population near Victoria, British Columbia (Costanzo 2003). Kellogg's Rush lives in vernal pools, in part of the larger Garry Oak ecosystem on Vancouver Island, and this habitat and associated vegetative communities are known to be very sensitive to changes in temperature and precipitation (see also Bog Bird's-foot Trefoil, Dwarf Sandwort, Rosy Owl Clover, Tall Woolly-heads and Water Plantain Buttercup) (Costanzo 2003; Graham 2004 as cited in Parks Canada Agency 2006b). The projected shift towards warmer temperatures and drier summer conditions in this region will likely cause earlier and more rapid drying of vernal pool habitat, which can result in a shortened growing season and lower seed production (M. Fairbairns, pers. comm., 2005 as cited in Parks Canada Agency 2006b; CCCSN 2007; Lemmen *et al.* 2008). Although Kellogg's Rush is thought to have drought-tolerant seeds that can survive through unfavourable growing seasons (Costanzo 2003), a long-term shift in the hydrologic regime of vernal pool habitat and limited mechanisms for dispersal may limit the overall adaptability of this species to new climate conditions. Furthermore, as with other endangered species inhabiting ephemeral wet areas in this region, identified threats from marine pollution and human disturbance due to recreation activities may be exacerbated by low to moderate sea level rise and warmer and lengthened recreation periods (Lemmen & Warren 2004; Parks Canada Agency 2006b; Scott & Jones 2006; Lemmen *et al.* 2008).

Kidneyshell (*Ptychobranhus fasciolaris*)
Taxonomic Group: Molluscs
Province: Ontario
Climate Change Impact: Negative

The Kidneyshell is a freshwater mussel that occurs in eastern North America; populations in Lake St. Clair and the Sydenham and Ausable Rivers in southern Ontario are at the northern extent of this species' range (COSEWIC 2003c). The Kidneyshell used to be more common in

the other areas of the Great Lake basin, but has been virtually extirpated in many areas as a result of the introduction of the Zebra Mussel (*Dreissena polymorpha*); reproducing populations in Canada are now limited to the Sydenham and Ausable rivers, but total population remains in decline (COSEWIC 2003c). Schindler (2001) theorizes that the Zebra Mussel (and other invasive species in the Great Lakes basin known to originate from the Ponto-Caspian area) are warm water adapted, which may further enhance their competitive edge under climate change relative to native species like the Kidneyshell. While the non-impounded river environments of remaining Kidneyshells (i.e., the Sydenham River) will likely be protected from zebra mussel invasion in future, the current primary threats to freshwater mussels species in Ontario, namely pollution, eutrophication, siltation and risk of dessication, are likely to be exacerbated under climate change due to projected long-term declines in water flows in southern Ontario (particularly during summer periods), and the dominantly sessile nature of this species will make rapid dispersal to new areas more difficult if current habitat become unsuitable (Bruce *et al.* 2003; AMEC Earth & Environmental; Morris 2006a; Morris & Burrige 2006; Lemmen *et al.* 2008). The Kidneyshell is known to be vulnerable to periods of intense river flow and flooding because of the risk of dislodgement and transport to areas of less suitable habitat (Morris 2006a). While spring flooding may decrease in southern Ontario under climate change, the occurrence of extreme rainfall events (particularly during times of already higher river flow) may be a negative threat to this species (Bruce *et al.* 2003; Lemmen *et al.* 2008). Morris (2006a) also indicates that climate change may alter the patterns of fish species that act as hosts during the larval stage of mussel development.

Killer Whale (Northeast Pacific Southern Resident Population) (*Orcinus orca*)

Taxonomic Group: Mammals (Marine)

Province: Pacific Ocean

Climate Change Impact: Insufficient Information

The southern resident population of the Killer Whale exists in three pods (that are part of a single clan) that spend their summers the northeast Pacific Ocean off the coast of southern British Columbia, Vancouver Island and northern Washington state (Resident Killer Whale Recovery Team 2007). Resident populations of the Killer Whale tend to be more specialized in their feeding than transient populations. Resident populations coincide their migration with the abundance of their prey species (salmon in the case of the southern resident population of British Columbia) and, unlike other types of Killer Whale populations, they do not feed switch their feeding to marine mammals when their main prey is not abundant (Resident Killer Whale Recovery Team 2007). Killer Whales are known to exist in a wide range of water temperatures, but changes to the availability and timing of salmon under climate change are likely to impact the southern resident population of this species (Resident Killer Whale Recovery Team 2007). However, while the behaviour of the Killer Whale has been developed according to long-term environmental patterns, a study of the northern resident population of the Killer Whale (off the coast of BC) demonstrated that the species has an ability to make adaptations to climate variability within a relatively short timeframe (Lusseau *et al.* 2004). More information is needed on the potential ability of the southern resident population of the Killer Whale to make behavioural adaptations to stochastic and long-term climate change impacts. Still, given its limited cultural and genetic diversity and more specialized predation habits, the southern resident population of Killer Whales is likely less adaptable than other populations.

King Rail (*Rallus elegans*)

Taxonomic Group: Birds

Province: Ontario

Climate Change Impact: Negative

The breeding range of the King Rail extends across most of eastern United States and extends north into southern Ontario (James 2000). The King Rail is a marsh bird, living in large, open, shallow freshwater marshes, and is particularly dependent on coastal wetland areas of the Great Lakes (James 2000; Mortsch *et al.* 2006). The current primary threat to the King Rail is the loss and alteration of its wetland habitat, which is a threat likely to be exacerbated by climate change. Declines in the water levels of the Great Lakes will reduce the total area of coastal wetlands, and lower water levels favour the growth of tall, dense monotypic vegetation (i.e., reeds and cattails) that is unsuitable as King Rail breeding grounds (Mortsch *et al.* 2006). Mortsch *et al.* (2006) determined that the King Rail is among the most hydrologically vulnerable of all bird species breeding in the coastal Great Lakes area, and the occurrence extreme climate change-related impacts, such as the loss of nests from intense flood events, could have significant negative implications for the survival of this species given its already low population size. The overwintering habitat of the King Rail in the along the Atlantic and Gulf coasts in the U.S. and Mexico may also be threatened by sea level rise and more intense tropical and extratropical storms that can destroy coastal wetland habitat (James 2000; IPCC 2007a).

Kirtland's Warbler (*Dendroica kirtlandii*)

Taxonomic Group: Birds

Province: Ontario

Climate Change Impact: Negative

Kirtland's Warbler is currently known to breed only in Michigan, but occasionally individual birds are sighted in southern and central Ontario, and if ongoing management efforts to restore the species are successful, there is potential for this species to become more established in Ontario in the near future (James 1999). Kirtland's Warbler has very specialized breeding habitat. The birds build nests only on sandy, well-drained soils beneath the low level branches of homogenous stands of young Jack Pine trees, which is a common phase of forest succession following disturbance across the range of Kirtland's Warbler (Botkin *et al.* 1991; James 1999). Preliminary research suggests that, due to the specialized habitat requirements of this species, Kirtland's Warbler will not have suitable breeding grounds in Canada if it migrates northward under climate change (Botkin *et al.* 1991; Root & Schneider 2002; Environment Canada 2006). A model of Jack Pine growth under climate change by Botkin *et al.* (1991) indicates that Michigan's Jack Pines may respond rapidly to climate change and this forest may become unsuitable to Kirtland's Warbler during the 21st century. While Jack Pine forests exist in much of Ontario, in most cases the soils in these forests do not meet the needs of this bird's required breeding habitat, and it has been speculated that projected northward range shifts of Kirtland's Warbler will be hindered by availability of suitable habitat (Botkin *et al.* 1991; Root & Schneider 2002). Although the winter habitat of this species in the Bahamas is not thought to be a limiting factor, more information is needed on how climate change may influence wintering grounds in future.

Large Whorled Pogonia (*Isotria verticillata*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

The Large Whorled Pogonia is a species of orchid that exists in the eastern United States, but may be extirpated from Canada, as it was last sighted in 1996 as a single plant in the Carolinian zone of southern Ontario (SARA Public Registry 2008q). Given that this species is at the northern extent of its range and possibly limited by cooler climates, the growth of this species in Ontario may benefit from warmer temperatures under climate change. More information is needed on the potential impact of climate change on the local microclimate of known Large Whorled Pogonia habitat, but any climate change impacts likely are a very minor threat relative to the low genetic diversity of plants if they still exist and the influence of habitat degradation due to current anthropogenic stressors.

Leatherback Seaturtle (*Dermochelys coriacea*)

Taxonomic Group: Reptiles

Province: Pacific Ocean, Atlantic Ocean

Climate Change Impact: Negative

The Leatherback Seaturtle is a large, migratory marine turtle that occurs in the Atlantic Ocean off the east and northeast coasts of eastern Canada and in the Pacific Ocean off the coast of British Columbia (James 2001). This species (particularly the Pacific population) has been in rapid decline and its lifespan, late age of maturity and the high mortality rate of its eggs and hatchlings make the Leatherback Seaturtle less adaptable to rapid environmental change and slow to recover from population declines (James 2001). All sea turtles are known to exhibit temperature-dependant sex determination; under climate change, higher temperatures during the incubation period of eggs at tropical and sub-tropical nesting beaches are expected to result in dominantly female hatchlings, which will hinder reproduction and the ability of populations to recover (Davenport 1997). Leatherback Seaturtles also have a tendency to repeatedly nest on the same beach, meaning that individuals are unlikely to adapt to warmer temperatures by nesting on cooler beaches at higher latitudes (Davenport 1997). Furthermore, sea-level rise and more frequent extreme weather events (i.e. hurricanes) may negatively affect the quantity and quality of tropical and sub-tropical beach habitat for sea turtle nesting (Fish *et al.* 2004; Atlantic Leatherback Turtle Recovery Team 2006). Potential impacts of climate change on the mature Leatherback Seaturtles that occur in Canadian waters in the summer and early autumn have not been studied, but Davenport (1997) suggests that potential climate-related changes in ocean currents could affect the migration and dispersal of the Leatherback Seaturtle.

Loggerhead Shrike *migrans* subspecies (*Lanius ludovicianus migrans*)

Taxonomic Group: Birds

Province: Manitoba, Ontario, Quebec

Climate Change Impact: Insufficient Information

The Loggerhead Shrike *migrans* subspecies (also known as the Eastern Loggerhead Shrike) is a medium sized predatory songbird that occurs as isolated populations in southeastern Manitoba, central and eastern Ontario and possibly southwestern Quebec (SARA Public Registry 2008r). The North American range of the eastern Loggerhead Shrike extends across much of east-central United States, but the species has been in decline for the past 50 years, particularly in the northern portion of its range (SARA Public Registry 2008r). According to projections by Matthews *et al.* (2004), total Loggerhead Shrike abundance could increase under climate change (2 x CO₂ conditions) and the species range will expand northward and little range to the south will be lost. This may favour the reestablishment of this bird in Canada, but it is unknown how climate change will affect local habitat availability and how impacts will interact with existing threats and trends in the northern portion of this species' range.

Long's Braya (*Braya longii*)

Taxonomic Group: Vascular Plants

Province: Newfoundland

Climate Change Impact: Negative

Long's Braya is known to grow only at the northwest corner of Newfoundland on limestone barrens habitat, which is a northern, tundra-like landscape with a rocky substrate (SARA Public Registry 2008s; Tilley *et al.* 2005). Long's Braya is adapted to a cold climate and relies on the extreme conditions and natural disturbances from surface processes (i.e., cryoturbation, frost-shattering, etc.) to prevent competition from other species (SARA Public Registry 2008s; Tilley *et al.* 2005). According to Slater (2005 as cited in Tilley *et al.* 2005), over the next century, mean annual temperature in the Limestone Barrens is expected to increase by approximately 4°C (which generally agrees with annual temperature trends projected for this region by CCCSN [2007]). Warmer temperatures will diminish the effectiveness of cold-climate processes at limiting competitive plant species and the geographical location of Long's Braya prevents potential adaptation through northward migration (Tilley *et al.* 2005). Furthermore, herbivory by the Diamondback Moth is known to be a threat to plant species in the Limestone Barrens; given that the survival of these moths is known to increase with warmer temperatures, their abundance may increase with climate change (Talekar & Shelton 1993 as cited in Tilley *et al.* 2005; Tilley *et al.* 2005). Long's Braya is also subject to infection from fungal pathogens and climate change is expected to intensify this threat (Hermanutz *et al.* 2004 and Parsons & Hermanutz 2006 as cited in Lemmen *et al.* 2008).

Margined Streamside Moss (*Scouleria marginata*)

Taxonomic Group: Mosses

Province: British Columbia

Climate Change Impact: Negative

Populations of Margined Streamside Moss have a scattered distribution across parts of western North American and the only known Canadian population of this species occurs in the Kootenay region of southeastern British Columbia (COSEWIC 2002d). Recent surveys for this species suggest it may be extirpated from its known location in Canada, but if current initiatives to locate other population in this region are successful, such populations are likely to be negatively impacted by climate change (British Columbia Bryophyte Recovery Team 2007). This species

lives on wet rocks on the borders of or submerged in cold, clear streams and is known to be vulnerable to fluctuations in water flow (COSEWIC 2002d). Changes to the hydrologic regime have been observed for areas of the Columbia River watershed (in which the Margined Streamside Moss is found). Average annual flow has increased slightly in the Columbia River watershed since 1970 and over the near term, current threats to this species from flooding could be significant, particularly during periods when heavier spring precipitation coincides with snowmelt (COSEWIC 2002d; Bruce *et al.* 2003). However, over the long-term, water flow is projected to decline under future climate change and drier conditions during low summer flow periods are likely to have a negative impact on current habitat of the Margined Streamside Moss (Bruce *et al.* 2003; Lemmen *et al.* 2008).

Maritime Ringlet (*Coenonympha nipisiquit*)

Taxonomic Group: Arthropods

Province: Quebec, New Brunswick

Climate Change Impact: Negative

The Maritime Ringlet is a butterfly species that lives only in salt marshes near Chaleur Bay in northern Quebec and northern New Brunswick (New Brunswick Maritime Ringlet Recovery Team 2005; SARA Public Registry 2008t). While this species is adaptable to periodic tidal flooding throughout its life cycle, Maritime Ringlet populations are known to decrease after severe storms that increase coastal flooding; this is due to both the prolonged submergence of individuals and the destruction of Sea Lavender and other plants that are sources of food for this species (New Brunswick Maritime Ringlet Recovery Team 2005; Sei 2004). The coastal zone of Chaleur Bay is predicted to have a moderate to high sensitivity to sea level rise and, sea level rise combined with more intense storms under climate change are likely to have a negative impact on Maritime Ringlet populations (Marlin *et al.* 2007; Lemmen *et al.* 2008). Furthermore, because the Maritime Ringlet has very rare and specialized habitat situated along a northern coastal area, its ability to disperse to new areas is geographically restricted should current growing conditions become unsuitable.

Mormon Metalmark (Southern Mountain Population) (*Apodemia mormo*)

Taxonomic Group: Arthropods

Province: British Columbia

Climate Change Impact: Insufficient Information

The core range of the Mormon Metalmark butterfly exists across the southwestern United States, and only two outlying populations exist in Canada: the threatened prairie population in southern Saskatchewan and the endangered southern mountain population in south-central British Columbia (COSEWIC 2002e). This species lives primarily in hot, arid regions, and, being at the northern most extent of its range, is believed to be somewhat limited by the cooler climate in Canada; the southern mountain population has been further limited by habitat loss and more particularly from the loss of Snow Buckwheat plants that are host to Mormon Metalmark larvae and are the primary food source for adult butterflies (COSEWIC 2002e). The dependence of the Mormon Metalmark on buckwheat plants hinders its ability to shift its range in response to climatic change and more information is needed on how both the Snow Buckwheat and the Mormon Metalmark may respond to climate change. However, the situation of the southern mountain

population at the northern periphery of the species range and its preference for hot, dry conditions suggest that this population may respond positively to climate change in Canada. More information is also needed on the evolutionary biology of Canadian populations of Mormon Metalmark, as their separation from core populations means they may have developed tolerance for a greater range of environmental conditions, which could be increasingly important for the species' survival as climate change progresses.

Morrison Creek Lamprey (*Lampetra richardsoni* var. *marifuga*)

Taxonomic Group: Fishes (Freshwater)

Province: British Columbia

Climate Change Impact: Insufficient Information

The Morrison Creek Lamprey is endemic to Morrison Creek on the eastern side of Vancouver Island in British Columbia, although its taxonomic distinction from the western brook lamprey (*Lampetra richardsoni*) is still being clarified (National Recovery Team for Morrison Creek Lamprey 2007). The headwaters of Morrison Creek occur at spring-fed wetlands that are modified by beaver dams to create year-round cold water flow in the Creek, as stored water is slowly released by dams throughout the summer (National Recovery Team for Morrison Creek Lamprey 2007). The National Recovery Team for Morrison Creek Lamprey (2007) suggests that because headwaters of Morrison Creek are groundwater driven, temperature of these waters may be more resilient to higher air temperatures and they suggest that the Morrison Creek watershed may become a refuge to cold-adapted species, such as the Morrison Creek Lamprey, as the climate warms. Changes to the Morrison Creek flow regime and water temperature and their impact on the Morrison Creek Lamprey require further investigation to understand the mutual interactions among beaver dams, groundwater supply and climate-related impacts.

Mountain Plover (*Charadrius montanus*)

Taxonomic Group: Birds

Province: Alberta, Saskatchewan

Climate Change Impact: Insufficient Information

The Mountain Plover breeding range extends across the western and central United States and into southeastern Alberta and southwestern Saskatchewan, and its wintering range occurs across the southwestern United States and northern Mexico (Wershler 2000). The Mountain Plover breeds in flat areas with short grasses that have been heavily grazed or recently burned. The Mountain Plover is at the northern extent of its range in Canada and naturally occurs rarely here, although it has been further restricted by the availability of preferred habitat (due to both natural and anthropogenic causes) (Wershler 2000). Over the last several decades, Townsend Peterson (2003) documented a subtle northward shift in the range of the Mountain Plover in the United States and declines in population abundance in the southern Mountain Plover range and population increases in more northern regions. This indicates that climate change may favour Mountain Plover populations in Canada. Biome projections across the Canadian range of this species also favour the growth and potential expansion of the type of ecological landscape preferred by the Mountain Plover (Wood 2007), but anthropogenic controls may continue to limit availability of suitable habitat. The Mountain Plover is also known to be sensitive to extremes in precipitation. Years with above average precipitation promotes thicker grass cover

that is unsuitable to Mountain Plover breeding, and low precipitation years and droughts, which may be the more significant threat to this species in the Canadian prairie region under climate change, can cause birds to leave breeding grounds early and lowers fledgling rates by affecting food supply and predation rates (Wershler 2000; Environment Canada 2006d). More information is needed to understand how the interaction of these factors will affect the survival of this species in Canada and to determine the potential impact of climate change on this species' winter range.

Mudpuppy Mussel (*Simpsonaias ambigua*)

Taxonomic Group: Molluscs

Province: Ontario

Climate Change Impact: Negative

The Mudpuppy Mussel is a small freshwater mussel that historically existed in the Detroit and Sydenham Rivers in southern Ontario, but the current Canadian population is restricted to a small portion of the eastern Sydenham River (Morris & Burrige 2006). Competition with the zebra mussel has decimated freshwater mussel populations in Ontario and, given that zebra mussel are warm water adapted, their competitive edge may be enhanced by climate change, (although areas not currently infested [i.e., the Sydenham River] will likely remained protected from zebra mussels in future) (Schindler 2001; Morris & Burrige 2006). Other primary threats to the Mudpuppy Mussel, namely pollution, eutrophication, siltation and risk of dessication, are likely to be exacerbated under climate change by projected long-term declines in water flows of rivers and lakes in southern Ontario, particularly during summer periods (Bruce *et al.* 2003; AMEC Earth & Environmental; Morris 2006; Morris & Burrige 2006; Lemmen *et al.* 2008). While more targeted information is needed, climate change may also influence the distribution of fish species that act as hosts during the larval stage of mussel development and the sessile nature of the Mudpuppy Mussel may make it difficult for remaining populations to adapt via migration (Morris & Burrige 2006).

Night Snake (*Hypsiglena torquata*)

Taxonomic Group: Reptiles

Province: British Columbia

Climate Change Impact: Positive

The range of the Night Snake extends across much of Central America, Mexico and the western United States and the species exists in Canada only in the southern Okanagan Valley in south-central British Columbia (Gregory 2001). The Night Snake is considered much more common in southern parts of its range and is likely limited by Canada's colder climate (Gregory 2001). As such, the Canadian population of the Night Snake may stand to benefit from climate change as the climatic range of this species shifts northward. Less extreme temperatures of during the winter may decrease mortality rates during the Night Snake's hibernation period. During its active period, this species favours areas with hot, dry and often desert-like conditions with shrub and grass vegetation, and increasing temperatures in the interior of British Columbia and the trend toward drier summer conditions may ameliorate the suitability of habitat conditions for the Night Snake within its current Canadian range (Gregory 2001; CCCSN 2007).

Nodding Pogonia (*Triphora trianthophora*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

The Nodding Pogonia is a species of orchid that currently grows only as a small population in Rondeau Provincial Park in southern Ontario (SARA Public Registry 2008). Given that this species is at the northern extent of its range in Canada and possibly limited by cooler climates, the growth of this species in Ontario may benefit from warmer temperatures under climate change. More information is needed on the potential impact of climate change on the local climate at the remaining Nodding Pogonia site and on the feasibility of this species' natural recovery in Canada given its critically small population.

Nooksack Dace (*Rhinichthys cataractae ssp.*)

Taxonomic Group: Fishes (Freshwater)

Province: British Columbia

Climate Change Impact: Negative

In Canada, the Nooksack Dace occurs in four small tributaries of the Nooksack River in southwestern British Columbia and its range extends only as far south as rivers and streams in northwestern Washington (COSEWIC 2007e). Adult Nooksack Dace live primarily in clear, shallow, fast-flowing parts of rivers and streams and young fish live downstream in calmer, shallow pools (COSEWIC 2007e). Although little is known about the thermal tolerance of this species, evidence suggests that this species can exist in warmer waters above 20°C (COSEWIC 2007e); however, the specialized habitat of this species and its limited tendency for dispersal make it vulnerable to long-term shifts in its climatic range. Furthermore, the most serious threat identified for this species is reduced water flow during the late summer due to stream and groundwater use (COSEWIC 2007e; Pearson *et al.* 2007). Although average annual flow in the Fraser River Valley system is projected to increase slightly by 2070-2099, climate change will exacerbate low flow conditions during the summer in southwestern British Columbia (Morrison *et al.* 2002; Lemmen *et al.* 2008). Lower flowing water may also increase existing threats from siltation, pollution, eutrophication and hypoxia during the summer (Lemmen & Warren 2004; COSEWIC 2007e; Pearson *et al.* 2007).

North Atlantic Right Whale (*Eubalaena glacialis*)

Taxonomic Group: Mammals (Marine)

Province: Atlantic Ocean

Climate Change Impact: Negative

Two species of northern right whale occur in the Atlantic and Pacific Oceans at the east and west coasts of Canada. The North Atlantic Right Whale that occurs in the west Atlantic Ocean spends its summers off the eastern coast of Canada and its winters in the subtropical waters of the coast of the southern United States (COSEWIC 2003d). The population of this species was severely reduced by the end of the 19th century as a result of commercial whaling, and low reproduction rates and other anthropogenic stressors are thought to have prevented the recovery of this species despite its protected status (COSEWIC 2003d). COSEWIC (2003d) has identified climate

change as a current and future stressor of the North Atlantic Right Whale because of climate-related changes in the abundance of calanoid copepods (and occasionally other zooplankton) and the whole marine food web in response to warming water temperature. Furthermore, according to Greene and Pershing (2004), the abundance the North Atlantic Right Whale's prey is usually favourable during periods of positive NAO and reproductive rates are usually higher during these periods. Since the mid-1990s, the NAO has been dominantly negative and has resulted in declines in the North Atlantic Right Whale population (Greene & Pershing 2004). Under climate change, the NAO is predicted to be more variable and to vary to greater extremes, and, while the specific impact this will have on the North Atlantic Right Whale is unknown, the extremely small population and low recovery rate of this species make it very sensitive to any change towards a negative NAO (Greene & Pershing 2004).

North Pacific Right Whale (*Eubalaena japonica*)

Taxonomic Group: Mammals (Marine)

Province: Pacific Ocean

Climate Change Impact: Negative

Much less information is known about the habitat requirements and population trends of the North Pacific Right Whale than the North Atlantic Right Whale (above). This species has occurred historically off the coast of British Columbia, but it has not been sited in recent decades (COSEWIC 2004b). Similar to Atlantic populations, the North Pacific Right Whale population was severely reduced during the 19th century by commercial whaling activities, and the remaining population size is unknown, but is believed to be extremely small and the species is likely near extinction (COSEWIC 2004b). The North Pacific Right Whale has the same dietary restrictions as the Atlantic Whale, feeding primarily on large amounts of calanoid copepods and occasionally other zooplankton (COSEWIC 2004b). As with the North Atlantic Right Whale, COSEWIC (2004b) has identified climate change as a potential threat to the North Pacific Right Whale because of changes in the abundance of this food source and the whole marine food web in response to warming water temperature. Furthermore, the extremely small remaining population of this species makes it more vulnerable to environmental change than its Atlantic counterpart.

Northern Bobwhite (*Colinus virginianus*)

Taxonomic Group: Birds

Province: Ontario

Climate Change Impact: Positive

The Northern Bobwhite is considered relatively common across much of central and eastern United States, but in Canada, this species has declined over the past century due primarily to habitat loss and fragmentation and only one viable population is thought occur on Walpole Island in southern Ontario (James & Cannings 2003). Matthews *et al.* (2004) modeled changes in this species distribution in the U.S. under 2 x CO₂ conditions and project that the Northern Bobwhite will increase its overall distribution and abundance by shifting northward and that areas of high Bobwhite incidence will shift towards the Canadian border. Climate change may favour the growth of grassland and savannah-type landscapes in southern Ontario, but actual benefits will likely be negligible due to development in this region (Wood 2007). Severe winters are known

to cause populations declines in the Northern Bobwhite and this threat may be lessened by climate change as a result of warmer temperatures (James & Cannings 2003). A study by Lusk *et al.* (2001) examined the potential impacts of climate change and variability on the abundance of the Northern Bobwhite in Oklahoma and found that populations were adaptable to long-term changes in normal climate conditions, but that Bobwhite abundance might be more sensitive to deviations away from the normal conditions to which they have become adapted. Lusk *et al.* (2001) suggest that only when these deviations exceed the Bobwhite's ability to cope will the survival and productivity be affected. These factors suggest that there is good potential for the Northern Bobwhite to respond positively to long-term climate change in Canada, especially if threats to habitat are mitigated.

Northern Bottlenose Whale (Scotian Shelf Population) (*Hyperoodon ampullatus*)

Taxonomic Group: Mammals (Marine)

Province: Atlantic Ocean

Climate Change Impact: Negative

Populations of Northern Bottlenose Whale occur across the north Atlantic Ocean; the endangered Scotian Shelf population exists off the eastern coast of Nova Scotia and can be found in this area year-round, although the full extent of its range is not known (Whitehead *et al.* 1996). Due to its restriction to colder waters, climate change is likely to be a threat to the Northern Bottlenose Whale and it is projected that the range of this species will contract under climate change (Learmonth *et al.* 2006; DFO 2007). Given that the Scotian Shelf population is at the southern portion of this species range, these whales may be most vulnerable to shifts in range. More information is needed on the potential impact of climate change on the primary food source (arctic squid) of the Northern Bottlenose Whale in the Scotian Shelf region, but it is likely that the abundance and distribution of this food source will be altered under climate change as marine temperatures increase.

Northern Cricket Frog (*Acris crepitans*)

Taxonomic Group: Amphibians

Province: Ontario

Climate Change Impact: Negative

The Northern Cricket Frog is a semi-aquatic species that occurs across much of eastern and central United States, but in Canada, the only extant population of this species occurs on Pelee Island in southern Ontario (SARA Public Registry 2008v). Climate change is already thought to be playing a role in the global decline of amphibians and therefore may also have a negative impact on the Northern Cricket Frog (i.e., Seburn & Seburn 2000; McCarty 2001; Walther *et al.* 2002; Carey & Alexander 2003). The primary threat to this species is the decline of its coastal wetland habitat, and this threat is likely to be exacerbated by climate change. While more information is needed on the specific habitat of the Northern Cricket Frog, significant changes are expected for coastal Great Lakes wetlands under climate change, and the small and isolated population remaining on Pelee Island will have difficulty adapting if wetland conditions become unsuitable.

Northern Leopard Frog (Southern Mountain Population) (*Rana pipiens*)

Taxonomic Group: Amphibians
Province: British Columbia
Climate Change Impact: Negative

The range of the Northern Leopard is widespread across central North America and extends into all provinces in Canada and as far north as the Northwest Territories (Seburn & Seburn 1998). However, large declines in this species throughout its range have been noted since the 1970s, and the Southern Mountain population in southeastern British Columbia has recently been classified as endangered due to its critically small size and isolation (Seburn & Seburn 1998). While climate change is already thought to be playing a role in the global decline of amphibians, and could be linked to the loss of the Northern Leopard Frog in Canada (i.e., Seburn & Seburn 2000; McCarty 2001; Walther *et al.* 2002; Carey & Alexander 2003), climate change is also likely to have a negative impact on the habitat and growing range of this species and the small size of the Southern Mountain population makes it very vulnerable to such changes, as well as stochastic events due to climate variability. The recent extinctions of populations of Northern Leopard Frog in mountainous areas of Colorado have been linked to the drying of breeding ponds (Corn & Fogelman 1984). Similarly, the small, seasonal ponds used for breeding by the southern mountain population of the Northern Leopard Frog in British Columbia are very susceptible to increased rate of drying due to projected higher temperatures and decreased summer precipitation (Seburn & Seburn 1998; Seburn & Seburn 2000; CCCSN 2007). Climate change-related decreases in water level in both breeding ponds and larger wetlands used for overwintering may also cause higher concentrations of pollutants and exacerbate the threat of toxicity (Seburn & Seburn 1998; Lemmen & Warren 2004).

Northern Madtom (*Noturus stigmosus*)

Taxonomic Group: Fishes (Freshwater)
Province: Ontario
Climate Change Impact: Insufficient Information

The Northern Madtom is a bottom-dwelling fish that occurs in large creeks and rivers in parts of central and eastern United States and as far north as the Detroit and Thames Rivers and Lake St. Clair in southern Ontario (Holm & Mandrak 1998). Water temperature during the spawning period of the Northern Madtom is thought to be a limiting factor in the dispersal of this species northward in Canada and, as a result, warmer water temperatures projected across the Great Lakes region indicate that climate change may allow for further range expansions of the Northern Madtom in Canada (Holm & Mandrak 1998; AMEC Earth & Environmental 2006). However, more species-specific information is needed on the potential impact of lower annual river flows and lake levels that are projected for systems in southern Ontario (i.e., Bruce *et al.* 2003; AMEC Earth & Environmental 2006; Lemmen *et al.* 2008); similarly, the potential impact of warmer temperatures and flow changes on the water quality of Northern Madtom habitat may exacerbate current sensitivities to pollution (Holm & Mandrak 1998).

Northern Riffleshell (*Epioblasma torulosa rangiana*)

Taxonomic Group: Molluscs
Province: Ontario
Climate Change Impact: Negative

The Northern Riffleshell is a freshwater mussel that has experienced significant population declines in the last 30 years and is now limited only to small portions of the Ausable and Sydenham Rivers in southern Ontario (Morris & Burrige 2006). Competition with the zebra mussel has decimated native freshwater mussel populations in Ontario and, given that zebra mussels are warm water adapted, their competitive edge may be enhanced by climate change, although areas not currently infested will likely remain protected from zebra mussel in the future (Schindler 2001; Morris & Burrige 2006). Other primary threats to the Northern Riffleshell in Ontario, namely pollution, eutrophication, and siltation, are likely to be exacerbated under climate change as a result of projected long-term declines in water levels of rivers and lakes in southern Ontario during summer periods (Bruce *et al.* 2003; Lemmen & Warren 2004; AMEC Earth & Environmental; Morris 2006a; Morris & Burrige 2006; Lemmen *et al.* 2008). While more targeted information is needed, climate change may also influence the distribution of fish species that act as hosts during the larval stage of mussel development and the sessile nature of the Northern Riffleshell may make it difficult for remaining populations to adapt via migration (Morris & Burrige 2006).

Oregon Forestsnail (*Allogona townsendiana*)

Taxonomic Group: Mollusks

Province: British Columbia

Climate Change Impact: Insufficient Information

The Oregon Forestsnail occurs in western Oregon, Washington and reaches its northernmost extent in the southwestern corner of British Columbia (COSEWIC 2002f). Although its moist habitat in dense understories of mixed wood forests provides a buffer against environmental fluctuations, this species is known to be particularly sensitive to variable weather and stochastic events in Canada because it is at the northern extent of its range. Warmer conditions may favour the growth of the Oregon Forestsnail in Canada over the long-term, but natural and anthropogenic habitat limitations may hinder potential dispersal and greater variability in environmental conditions (particularly with respect to precipitation) and more extreme events may negatively affect this species. The Oregon Forestsnail is most active during the spring and the overall impact of climate change during this period is not clear.

Oregon Spotted Frog (*Rana pretiosa*)

Taxonomic Group: Amphibians

Province: British Columbia

Climate Change Impact: Negative

The Oregon Spotted Frog historically occurred from northern California to the southwestern corner of mainland British Columbia, but the species has declined significantly throughout its whole range and in Canada it currently only occurs as three very small and isolated populations (Haycock 2000). Climate change is already thought to be playing a role in the global decline of amphibians (i.e., Seburn & Seburn 2000; McCarty 2001; Walther *et al.* 2002; Carey & Alexander 2003) and is likely to have a direct impact on the ephemeral pools and floodplain wetlands that are used during the breeding process of the Oregon Spotted Frog. Flood events during the late winter and early spring are known to be a threat to the Columbia Spotted Frog

(*Rana luteiventris*), which is related to the Oregon Spotted Frog (Bull 2005). Mean annual flow rate is projected to increase slightly in the Fraser River watershed, and, although mean peak flow rate is expected to decrease, variability in the timing and intensity of winter and spring precipitation events and spring melt event means that flooding will remain a threat to river systems in southern British Columbia and could result in the loss of eggs masses (Haycock 2000; Morrison *et al.* 2002; Bruce *et al.* 2003; CCCSN 2007; Lemmen *et al.* 2008). This species may also be vulnerable to warmer temperatures and decreased precipitation during the summer (CCCSN 2007; Lemmen *et al.* 2008), which can lead to the early drying of the wet areas used during the larval development stage (Haycock 2000; Bull 2005).

Ottoo Skipper (*Hesperia ottoe*)

Taxonomic Group: Arthropods

Province: Manitoba

Climate Change Impact: Insufficient Information

The Ottoo Skipper is a butterfly species that occurs in isolated populations in central and western United States and is known to have occurred in three separate locations in southern Manitoba, but has not been sighted at any of these locations since the 1980s and may be extirpated from Canada (COSEWIC 2005f). In Canada, the Ottoo Skipper is known to live only in undisturbed mixed-grass and sand prairie habitats; most of this habitat in southern Manitoba has been modified for agricultural purposes and remaining natural habitat is very fragmented (COSEWIC 2005f). Given that the species is at the northern extent of its range in Canada, climate change may have a positive impact on remaining populations or on the assisted recovery of this species. The growing range of this species may shift northward under climate change and biome projections suggest that climate change may expand the grassland landscape favoured by this species in Manitoba, but habitat availability and fragmentation are still likely to be an overriding threat even in the event of such changes. Invasive grassland species are known to be diminishing the native flower species that are strongly preferred by the Ottoo Skipper as a primary food source, and the potential for climate-related changes in natural vegetation composition and greater threats from warm-adapted invasive species could further alter the habitat of the Ottoo Skipper (COSEWIC 2005f).

Pink Coreopsis (*Coreopsis rosea*)

Taxonomic Group: Vascular Plants

Province: Nova Scotia

Climate Change Impact: Negative

Pink Coreopsis is a perennial herb that grows along the eastern coast of the United States and in southwestern Nova Scotia (SARA Public Registry 2008x). The species occurs along the shorelines of three separate lakes and is dependent on some natural disturbance from flooding, wave action and ice scour to prevent the establishment of competing vegetation (SARA Public Registry 2008x). Although more information is needed on the impact of climate change on the specific lakes of the Pink Coreopsis, lower water flows and changes in the timing and magnitude of flooding and ice break up events in this region are likely to influence shoreline vegetation and the ability of the Pink Coreopsis to disperse (Bruce *et al.* 2003; Lemmen *et al.* 2008). The small, isolated populations of this species and its low seed production and reproductive success will

make it more difficult to adapt to negative impacts, particularly during periods of more extreme hydrologic conditions (SARA Public Registry 2008x).

Pink Milkwort (*Polygala incarnata*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient information

The Pink Milkwort is an annual herb that can be found across much of central and eastern United States and on Walpole Island and other areas near Lake St. Clair in southern Ontario (SARA Public Registry 2008y). Although this species is at the northern extent of its range in Canada and in some scenarios climate change favours the expansion of the grassland type landscape preferred by this species, the high degree of development and habitat fragmentation in this region will remain a limiting factor for the growth of this species (SARA Public Registry 2008y; Wood 2007). This species has relatively specific soil moisture preferences and will not grow in very wet or dry conditions (SARA Public Registry 2008y). The Pink Milkwort is known to be sensitive to changes in soil moisture regime, but more information is needed on how climate change-related impacts may influence the local habitat of this species (SARA Public Registry 2008y); current projections for this region suggest that annual precipitation may increase slightly over the long-term, but summers will be drier and the overall impact is not known (AMEC Earth & Environmental 2006; CCCSN 2007; Lemmen *et al.* 2008).

Pink Sand-verbena (*Abronia umbellata*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Negative

Pink Sand-verbena is a perennial herb that grows on sandy beaches within the upper limit of the high tide zone (Douglas 2004). This species occurs sporadically along parts of the western coast of the United States; only one population is known to have occurred recently in Canada at a beach in Pacific Rim National Park on the western coast of Vancouver Island, but the species has not been observed for the past couple years (Douglas 2004). While the greatest threat to this species in Canada is its imminent extirpation, the seeds of this species are long-lasting and renewed growth or reintroduction of the Pink Sand-verbena at this site may be possible (Douglas 2004; Fairbarns *et al.* 2007). However, both plants and seeds of this species are currently very vulnerable to wave action and scouring during winter storms (Douglas 2004). The coastal zone of Pacific Rim National Park is classified as moderately sensitive to sea level rise, which may result in increased beach erosion and exacerbate current threats from wave action in the upper intertidal zone (Scott & Suffling 2000; Lemmen & Warren 2004; Lemmen *et al.* 2008). Climate change may also increase summer visitation to Pacific Rim National Park and intensified use of beach habitat may exacerbate the current threat of damage from human interaction (Scott & Suffling 2000; Fairbarns *et al.* 2007).

Piping Plover *circumcinctus* subspecies (*Charadrius melodus circumcinctus*)

Taxonomic Group: Birds

Province: Alberta, Saskatchewan, Manitoba, Ontario

Climate Change Impact: Negative

The Piping Plover is a small shorebird that occurs as two subspecies in Canada: *circumcinctus* and *melodus*. Populations of the *circumcinctus* subspecies currently exist in southern Alberta, Saskatchewan and Manitoba and northeastern Ontario, but this species has been in decline across all of its North American range (Environment Canada 2006e). The *circumcinctus* subspecies is known to nest just above the high water mark on sandy or gravel beaches of prairie lakes or other water bodies (Environment Canada 2006e). Due to its preferred habitat, the Piping Plover is subject to significant disturbance from human use of beaches, as well as from natural and anthropogenic fluctuations in water level (Environment Canada 2006e). The potential impact of climate change on the hydrologic regime of the *circumcinctus* subspecies is uncertain. Projections of rivers flows in prairie regions indicate that mean annual flow will be reduced under climate change (although increased flow could occur in parts of Manitoba), but increased likelihood for intense precipitation events and changes in the timing of melting and precipitation patterns may increase the risk of spring flooding that could destroy Piping Plover nests (Bruce *et al.* 2003; Lemmen *et al.* 2008). However, much of the southern prairie region is expected to experience warmer and drier conditions under climate change and periods of drought are more likely (CCCSN 2007; Lemmen *et al.* 2008). More information is needed on the specific impacts of drier summer conditions on the Piping Plover *circumcinctus* subspecies are not clear, but significant benefits are not likely. Warmer and lengthened recreation periods may exacerbate current threats from human activity in the beach areas where Piping Plovers nest (Environment Canada 2006e; Scott & Jones 2006). The coastal wetland overwintering habitat of the Piping Plover along the southern and southeastern coast of the United States will be threatened by sea level rise, coastal erosion and more intense storm activity (Daniels *et al.* 1993; Environment Canada 2006e; IPCC 2007a).

Piping Plover *melodus* subspecies (*Charadrius melodus melodus*)

Taxonomic Group: Birds

Province: Quebec, New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland

Climate Change Impact: Negative

The breeding range of the *melodus* subspecies of Piping Plover extends from South Carolina north to coastal areas of Canada's maritime provinces (Environment Canada 2006e). Climate change may pose a significant threat to the coastal beach habitat of this species (Solomon *et al.* 2001; Environment Canada 2006e). Much of the eastern coast of Canada is moderate to highly sensitive to sea level rise; Piping Plover nests may be at increasing risk of destruction from storm surge during breeding periods and sea level rise will likely contribute to long-term loss of suitable beach nesting habitat (Solomon *et al.* 2001; Environment Canada 2006e; Lemmen *et al.* 2008). The coastal wetland overwintering habitat of the Piping Plover along the southern and southeastern coast of the United States will be threatened by sea level rise, coastal erosion and more intense storm activity (Daniels *et al.* 1993; Environment Canada 2006e; IPCC 2007a).

Pitcher's Thistle (*Cirsium pitcheri*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Negative

Pitcher's Thistle is endemic to the Great Lakes region and in Canada, populations occur along the eastern shores of Lake Huron and Georgian Bay on Manitoulin Island and in Pukaskwa National Park along Lake Superior (Maun 1999). This species grows primarily on sand dunes and upper beaches in open areas with other grasses and small plants (Maun 1999). Although this species can grow in later stages of vegetative succession, long-term declines in lake levels of Lakes Huron and Superior may accelerate stabilization of beaches and sand dunes in some areas and competition with other plants may increasingly threaten this species if it is unable to sufficiently disperse to new habitat closer to the shoreline (Maun 1999; AMEC Earth & Environmental 2006). Disturbance from recreation activities in Pitcher's Thistle habitat is a current threat to this species that is likely to be exacerbated by climate change as summer recreational periods lengthen and intensify due to warmer conditions (Maun 1999; Scott & Suffling 2000; Scott & Jones 2006). More information is needed on the tolerance of this species to a warmer growing range; due to the restricted range and habitat needs of this species, dispersal to new regions in Canada may not be possible if current growing conditions become less suitable.

Poor Pocket Moss (*Fissidens pauperculus*)

Taxonomic Group: Mosses

Province: British Columbia

Climate Change Impact: Negative

The last remaining Canadian population of Poor Pocket Moss occurs near North Vancouver in southwestern British Columbia and is very isolated from the main range of the species, which is scattered along western portions of Washington, Oregon and California (SARA Public Registry 2008z; Poor Pocket Moss Recovery Team 2007). The Canadian population lives in a moist silt outcrop that its wetted primarily during the winter and remains moist throughout the summer because of shady, protective overstory vegetation (Poor Pocket Moss Recovery Team 2007). Under climate change, this species is vulnerable to periods of drought and changes towards warmer and slightly drier summer conditions over the long term (CCCSN 2007; Lemmen *et al.* 2008). It is suggested that a series two to three hotter and drier than average summers could completely dry the silt substrate that the Canadian population of Poor Pocket Moss depends on (SARA Public Registry 2008z).

Prairie Lupine (*Lupinus lepidus* var. *lepidus*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Insufficient Information

In Canada, the Prairie Lupine is rare, occurring only at two sites on the southeast corner of Vancouver Island in British Columbia, but in the southern portion of its range through western Washington and Oregon this species is considered relatively common (Parks Canada Agency 2006a). The Prairie Lupine is an endangered species of the Garry Oaks Maritime Meadows habitat and, similar to other endangered plant species in this region, the potential climate change impacts on the Prairie Lupine does yield a clear overall pattern (see also Bearded Owl-clover, Bear's-foot Sanicle, Coastal Scouler's Catchfly, Golden Paintbrush and Seaside Birds-foot

Lotus) (Parks Canada Agency 2006a). Although this species is at the northern extent of its range on Vancouver Island, its ability to disperse is limited by lack of suitable connective habitat and isolation due to geographic barriers. The landscape in which this species grows is prone to summer drought and salt spray, creating a water-stressed environment that maintains the dry, open maritime meadows habitat preferred by the Prairie Lupine. However, the potential effect of changes to soil moisture pattern and low to moderate sea level rise requires further examination as relatively little is known about the specific biology of the Prairie Lupine (Lemmen & Warren 2004; Parks Canada Agency 2006a; CCCSN 2007; Lemmen *et al.* 2008). Evidence suggests that periodic fires are required by this species to maintain healthy populations of Prairie Lupine (Parks Canada Agency 2006a), but, although climate change will affect natural fire regimes, artificial fire suppression in this region will likely counteract potential impacts.

Prairie Skink (*Eumeces septentrionalis*)

Taxonomic Group: Reptiles

Province: Manitoba

Climate Change Impact: Insufficient Information

The Prairie Skink is one of only six lizard species that live in Canada. This species occurs primarily in the central United States and in Canada the species is known to occur only in southwestern Manitoba, where it is isolated from the American population and is theorized to be genetically distinct (COSEWIC 2004c). The Prairie Skink lives in sandy, mixed grass prairie habitats and has been endangered primarily because of habitat loss and fragmentation (COSEWIC 2004c). Although the range of this species has potential to expand in Canada and some climate change projections favour the expansion of grassland landscapes in southern Manitoba, habitat availability and a low population may limit this species' ability to capitalize on opportunities (COSEWIC 2004c; Wood 2007). Canadian populations of the Prairie Skink have longer winter hibernation periods than their southern counterparts, but it is unknown how warmer and slightly wetter winters in southern Manitoba may affect the hibernation routines of the Canadian Prairie Skink (COSEWIC 2004c; CCCSN 2007; Lemmen *et al.* 2008).

Prothonotary Warbler (*Protonotaria citrea*)

Taxonomic Group: Birds

Province: Ontario

Climate Change Impact: Negative

The Prothonotary Warbler is a small songbird that is relatively common across much of southeastern United States, but in Canada its distribution is limited to southern Ontario, where total population size has declined significantly over the past 10 years (COSEWIC 2007f). Matthews *et al.* (2004) project that in the United States, total population size of the Prothonotary Warbler may decrease under climate change (2 x CO₂), but the range of this species will shift northward; this may have positive implications for the abundance of this species in Canada, but COSEWIC (2007f) suggests that the potential benefits of northward range expansion may be offset by current and future habitat limitations. The Prothonotary Warbler has very specific habitat requirements: it nests only in the cavities of dead trees, usually above pools of water in deciduous swamp forests and riparian flood zones (COSEWIC 2007f). As a result, climate change will likely have an impact on the hydrologic regime of Prothonotary Warbler habitat.

Declining lake levels and annual river flows and drier summers projected for southern Ontario may negatively impact habitat utilized during the breeding season; variability in the timing of spring melt and flooding events, as well potential changes in the timing of Prothonotary Warbler migration require further investigation (Bruce *et al.* 2003; AMEC Earth & Environmental 2006; CCCSN 2007; COSEWIC 2007f; Lemmen *et al.* 2008). Increased risk of severe weather events has also been identified as a potential climate change-related threat to the Prothonotary Warbler in both its summer and winter habitat (in coastal Central and South America) (COSEWIC 2007f; Environment Canada 2007d).

Pugnose Shiner (*Notropis anogenus*)

Taxonomic Group: Fishes (Freshwater)

Province: Ontario

Climate Change Impact: Insufficient Information

The distribution of the Pugnose Shiner ranges across several river basins in the north-central United States; in Canada, the species occurs as small, isolated populations in parts of the southern Ontario Great Lakes system (Holm & Mandrak 2002). Chu *et al.* (2005) modeled the potential impact of climate change on the distribution of the Pugnose Shiner in Canada, considering it as a species representative of those that are partially limited by their thermal tolerance of the cooler Canadian climate. Chu *et al.* (2005) project that the Pugnose Shiner distribution will continue to exist in watersheds where the species is currently found and that it is possible for the species to expand into as many as 60 new watersheds across central Ontario and southern and eastern Quebec by the 2050s. However, the probability of the migration of this species into new watersheds is low and Chu *et al.* (2005) indicate that their study does not consider the direct stresses placed on the aquatic systems of this species, such as pollution, competition and predation. More information is needed on how changes in lake level and water flow predicted for southern Ontario may influence the suitability of Pugnose Shiner habitat.

Purple Twayblade (*Liparis liliifolia*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

Purple Twayblade is an orchid that grows in oak savannah or successional deciduous or mixwood forests (SARA Public Registry 2008aa). It is at the northern extent of its range in Canada, but any opportunities created by shifts in the climatic growing range of this species and its preferred habitat may be limited by the high degree of anthropogenic development in southern Ontario. More information is needed on the biology of this species to understand its potential response to climate-related impacts in its current habitat.

Rayed Bean (*Villosa fabalis*)

Taxonomic Group: Mollusks

Province: Ontario

Climate Change Impact: Negative

The Rayed Bean is a very small freshwater mussel species that has declined significantly in terms of distribution and abundance in its core habitat range in the Great Lakes region of eastern United States, and in Canada, the species is now limited to the Sydenham River in southern Ontario (Morris & Burrige 2006). Competition with the zebra mussel has decimated freshwater mussel populations in Ontario and, given that zebra mussel are warm water adapted, their competitive edge may be enhanced by climate change, although areas not currently infested will likely remained protected from zebra mussel in future (Schindler 2001; Morris & Burrige 2006). Other primary threats to the Rayed Bean in Ontario, namely pollution, eutrophication, and siltation, are likely to be exacerbated under climate change as a result of projected long-term declines in water flows of rivers and lakes in southern Ontario during summer periods (Bruce *et al.* 2003; Lemmen & Warren 2004; AMEC Earth & Environmental; Morris 2006a; Morris & Burrige 2006; Lemmen *et al.* 2008). While more targeted information is needed, climate change may also influence the distribution of fish species that act as hosts during the larval stage of mussel development and the sessile nature of the Rayed Bean may make it difficult for remaining populations to adapt via migration (Morris & Burrige 2006).

Red Crossbill *percna* subspecies (*Loxia curvirostra percna*)

Taxonomic Group: Birds

Province: Newfoundland

Climate Change Impact: Negative

Red Crossbills exist in many boreal and conifer forest areas throughout the world, but the *percna* subspecies is known to breed only on the island of Newfoundland, although it is occasionally sighted in other nearby maritime provinces (COSEWIC 2004d). The Red Crossbill *percna* subspecies lives in the boreal forest; it is morphologically adapted for a diet consisting primarily of conifer seeds and thrives in areas where a variety of conifer trees are present to provide food sources at different times of the year, as well as provide habitat for nesting and roosting (COSEWIC 2004d). Climate change projections indicate that the boreal forest biome will disappear on the island of Newfoundland by 2080 and will be replaced by the temperate mixed forest biome, which will result in significant change to current Red Crossbill *percna* subspecies habitat (Wood 2007). The specialized nature and small population size of the Red Crossbill *percna* subspecies and the ability of recently introduced red squirrels to outcompete it for food sources during periods of seed shortages, mean that the Red Crossbill *percna* subspecies will have difficulty adapting to the loss of boreal forests in Newfoundland under climate change, particularly during years with more extreme seed shortage events (COSEWIC 2004d). Although this species does foray into Labrador and northern Quebec during periods of low seed production, it is known breed only on the island of Newfoundland and the potential for expansion of this species' breeding range to mainland Canada as habitat conditions on the island of Newfoundland decline is unknown (COSEWIC 2004d).

Red Mulberry (*Morus rubra*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

The Red Mulberry is a small to medium sized understory tree that is relatively common across most of the eastern United States, but it is at the northern limit of its range in southern Ontario and historically it has never been present in large numbers in Canada (SARA Public Registry 2008bb). In all six climate change scenarios projected by NRCan (2007), the growing range and core distribution of this species is expected to shift further into Ontario and other parts of southern Canada by 2071-2100. While this suggests that the growth of this species in Canada may improve under climate change, habitat availability and the small, isolated populations currently existing in Ontario may still be a limiting factor for this species. Furthermore, the Red Mulberry is threatened by hybridization with the White Mulberry, which is a more aggressive introduced species (SARA Public Registry 2008bb). NRCan (2007) projects that the growing range of the White Mulberry will advance northward in Canada in a similar fashion to the Red Mulberry and thus is likely to remain a persistent threat. More information is also needed on the impact of climate change on the moist forest habitat preferred by the Red Mulberry, as soil moisture conditions will be influenced by changes in temperature and precipitation patterns, and periods of summer drought that are projected to be more common in southern Ontario are likely to have a negative influence on vulnerable Red Mulberry populations (CCCSN 2007; Lemmen *et al.* 2008; SARA Public Registry 2008bb)

Rigid Apple Moss (*Bartramia stricta*)

Taxonomic Group: Mosses

Province: British Columbia

Climate Change Impact: Insufficient Information

The Rigid Apple Moss is considered rare within its range in south-central and western United States and is at its northern limit in Canada, where small populations occur within Garry Oak and coastal Douglas Fir ecosystems on southern and southeastern Vancouver Island and nearby coastal islands of British Columbia (SARA Public Registry 2008cc; British Columbia Bryophyte Recovery Team and Garry Oak Ecosystems Recovery Team 2007). The Rigid Apple Moss is known to grow on rocky outcrops and very thin soils, but more information is needed about the detailed habitat requirements of this species to understand the potential implications of climate change. While the Rigid Apple Moss appears to favour moist soils and therefore may be threatened by loss of soil moisture during warmer and drier summer conditions, the species is adapted to some seasonal drying and its tolerance of climate extremes is not known (SARA Public Registry 2008cc; CCCSN 2007). Climate change may also play a role in exacerbating threats from exotic species that compete directly with the Rigid Apple Moss or that create growing conditions with insufficient direct sunlight (British Columbia Bryophyte Recovery Team and Garry Oak Ecosystems Recovery Team 2007).

Rocky Mountain Tailed Frog (*Ascaphus montanus*)

Taxonomic Group: Amphibians

Province: British Columbia

Climate Change Impact: Negative

The Rocky Mountain Tailed Frog occurs as isolated populations in mountainous interiors of southeastern British Columbia, Montana and Idaho (SARA Public Registry 2008dd). This species is known to live in small, cold streams located in moist, forested, alpine slopes that

favour cool, humid conditions (SARA Public Registry 2008dd). While climate change is already thought to be playing a role in the global decline of amphibians (i.e., Seburn & Seburn 2000; McCarty 2001; Walther *et al.* 2002; Carey & Alexander 2003), climate change is also likely to have a negative impact on the habitat of this species and the small size of remaining populations makes it very vulnerable to such changes, as well as to stochastic events and climate variability. This species has a lengthy egg incubation and larval development phase (up to five years in length) and is known to have a narrow thermal tolerance range and sensitivity to higher temperatures during both its aquatic residency and its adult terrestrial phase (Seburn & Seburn 2000; Dupuis & Friele 2006; SARA Public Registry 2008dd). Climate change-related increases in air and water temperatures, as well as changes in water flow, precipitation and evapotranspiration rates are likely to have a negative impact on the specialized habitat conditions preferred by the Rocky Mountain Tailed Frog (Seburn & Seburn 2000; Dupuis 2004; CCCSN 2007; Lemmen *et al.* 2008).

Roseate Tern (*Sterna dougallii*)

Taxonomic Group: Birds

Province: Quebec, New Brunswick, Nova Scotia

Climate Change Impact: Negative

The Roseate Tern occurs globally, but Canadian populations breed along the coast of eastern Canada and winter along the northern coast of South America (Whittam 1999). This species nests almost exclusively on small coastal islands (Whittam 1999). Most of the current Canadian breeding range of the Roseate Tern is projected to be moderately to highly sensitive to sea level rise, which will threaten the availability and quality of this species' habitat (Lemmen *et al.* 2008). The Roseate Tern is also known to be vulnerable to extreme storms, and more intense storms expected to impact coastal areas of the eastern Atlantic Ocean under climate change will exacerbate this threat in both its summer and winter ranges (Whittam 1999; IPCC 2007a). Climate change has also been speculated as a possible cause of the decline of suitable food sources for the Roseate Tern along the northeast coast of England (BBC 2004), but more information is needed on the potential for similar impacts in Canada.

Rosy Owl-clover (*Orthocarpus bracteosus*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Negative

The Rosy Owl-clover occurs along parts of the northwest coast of the United States and extends as far north as the southern tip of Vancouver Island in British Columbia, where a single population exists in a vernal seep that is part of the larger Garry Oak ecosystem (Fairbarns 2004). Similar to other endangered species living in Garry Oaks ephemeral wet areas, the habitat of the Rosy Owl-clover and associated vegetative communities are known to be very sensitive to changes in temperature and precipitation, and climate change is likely to have a significant influence on the Rosy Owl-clover (see also Bog Bird's-foot Trefoil, Dwarf Sandwort, Kellogg's Rush, Tall Woolly-heads and Water Plantain Buttercup) (Graham 2004 as cited in Parks Canada Agency 2006b). The projected shift towards warmer temperatures and drier summer conditions over the next century will likely cause earlier and more rapid drying of the

Rosy Owl-clover's vernal seep habitat, which can result in a shortened growing season and lower seed production (M. Fairbarns, pers. comm., 2005 as cited in Parks Canada Agency 2006b; CCCSN 2007; Lemmen *et al.* 2008). Moreover, the small population size of this species means that it is very sensitive to more extreme environmental events, such as drought, and, if climate change gradually renders its current growing range unsuitable, the Rosy Owl-clover's ability to colonize new habitat is limited by the fragmented nature of its habitat and its isolation from mainland ecosystems (Parks Canada Agency 2006b). Furthermore, as with other endangered species inhabiting ephemeral wet areas in this region, current threats from marine pollution and human disturbance due to recreation activities may be exacerbated by low to moderate climate change related sea level rise and warmer and lengthened recreation periods (Lemmen & Warren 2004; Parks Canada Agency 2006b; Scott & Jones 2006; Lemmen *et al.* 2008).

Round Hickorynut (*Obovaria subrotunda*)

Taxonomic Group: Molluscs

Province: Ontario

Climate Change Impact: Negative

The only Canadian population of the freshwater mussel, Round Hickorynut, exists in Lake St. Clair and East Sydenham River in southern Ontario, but the whole North American population of this species has declined significantly (COSEWIC 2003e). Competition with the zebra mussel has decimated freshwater mussel populations in Ontario and, given that zebra mussel are warm water adapted, their competitive edge may be enhanced by climate change, although areas not currently infested (i.e., the Sydenham River) will likely remain protected from zebra mussel in future (Schindler 2001; COSEWIC 2003e). The other primary threats to freshwater mussel species in Ontario, namely pollution, eutrophication, siltation and risk of dessication, are likely to be exacerbated under climate change by projected long-term declines in water flows of rivers and lakes in southern Ontario, particularly during summer periods (Bruce *et al.* 2003; AMEC Earth & Environmental; Morris 2006a; Morris & Burrige 2006; Lemmen *et al.* 2008). Climate change-related variability and extremes during higher river flow periods may also increase the risk of dislodgment and transport of the Round Hickorynut to areas of less suitable habitat (Bruce *et al.* 2003; Morris 2006a). These types of punctuated threats may make it difficult for the very small and isolated remaining Round Hickorynut populations to recover, particularly if climate change influences the abundance of competitive warm-adapted species and/or changes in patterns of fish species that act as hosts during the larval stage of mussel development (Morris 2006a). Furthermore, the dominantly sessile nature of this species will make dispersal to new areas difficult if current habitat becomes unsuitable.

Round Pigtoe (*Pleurobema sintoxia*)

Taxonomic Group: Molluscs

Province: Ontario

Climate Change Impact: Negative

The Round Pigtoe is a freshwater mussel that is relatively rare across its range in central United States, but it has experienced significant population declines and, in Canada, it currently exists in Lake St. Clair and the Grand, Thames and Sydenham Rivers in southern Ontario (COSEWIC 2004e). Competition with the zebra mussel has decimated freshwater mussel populations in

Ontario and, given that zebra mussel are warm water adapted, their competitive edge may be enhanced by climate change, although areas not currently infested (i.e., the Sydenham River) will likely remain protected from zebra mussel in future (Schindler 2001; COSEWIC 2004e; Morris & Burrige 2006). Other primary threats to the Round Pigtoe in Ontario, namely pollution, eutrophication, and siltation, are likely to be exacerbated under climate change as a result of projected long-term declines in water flows of rivers and lakes in southern Ontario during summer periods (Bruce *et al.* 2003; AMEC Earth & Environmental; Morris 2006a; Morris & Burrige 2006; Lemmen *et al.* 2008). While more targeted information is needed, climate change may also influence the distribution of fish species that act as hosts during the larval stage of mussel development and the sessile nature of the Round Pigtoe may make it difficult for remaining populations to adapt via migration (Morris & Burrige 2006).

Rusty Cord Moss (*Entosthodon rubiginosus*)

Taxonomic Group: Mosses

Province: British Columbia

Climate Change Impact: Negative

The Rusty Cord Moss occurs very sporadically across parts of western North America and only three isolated populations currently occur in Canada in the south-central interior of British Columbia (COSEWIC 2004f). Although this species exists at the northern extent of its North American range, the discontinuity and large distances among most populations will make the Rusty Cord Moss vulnerable to changes that may make current habitat unsuitable. This species is found in arid environments on the periphery of small ponds and lakes or on seepage slopes, where conditions are seasonally wet during the spring but dry during the summer (COSEWIC 2004f). Projected warmer temperatures and decreased summer precipitation are likely to shorten the growing season for this species and it is theorized that prolonged periods of drought, which are expected to become more common in this region under climate change, cause Rusty Cord Moss populations to decline (COSEWIC 2004f; CCCSN 2007).

Sage Thrasher (*Oreoscoptes montanus*)

Taxonomic Group: Birds

Province: British Columbia, Alberta, Saskatchewan

Climate Change Impact: Negative

The Sage Thrasher is a migratory bird that occurs in the western United States and in areas of southern British Columbia, Alberta and Saskatchewan, but in its Canadian range, it only breeds on a regular basis in British Columbia; the Sage Thrasher winters in southwestern United States and Mexico (Cannings 2000). Similar to the Greater Sage-Grouse (above), the Sage Thrasher relies on the sagebrush plant and associated mixed grass prairie habitat for its breeding grounds (Cannings 2000). The reliance of the Sage Thrasher on a specific plant species makes it vulnerable to changes under climate change. Although climate change may favour the expansion of grassland landscapes in parts of southwestern Canada (Wood 2007), it has been suggested that the sagebrush plant may be vulnerable to shifts in vegetative species that are better adapted to warmer and drier growth conditions (Connelly *et al.* 2004; Lungle & Pruss 2008). More frequent periods of drought under climate change may increase competition for sagebrush

vegetation among grazers and climate change-related changes in natural fires patterns could potentially accelerate the loss of sagebrush habitat (Connelly *et al.* 2004; McKenzie *et al.* 2004).

Salish Sucker (*Catostomus catostomus ssp.*)

Taxonomic Group: Fishes (Freshwater)

Province: British Columbia

Climate Change Impact: Insufficient Information

Salish Suckers are found only in the Puget Sound area of Washington state and in parts of the lower Fraser River valley in the southwestern corner of British Columbia, where they generally occur in smaller lowland streams and associated ponds (COSEWIC 2002g). Little is known about the exact temperature preferences and tolerance limits of the Salish Sucker. Circumstantial evidence suggests that this species is more tolerant of exposure to higher water temperatures than other cold-water adapted species such as salmon, but the potential effects of long-term increases in water temperature are unknown (Inglis *et al.* 1992 as cited in COSEWIC 2002g). A study by Morrison *et al.* (2002) modeled projected changes in water temperature in the Fraser River watershed and found that mean summer water temperature is expected to increase by 1.9°C. Slight increases in mean annual river flow are also projected for this region, as well as changes in the timing and magnitude of peak river flows and declines in average summer flow, but the implications of such changes for Salish Sucker habitat are unclear (Morrison *et al.* 2002; Lemmen *et al.* 2008).

Sand-verbena Moth (*Copablepharon fuscum*)

Taxonomic Group: Arthropods

Province: British Columbia

Climate Change Impact: Negative

The Sand-verbena Moth is endemic to the Puget Sound region in northwestern Washington and the eastern coast of Vancouver Island in British Columbia (COSEWIC 2003f). Throughout its life, the Sand-verbena Moth lives in close association with colonies of its host plant, the Yellow Sand-verbena (*Abronia latifolia*), which lives on coastal sand dunes, spits and beaches (COSEWIC 2003f). This habitat is relatively rare along the eastern coast of Vancouver Island and is in constant flux from erosion and deposition processes. COSEWIC (2003f) identified climate change as a potential threat to the Sand-verbena moth, as much its habitat exists near sea level and, although sea level rise along the southwestern coast of British Columbia is classified as low to moderate, this type of sand-dominated habitat is very vulnerable to further erosion and inundation (Lemmen & Warren 2004; Lemmen *et al.* 2008). COSEWIC (2003f) goes on to suggest that climate change-related sea level rise could also have a positive effect on the Sand-verbena Moth if accelerated coastal disturbance and sediment transportation and deposition increase the growth rate of sand-dominated features. However, given that Canadian populations of Sand-verbena are small and relatively isolated from each other, the influence of habitat loss via coastal erosion, particularly during severe storms, is likely to have a much more immediate and greater negative effect on the survival of the species than potential benefits from increased coastal habitat, as more time is required for establishment and colonization of the Yellow Sand-verbena before benefits can be realized.

Scarlet Ammannia (*Ammannia robusta*)

Taxonomic Group: Vascular Plants

Province: British Columbia, Ontario

Climate Change Impact: Insufficient Information

The Scarlet Ammannia is an annual aquatic plant that occurs in Mexico, central and western United States and as far north as the southern interior of British Columbia and the southern tip of Ontario (SARA Public Registry 2008ee). This species lives on moist shorelines of lakes and wetlands where it is submerged in the spring and emerges during the summer (Douglas 1999; SARA Public Registry 2008ee). Given that the species is at the northern extent of its range in Canada, its growth may benefit from northward shifts in climatic growing range where suitable habitat is available. Although mean annual water flow in the Columbia River basin has increased slightly in recent decades, it is projected that water flow will eventually decrease in southwestern British Columbia under climate change, particularly during the summer (Bruce *et al.* 2003; Lemmen *et al.* 2008); water flows and lake levels in the southern Ontario Great Lakes region are also expected to decrease under climate change (AMEC Earth & Environmental 2006; Lemmen *et al.* 2008). As a result, changes in the timing and magnitude of water dynamics in the natural habitat of the Scarlet Ammannia may limit the growth of this plant, but more information is needed on how populations may respond in areas where water levels are artificially controlled.

Seaside Bird's-foot Lotus (*Lotus formosissimus*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Insufficient Information

The Seaside Bird's-foot Lotus occurs along the western coast of North America from central California north to the southern tip of Vancouver Island in British Columbia in the Garry Oak Maritime Meadow habitat (see also Bearded Owl-clover, Bear's-foot Sanicle, Coastal Scouler's Catchfly, Golden Paintbrush and Prairie Lupine) (Parks Canada Agency 2006a). The potential climate change impacts on the Seaside Bird's-foot Lotus do not yield a clear cumulative direction (Parks Canada Agency 2006a). Although this species is at the northern extent of its range on Vancouver Island, its ability to disperse is limited by lack of suitable connective habitat and isolation due to geographic barriers. The landscape in which the Seaside Bird's-foot Lotus grows is prone to summer drought and salt spray, creating a water-stressed environment preferred by the Seaside Bird's-foot Lotus and that is also critical in the maintenance of the open maritime meadows habitat. However, the potential effect of changes to soil moisture pattern and low to moderate sea level rise requires further examination (Lemmen & Warren 2004; Parks Canada Agency 2006a; CCCSN 2007; Lemmen *et al.* 2008). The reproductive success of the Seaside Bird's-foot Lotus is also very dependent on favourable seasonal weather conditions that cue various stages of growth, but the specific impact of climate change on these conditions cannot be projected in sufficient detail (Parks Canada Agency 2006a).

Seaside Centipede Lichen (*Heterodermia sitchensis*)

Taxonomic Group: Lichens

Province: British Columbia

Climate Change Impact: Negative

The range of the Seaside Centipede Lichen is limited primarily to the western coast of Vancouver Island in British Columbia (COSEWIC 2006d). This species has very specialized habitat requirements: it is known to grow only in defoliated twigs in the lower canopies of old-growth Sitka spruce trees that are near the high tide zone (COSEWIC 2006d). Currently, only two Canadian populations of this species remain, and its small distribution and limited ability to disperse and adapt mean that the Seaside Centipede Lichen is vulnerable to long-term climate-related changes in the suitability of its habitat and growing range (COSEWIC 2006d; National Recovery Team for *Heterodermia sitchensis* [Seaside Centipede Lichen] 2007). Severe winter storms are already known to have a negative impact on the Seaside Centipede Lichen because of increased salt spray and violent wave action, and the potential for more intense severe weather events under climate change will put this species at further risk (COSEWIC 2006d; National Recovery Team for *Heterodermia sitchensis* [Seaside Centipede Lichen] 2007). Periods of prolonged drought are also known to increase mortality of the Seaside Centipede Lichen and projected long-term trends toward increase temperatures, decreased summer precipitation and more frequent periods of summer drought are likely to negatively affect this species (COSEWIC 2006d; National Recovery Team for *Heterodermia sitchensis* [Seaside Centipede Lichen] 2007; CCCSN 2007; Lemmen *et al.* 2008).

Sei Whale (Pacific Population) (*Balaenoptera borealis*)

Taxonomic Group: Mammals (Marine)

Province: Pacific Ocean

Climate Change Impact: Negative

The Pacific population of the Sei Whale has historically been found in Canadian marine waters off the coast of BC, but the species was severely reduced by commercial whaling and there have been no sightings of the species in Canada for the past couple decades (although it does exist elsewhere in the world, including Canadian waters off the coast of Nova Scotia) (COSEWIC 2003g). Similar to the Pacific population of the Blue Whale (another member of the Balaenopteridae family), the Sei Whale population is known to respond to climate variability (Gregr *et al.* 2006). Under long-term climate change the Sei Whale is likely to be threatened by changes in the abundance of its zooplankton prey as a result of changing ocean temperatures (Gregr *et al.* 2006; Learmonth 2006) and declines in zooplankton abundance have already been linked to climate warming in the Pacific Ocean off the coast of California (Roemmich & McGowan 1995 as cited in Gregr *et al.* 2006).

Sharp-tailed Snake (*Contia tenuis*)

Taxonomic Group: Reptiles

Province: British Columbia

Climate Change Impact: Insufficient Information

The range of the Sharp-tailed Snake extends across western North America from central California north to the southeastern corner of Vancouver Island and nearby coastal islands in British Columbia. In Canada, the species is considered naturally rare, but it has been further limited by habitat loss (Spalding 1993; SARA Public Registry 2008ff). The Sharp-tailed Snake leads a relatively secretive nocturnal lifestyle and many details of its preferred habitat are

unknown. The Canadian population of this species is known to occur near the edges of coastal Douglas Fir forest stands, often on south-facing rocky slopes that may provide protection and suitable egg-laying habitat (SARA Public Registry 2008ff). Because the Sharp-tailed Snake is thought to be limited by the colder conditions that prevail in its Canadian range, the species may respond positively to climate change, and is capable of adapting to drier summer conditions projected in this region by entering an aestivation period (summer dormancy) (CCCSN 2007; Lemmen *et al.* 2008; SARA Public Registry 2008ff). Large-scale changes in the ecological structure of this species habitat are not projected for southern Vancouver Island (Wood 2007), but this species' limited ability for dispersal and its isolation from the mainland prevents possible population inputs from northward migration or new habitat opportunities via dispersal (BC Ministry of Air, Water & Land Protection 2004). More information is also needed on the food preferences of the Sharp-tailed Snake and the potential impact of climate change on food availability.

Showy Goldenrod (*Solidago speciosa*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

The Showy Goldenrod is a wildflower that grows sparsely across the northeastern and north-central United States and, in Canada, exists at the northern extent of its range with populations occurring only on Walpole Island at the tip of southern Ontario (SARA Public Registry 2008gg). Six climate change scenarios projected by NRCAN (2007) do not yield a clear consensus in terms of the potential range of the Showy Goldenrod by 2100; the growing range of this species is likely to shift in a northeastern direction, but the total suitable area (based on temperature and precipitation variables) may shrink in both the United States and Ontario. This species is known to prefer prairie and open oak savannah type habitat (SARA Public Registry 2008gg). Climate change may favour the growth of this type of landscape in southern Ontario, but, similar to other species in this region, habitat availability (and modification via fire suppression) may limit any potential benefits of climate change the growth of this species (Wood 2007).

Silver Hair Moss (*Fabronia pusilla*)

Taxonomic Group: Mosses

Province: British Columbia

Climate Change Impact: Positive

The Silver Hair Moss is at the northern limit of its range in southern British Columbia, and is more widespread and common in its southern range across the western United States and Mexico (COSEWIC 2002h). This species is known to occur at only one site in the southwestern corner of British Columbia and its continued existence has not been recently confirmed, but COSEWIC (2002h) suggests that the small size of this species, its inaccessible habitat and its occurrence with other similar moss species mean that extant populations of Silver hair Moss have not been found or have been overlooked. If the Silver Hair Moss is still present in Canada, its situation at the northern periphery of its range means that the Canadian population may benefit from climate change as the species core growing range shifts northward. This species is thought to be a potential relict species in Canada from a warmer climatic period and is known to grow in areas

with hot, dry summers (COSEWIC 2002h). Warmer temperatures and slight decreases in precipitation projected during the summer in southwestern BC may therefore favour the growth of this species in Canada (CCCSN 2007). COSEWIC (2002h) lists relatively few environmental or anthropogenic threats to the Silver Hair Moss that may be influenced by climate change. Forest fire is thought to be a minor threat to this species, but as remaining Canadian populations of this species grow in rocky cliffs rather than in rocky forest outcrops, the impact of fire may be less significant.

Skinner's Agalinis (*Agalinis skinneriana*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

Similar to Gattinger's Agalinis, Skinner's Agalinis is an annual herb that lives in the southernmost tip of Ontario, near Lake St. Clair and on Walpole Island (SARA Public Registry 2008hh). The species is considered rare across its range in central and eastern United States and several isolated populations have disappeared in Ontario over the last two decades as a result of habitat loss and disturbance (SARA Public Registry 2008hh). This species is known to prefer dry, open woods or sparsely vegetated habitat (SARA Public Registry 2008hh). Given that Skinner's Agalinis is at the northern extent of its range in Canada and that climate change may favour the growth of open, grassland and savannah type biomes in southern Ontario, this species may stand to benefit from climate change in Canada (Wood 2007). However, similar to other species in this region, habitat availability (and modification via fire suppression) may limit any potential benefits of climate change and translocation and relocation is not considered a feasible recovery option for this species (SARA Public Registry 2008hh). More information is needed on the potential impact of climate change on the biology and localized growing conditions of current populations; two populations live on a delta island and may be threatened by declines in Lake St. Clair water levels and subsequent competition from vegetative succession (AMEC Earth & Environmental 2006; SARA Public Registry 2008hh).

Slender Bush-clover (*Lespedeza virginica*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

The Slender Bush-clover is a perennial herb that can be found across much of the eastern United States and at the tip of southwestern Ontario (Cedar 1999). Six climate change scenarios projected by NRCAN (2007) do not yield a clear consensus in terms of the potential growing range of the Slender Bush-clover by 2100. The range of this species is likely to shift in a northeastern direction, but the total suitable area (based on temperature and precipitation variables) may shrink in both the United States and Ontario. The Slender Bush-clover grows in tall grassland habitat and appears to have relatively specific soil preferences that are dependent on periodic disturbance from fire (Cedar 1999). Climate change may favour the growth of grassland type landscapes in southwestern Ontario under dynamic fire scenarios, but because the region is very developed, the practice of fire suppression and resultant vegetative succession will remain a threat to the Slender Bush-clover (Cedar 1999; Wood 2007). More information is

needed on how changes in temperature and precipitation may affect local soil moisture conditions in the vicinity of the two remaining Slender Bush-clover populations.

Slender Collomia (*Collomia tenella*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Neutral

The Slender Collomia is an annual herb that is at the northern limit of its range in south-central British Columbia, where a single, extremely small population occurs in relative isolation from the rest of the species' range in the western United States (Douglas & Penny 2003b). Although the remaining population of this species may be vulnerable to extreme events related to climate change, such as drought, the Slender Collomia is generally adapted to hot, dry conditions that will become more prevalent during the summer growing period of this species (Douglas & Penny 2003b; CCCSN 2007). The isolation and specialized habitat needs (steep, sparsely vegetated slopes) of this species suggests that recolonization from more southern plants is unlikely, even if the core growing range of this species shifts northwards (Douglas & Penny 2003b). Any potential impacts of climate change on this species in Canada are likely negligible compared to the inherent vulnerability of the few remaining plants and the impact of direct anthropogenic disturbance (Douglas & Penny 2003b).

Small White Lady's-slipper (*Cypripedium candidum*)

Taxonomic Group: Vascular Plants

Province: Manitoba, Ontario

Climate Change Impact: Insufficient Information

The Small White Lady's-slipper is a small orchid species that exists as isolated populations in areas of southern Manitoba and southern Ontario, with the core range of the species extending into central and eastern United States (SARA Public Registry 2008ii). The Small White Lady's-slipper exists in tall grass or open wood prairie habitats and it is projected that climate change will favour the expansion of grassland and savannah landscapes in both southern Manitoba and southwestern Ontario (SARA Public Registry 2008ii; Wood 2007). Given that the Small White Lady's-slipper is at the northern extent of its range in Canada, warmer temperatures and northward shifts in the species growing range may positively impact this species. Late spring frosts, which are known to negatively impact flowering and seed production, may be less severe and less frequent under climate change as spring temperatures across the current range of this species increase over the long-term (SARA Public Registry 2008ii; CCCSN 2007). However, more information is needed on how climate change may impact the soil and moisture conditions of the local habitat of this species. Although the Small White Lady's-slipper has been found in a variety of soil conditions in the past, many of the remaining populations live in fens and marshes and therefore may be sensitive to changes in temperature and hydrologic regime (SARA Public Registry 2008ii). Warmer and drier conditions projected during the summer in southern Manitoba and Ontario may have a negative impact on the Small White Lady's-slipper if the drying of its wetland habitat leads to increased competition with successive vegetation or if periods of drought further reduce the already small populations of this species (CCCSN 2007; Lemmen *et al.* 2008).

Small Whorled Pogonia (*Isotria medeoloides*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

The Small Whorled Pogonia is a rare orchid that exists as isolated populations across the eastern United States and at a single site in southern Ontario, but only one remaining plant was sighted in 1998 and it is unknown if the species is currently dormant or extirpated in Canada (White 1998c; McConnell 2007). Given that this species is at the northern extent of its range and possibly limited by cooler climates, the growth of this species in Ontario may benefit from warmer temperatures under climate change. More information is needed on the potential impact of climate change on the local microclimate of the remaining Small Whorled Pogonia population, but climate change impacts are likely to be relatively negligible compared to the influence of habitat degradation in southern Ontario and the critically small and isolated nature of the current population.

Small-flowered Lipocarpha (*Lipocarpha micrantha*)

Taxonomic Group: Vascular Plants

Province: British Columbia, Ontario

Climate Change Impact: Negative

The distribution of the Small-flowered Lipocarpha extends from Brazil through to the central and eastern United States; in Canada, two separate populations of this species occur in northwestern Ontario and in southwestern British Columbia, where it is very disjunct from the core species' range (COSEWIC 2002i). Canadian populations of the Small-flowered Lipocarpha grow on the sandy shorelines of lakes in areas prone to seasonal flooding (COSEWIC 2002i). This species is at the northern extent of its range in Canada and therefore may stand to benefit from warmer growing conditions under climate change. However, the potential for significant opportunities will be limited by this species small, isolated populations and restricted habitat needs. In areas where the Small-flowered Lipocarpha is not already threatened by artificially controlled water flows, it could experience negative impacts from changes in spring flooding patterns and long-term declines in lake levels, particularly if populations are unable to relocate relatively quickly or to adapt to threats from fast-colonizing successional plants (AMEC Earth & Environmental 2006; Lemmen *et al.* 2008). One of the current critical threats to this species is loss of habitat due to development for recreational purposes, as well as disturbance from recreational activities (COSEWIC 2002i). This threat is likely to be exacerbated by lengthened and intensified warm-weather recreation periods under climate change (AMEC Earth & Environmental 2006; Scott & Jones 2006).

Small-flowered Sand-verbena (*Tripterocalyx micranthus*)

Taxonomic Group: Vascular Plants

Province: Alberta, Saskatchewan

Climate Change Impact: Positive

The Small-Flowered Sand-verbena occurs across much of western United States, but is at the northernmost limit of its range in Canada, with populations occurring at isolated sites in southeastern Alberta and southwestern Saskatchewan (Smith 2002). The Small-Flowered Sand-verbena lives in warm, dry areas, usually on sand dunes and sand hills that are active and not stabilized by vegetation (which is the primary threat to this species) (Smith 2002). Climate conditions in southern Alberta and Saskatchewan are projected to be warmer and drier during the summer growing season (CCCSN 2007; Lemmen *et al.* 2008), which may expand the climatic range of this species in Canada and favour its growth relative to other species that are not as well adapted to drought conditions as the Small-flowered Sand-verbena (Smith 2002). Biome projections by Wood (2007) also indicate that climate change will facilitate the expansion of open shrub and grassland type landscapes and Smith (2002) suggests that long-term climate change could play a role in eventually reversing and reactivating sand dunes that have become stabilized by vegetation.

Small-flowered Tonella (*Tonella tenella*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Insufficient Information

In Canada, the Small-flowered Tonella occurs only on Salt Spring Island off the southwestern coast of mainland British Columbia and is isolated from the American range of this species, which occurs from southern Washington to central California (Douglas & Penny 2003c). This species is known to occur on the west-facing sides of stable talus slopes in Garry Oak woodland habitat (see also Deltoid Balsamroot and Howell's Triteleia) (Douglas & Penny 2003c). This species is at the northern limit of its range in Canada, but potential range expansion under climate change will likely be limited by its geographic isolation and specialized habitat needs. Biome composition in this region is not projected to change substantially under climate change (Wood 2007), but current biological information on the Small-flowered Tonella does not yield a solid indication of how this species will respond to changes in temperature and seasonal precipitation. Douglas and Penny (2003c) indicate that the suppression of fire on Salt Spring Island may threaten populations of Small-flowered Tonella in the future, as buildup of vegetative debris may eventually result in a more catastrophic fire that could make current Small-flowered Tonella habitat unsuitable; climate change may enhance this threat via drier summers and increased likelihood of drought in this region (CCCSN 2007; Lemmen *et al.* 2008).

Small-mouthed Salamander (*Ambystoma texanum*)

Taxonomic Group: Amphibians

Province: Ontario

Climate Change Impact: Negative

The Small-mouth Salamander exists at the northern extent of its distribution on Pelee Island in southern Ontario (Bogart & Licht 2004). The Small-mouthed Salamander spends most of its time buried in leaf litter or soil in a variety of prairie, forest or agricultural habitat that is in close proximity to ponds and wetlands, as the salamander emerge in the spring to breed and lay eggs in aquatic habitats where the larvae live until they metamorphose (Bogart & Licht 2004). Climate change is already thought to be playing a role in the global decline of amphibians (i.e., Seburn &

Seburn 2000; McCarty 2001; Walther *et al.* 2002; Carey & Alexander 2003) and may have negative local impacts on the habitat of the Small-mouthed Salamander in Canada. Low water levels in some of this species habitat is already a current threat during larval development, which usually lasts through July (Bogart & Licht 2004). Higher temperatures and decreased summer precipitation and the potential for more frequent and prolonged periods of drought will exacerbate the threat of early drying of larval wetlands as climate change progresses (CCCSN 2007; Lemmen *et al.* 2008).

Snuffbox (*Epioblasma triquetra*)

Taxonomic Group: Molluscs

Province: Ontario

Climate Change Impact: Negative

The Snuffbox is a small freshwater mussel that has been in decline across its range in eastern and central North America and the only remaining Canadian population occurs in the East Sydenham River of southern Ontario (Morris & Burrige 2006). Competition with the zebra mussel has decimated freshwater mussel populations in Ontario and, given that zebra mussel are warm water adapted, their competitive edge may be enhanced by climate change, although areas not currently infested (the Sydenham River) will likely remained protected from zebra mussel in future (Schindler 2001; Morris & Burrige 2006). Other primary threats to the Snuffbox in Ontario, namely pollution, eutrophication, and siltation, are likely to be exacerbated under climate change as a result of projected long-term declines in water levels of rivers and lakes in southern Ontario during summer periods (Bruce *et al.* 2003; AMEC Earth & Environmental; Morris 2006a; Morris & Burrige 2006; Lemmen *et al.* 2008). While more targeted information is needed, climate change may also influence the distribution of fish species that act as hosts during the larval stage of mussel development and the sessile nature of the Snuffbox may make it difficult for remaining populations to adapt quickly via migration (Morris & Burrige 2006).

Southern Maidenhair Fern (*Adiantum capillus-veneris*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Neutral

The Southern Maidenhair Fern is a tropical/subtropical species that is common and widespread across its main range in the southern United States, Mexico and southward into parts of South America; in Canada, this species is known to occur only in southeastern British Columbia near the Fairmont Hot Springs, more than 1000km north of its core range (White & Douglas 1998). The warm, humid microclimate generated by the hot springs allows this species to survive in Canada, but the much of the Canadian population has been lost due to the redirection of hot water from the springs to supply bathing pools at the nearby Fairmont Springs Resort, making the local climate too cold for the Southern Maidenhair Fern to survive (White & Douglas 1998). The only known colony of this plant remaining in Canada is surviving due to a leak in a pipe that transports hot water to the resort (White & Douglas 1998). Although climate change may influence water flow in this area, any potential impacts are likely negated by the overriding control of the hot springs for tourism. Changes in annual temperatures under climate change in

this region are not significant to this species relative to the influence of the local hot springs microclimate.

Spalding's Campion (*Silene spaldingii*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Negative

Spalding's Campion is a perennial herb with a very limited distribution in parts of the northwestern United States and a single, isolated population in southeastern British Columbia (COSEWIC 2005g). Both COSEWIC (2005g) and the U.S. Fish and Wildlife Service (2007) list climate change and climate variability as a potential stressor to this species due to its limited distribution, small total population and sensitivity to hot and dry conditions. Although Spalding's Campion is adapted to periodic drought conditions via seed dormancy, prolonged or repeated periods of drought, which may be more common in the southern interior of British Columbia as temperatures increase and summer precipitation rates decrease, may drastically reduce the number of individual plants found at a given site, making populations highly susceptible to extinction (COSEWIC 2005g; CCCSN 2007; U.S. Fish and Wildlife Service 2007). Fire suppression is a current threat to this species (COSEWIC 2005g), but while climate change may increase the risk of forest fire in southern British Columbia, impacts are unlikely to be locally significant given anthropogenic fire controls. Current threats from pests and competitive invasive species are also likely to be exacerbated under climate change (COSEWIC 2005g).

Spoon-leaved Moss (*Bryoandersonia illecebra*)

Taxonomic Group: Mosses

Province: Ontario

Climate Change Impact: Insufficient Information

The Spoon-leaved Moss occurs across eastern North America and is at the northern extent of its range in the Carolinian zone of southern Ontario (Doubt 2003). The species is believed to have always been uncommon in Canada due to restrictions of the colder Canadian climate outside of the Carolinian zone and the natural biological limitations of the species that limit reproduction, but the Spoon-leaved Moss is thought to have recently declined as a result of habitat loss and fragmentation (Doubt 2003). Doubt (2005) suggests that Canadian populations of the Spoon-leaved Moss may be well positioned if the growing range of this species shifts northward under climate change, but the fragmented nature of current habitat and low habitat availability across southern Ontario may limit opportunities for dispersal. The Spoon-leaved Moss is found in moist, deciduous forests and often in seasonally flooded areas (Doubt 2003). The growth of this species is known to be sensitive to changes in the local micro-climate, and therefore may be sensitive to long-term climate change in the summer that could result in drying of some Spoon-leaved Moss habitat or alterations to spring flooding patterns (Doubt 2003; CCCSN 2007). However, according to Doubt (2003), the Spoon-leaved Moss may be a suitable species for reintroduction to new sites if current habitat become unsuitable or if there is desire to increase populations in Canada as a buffer against extinction.

Spotted Owl *caurina* subspecies (*Strix occidentalis caurina*)

Taxonomic Group: Birds

Province: British Columbia

Climate Change Impact: Negative

The Spotted Owl *caurina* subspecies (also known as the Northern Spotted Owl) is a year-round resident in its range from northern California to the southwestern and south-central portions of mainland British Columbia (Kirk 1999). Chutter *et al.* (2004) suggest that, because the Spotted Owl *caurina* subspecies is at the northern limit of its range in Canada, the Canadian population of the species could benefit from climate change if climatic conditions become similar to those in the southern range of the species where populations are denser. However, although more localized information is needed, the potential for biome change in southwestern British Columbia may play a role in the availability of old-growth conifer forest habitat, which is already rare in this region and is the main limiting factor for this species (Kirk 1999; Wood 2007). Increased risk of climate change-related forest fire or pests/disease in southern British Columbia during drier summer periods projected for this region may also have a negative impact on Spotted Owl habitat (Dale *et al.* 2001; Chutter *et al.* 2004; Lemmen & Warren 2004; CCCSN 2007; Lemmen *et al.* 2008). Furthermore, it has been suggested that climate change may be related to the expansion of the range of the Barred Owl in Canada, which is a competitive threat to the Spotted Owl *caurina* subspecies (Johnson 1994 as cited in Kelly *et al.* 2003).

Spotted Turtle (*Clemmys guttata*)

Taxonomic Group: Reptiles

Province: Ontario, Quebec

Climate Change Impact: Negative

The range of the Spotted Turtle extends along the eastern coast of the United States from Florida into the Great Lakes-St. Lawrence basin area, including parts of southern Ontario and Quebec (COSEWIC 2004g). Although more specific information is needed on the local impacts of climate change, the Spotted Turtle is likely to be threatened by change and variability in its shallow wetland habitat during both the spring when it is seasonally flooded and during the summer when drying may limit habitat availability, as well as over the long term as water flows and lake levels decline across the Great Lakes region (Mortsch *et al.* 2006). Climate change may also begin to affect hibernation and breeding patterns as the timing of environmental cues for these phenological events change. Given the currently low populations of this species and its limited reproductive potential and long lifespan, the Spotted Turtle is inherently vulnerable to any potential climate stressors on its habitat and biology (COSEWIC 2004g).

Spotted Wintergreen (*Chimaphila maculata*)

Taxonomic Group: Vascular Plants

Province: Ontario, Quebec

Climate Change Impact: Neutral

The Spotted Wintergreen is a perennial herb that has a widespread range across much of the eastern United States and in Canada occurs as only in five populations in southern Ontario and southern Quebec (White 1998d; SARA Public Registry 2008jj). Given that this species is at the

northern extent of its range and is believed to be limited to warmer regions moderated by the Great Lakes, the Spotted Wintergreen may stand to benefit from potential northward shifts in its climatic growing range. However, while the preferred habitat of this species (dry mixed wood forests on sandy soils) may not be significantly altered in terms of large scale ecological change, this specific combination of habitat conditions is relatively rare in southern Ontario and new connective habitat opportunities are unlikely to exist for this species (White 1998d; Wood 2007).

Stoloniferous Pussytoes (*Antennaria flagellaris*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Insufficient Information

Three populations of the Stoloniferous Pussytoes occur in a localized area in southwestern British Columbia in relative isolation of the rest of the species' range in the western United States (Douglas *et al.* 2004). Although the species is at the northern extent of its range in Canada, and its growing range has potential to expand in Canada under climate change, it lives in relatively specialized habitat and its ability for dispersal is limited (Douglas *et al.* 2004). Stoloniferous Pussytoes occurs on unstable slopes that are saturated in the winter by underground seepage and dry completely in the summer; as a result, vegetation in these habitats is sparse and is often dominated by the Stoloniferous Pussytoes where it is present (Douglas *et al.* 2004). Projected increases in winter precipitation and decreases in summer precipitation may affect the suitability of current habitat, but more localized information is needed to understand the overall impact (CCCSN 2007).

Streambank Lupine (*Lupinus rivularis*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Negative

The Streambank Lupine exists along the western coast of North America from northern California to the southwestern corner of mainland British Columbia and southeastern Vancouver Island (COSEWIC 2002j). Although the species is at the northern limit of its range in Canada, it has already been severely limited by habitat modification and loss from industrial and urban development across its habitat; the potential for dispersal if its growing range expands northward in Canada will likely also be limited by this development (COSEWIC 2002j). Extensive dyking in developed areas along the lower Fraser River Valley where the Streambank Lupine is found has prevented the periodic flooding of the river and may have left some populations in too dry conditions to survive (SARA Public Registry 2008kk). These conditions are likely to be exacerbated for remaining populations of Streambank Lupine as temperatures rise under climate change, particularly during the summer when precipitation levels are expected to decrease (CCCSN 2007; Lemmen *et al.* 2008). Over the long-term, Streambank Lupine in lowlands areas of mainland British Columbia and the Fraser River Delta (areas most vulnerable to sea level rise in British Columbia) may be threatened by habitat inundation (Neil 2001; Lemmen & Warren 2004; Lemmen *et al.* 2008).

Swift Fox (*Vulpes velox*)

Taxonomic Group: Mammals (Terrestrial)
Province: Alberta, Saskatchewan
Climate Change Impact: Insufficient Information

The Swift Fox occurs in short/mixed grass prairie habitats in central United States and southeastern Alberta and southwestern Saskatchewan, but the range and population size of this species has steadily declined over the past century; in fact, the Swift Fox was extirpated in Canada until captive-bred populations were reintroduced in 1999 and the species was down-listed to endangered (Carbyn 1998; Pruss *et al.* 2008). In the proposed recovery strategy for current populations, Pruss *et al.* (2008) identify the need to begin incorporating climate change into the conservation strategies of Swift Fox. The potential for northward range shifts under climate change mean that the core distribution of this species may shift further towards Canada. However, current populations may migrate from their reintroduced locations towards areas of potentially less suitable habitat and, in the case of one of the two reintroduced populations, away from the protection of Grasslands National Park. Biome projections suggest that climate change may favour the growth of grassland landscapes in this region, but the availability of safe, connective habitat will be critical if new opportunities for dispersal become available (Wood 2007). More specific information is needed on the potential impact of climate change on food sources of the Swift Fox, but warmer temperatures and decreased summer precipitation will increase the potential for summer drought across the range of the Swift Fox, which likely to have negative implications for this species' prey (Scott & Suffling 2000; CCCSN 2007; Lemmen *et al.* 2008; Pruss *et al.* 2008).

Tall Bugbane (*Actaea elata*)

Taxonomic Group: Vascular Plants
Province: British Columbia
Climate Change Impact: Insufficient Information

Tall Bugbane is a perennial herb that occurs in the understories of mature forest habitat from southwestern Oregon to southwestern British Columbia (Penny & Douglas 2001). This species is known to growth in both coniferous and deciduous forest and, while the potential for biome change exists across this region, more localized information is needed on the potential impacts of climate change on the Canadian habitat of Tall Bugbane populations (Penny & Douglas 2001; Wood 2007). Climate change may disrupt soil moisture patterns in the moist, lowland areas where Tall Bugbane is currently found, but its tolerance for potentially wetter winter/spring periods and drier summers are not known (Penny & Douglas 2001; CCCSN 2007). Experimental studies indicate that seeds of the Tall Bugbane require a period of cold stratification to successfully germinate in artificial settings, but it is unknown if warmer winter temperatures could also have an impact on the germination process in the natural environment (Kaye & Kirkland 1994 as cited in Penny & Douglas 2001; CCCSN 2007).

Tall Woolly-heads (Pacific Population) (*Psilocarphus elatior*)

Taxonomic Group: Vascular Plants
Province: British Columbia
Climate Change Impact: Negative

The range of the Tall Woolly-heads extends across much of the western United States and in Canada occurs in southwestern Saskatchewan, southeastern Alberta and on southern Vancouver Island in British Columbia; however, only the pacific population of the species on Vancouver Island has been classified as endangered (SARA Public Registry 2008ll; Parks Canada Agency 2006b). The pacific population occurs in ephemeral wet areas of the Garry Oak ecosystem and will be sensitive to changes in temperature and precipitation (see also Bog Bird's-foot Trefoil, Dwarf Sandwort, Kellogg's Rush, Rosy Owl-clover and Water Plantain Buttercup) (Graham 2004 as cited in Parks Canada Agency 2006b). The projected shift towards warmer temperatures and drier summer conditions over the next century will likely cause earlier and more rapid drying of vernal pool habitat, which can result in a shortened growing season and lower seed production for species such as the Tall Woolly-heads (M. Fairbarns, pers. comm., 2005 as cited in Parks Canada Agency 2006b; CCCSN 2007). The pacific population of this species is very small and its capacity for range shifts is limited by its fragmented habitat, relative isolation and limited ability for dispersal (Parks Canada Agency 2006b). As such, the pacific population of Tall Woolly-heads is likely to be vulnerable to more extreme events (i.e drought) and if its current habitat becomes unsuitable in the long-term under climate change, it is unlikely that this population will be able to adapt by migrating to regions with more appropriate growing conditions (although there is greater potential for dispersal among non-endangered mainland populations). Furthermore, as with other endangered species inhabiting ephemeral wet areas in this region, threats from marine pollution and human disturbance due to recreation activities may be exacerbated by low to moderate sea level rise and warmer and lengthened recreation periods (Lemmen & Warren 2004; Parks Canada Agency 2006b; Scott & Jones 2006; Lemmen *et al.* 2008).

Taylor's Checkerspot (*Euphydryas editha taylori*)

Taxonomic Group: Arthropods

Province: British Columbia

Climate Change Impact: Insufficient Information

The range of the butterfly, Taylor's Checkerspot, is restricted to northern Oregon, Washington and southeastern Vancouver Island in British Columbia, but most recent reports suggest the species may be extirpated from Canada (Parks Canada Agency 2006a). The Taylor's Checkerspot recovery strategy identified climate change as a potentially important factor in this species recovery (Parks Canada Agency 2006a). Furthermore, Taylor's Checkerspot is a subspecies of Edith's Checkerspot, which has a wide distribution across much of western North America (including parts of southwestern Canada) and has been relatively well-studied with respect to climate change (Shepard 2000; SARA Public Registry 2008mm). Research indicates that the North American range of Edith's Checkerspot has shifted northward by 92km as a result of recent climate warming, and local extinctions are much more common at the southern extent of the species range than at its northern extent in Canada (Parmesan 1996; Parmesan 1999). While this suggests that climate change may benefit Canadian populations of Edith's Checkerspot and is an important factor to consider in the reintroduction of Taylor's Checkerspot in Canada, other studies have shown that this species is very sensitive to climate variability and extreme events that may be more frequently observed under climate change (Parmesan 2000; McLaughlin 2002). Parks Canada Agency (2006a) suggests that drought may have contributed to the extirpation of at least one Canadian population of Taylor's Checkerspot and other studies

suggest that the desiccation of plants used as larval hosts for Taylor's Checkerspot can result in larval starvation during the summer (Vaughn & Black 2002b as cited in Parks Canada Agency 2006a). Projected warmer temperatures, decreased summer precipitation and increased likelihood of drought events across the historical Canadian habitat of Taylor's Checkerspot may therefore hinder reintroduction efforts in this region (CCCSN 2007; Lemmen *et al.* 2008).

Thread-leaved Sundew (*Drosera filiformis*)

Taxonomic Group: Vascular Plants

Province: Nova Scotia

Climate Change Impact: Insufficient Information

The main range of the Thread-leaved Sundew, a perennial carnivorous plant, occurs along the eastern and southern coasts of the United States and is isolated from the only Canadian occurrences of this species in the southeast corner of Nova Scotia (Freedman & Jotcham 2001). In Canada, this species lives in relatively specialized habitat: it is known to grow only in raised bogs that are highly acidic, which limits competition from other plant species. This type of habitat may be sensitive to climate-related changes in hydrologic regime, but localized information is needed on projected hydrologic changes at these bogs. Annual and summer precipitation in Nova Scotia is projected to increase slightly under climate change, but it is unclear if these change in precipitation as well as projected increased temperatures will have a significant drying/wetting effect on average Thread-leaved Sundew habitat conditions (CCCSN 2007; Lemmen *et al.* 2008).

Tiger Salamander (Southern Mountain Population) (*Ambystoma tigrinum*)

Taxonomic Group: Amphibians

Province: British Columbia

Climate Change Impact: Negative

This species has a wide distribution across North America and, in Canada, exists in British Columbia, Alberta and Saskatchewan, but has recently been classified as extirpated from Ontario (SARA Public Registry 2008nn). The southern mountain population of this species occurs in the southern Okanagan Valley in south-central British Columbia near the U.S. border and is the only Canadian population currently classified as endangered, due to its small range and anthropogenic threats to its habitat (SARA Public Registry 2008nn). Climate change is already thought to be playing a role in the global decline of amphibians (i.e., Seburn & Seburn 2000; McCarty 2001; Walther *et al.* 2002; Carey & Alexander 2003) and may have negative local impacts on the southern mountain population of the Tiger Salamander. Although adult salamanders are tolerant of hot conditions, climate change-related increases in temperature may have a drying effect on the shallow ponds that are used for salamander breeding and larval development (Richardson *et al.* 2000; CCCSN 2007). A study by Richardson *et al.* (2000) showed that shallow ponds are currently the most productive environment (in terms of reproductive success) of all the habitat used by the Tiger Salamander in the southern Okanagan Valley. However, these ponds are also most susceptible to the drying effects of future climate change and the loss of such ponds may have a greater impact on the overall survival of the southern mountain population. Furthermore, juvenile salamanders leave ponds for terrestrial habitat during the late summer/early fall when they are most at risk from desiccation (Richardson *et al.* 2000). While

warmer temperatures under climate change during this transition period may exacerbate the threat of desiccation for individual salamanders, more information is also needed on potential changes in the composition of local vegetation due to climate change, as changes in vegetation may influence its effectiveness as a protective cover for salamanders against desiccation.

Tiny Cryptanthe (*Cryptantha minima*)

Taxonomic Group: Vascular Plants

Province: Alberta, Saskatchewan

Climate Change Impact: Positive

The Tiny Cryptanthe is an annual plant that occurs in central United States and in isolated locations in southwestern Alberta and southeastern Saskatchewan, where it is at the northern extent of its distribution (Environment Canada 2006f). The Tiny Cryptanthe occupies dry slopes and terraces that experience some natural disturbance resulting in deposition of sediment, which may be critical to maintaining the sparsely vegetated habitat of this species (Environment Canada 2006f). This species is considered more common in the southern portion of its range and prefers warm, dry climatic conditions (Environment Canada 2006f). As a result, projected warmer and drier growing conditions across the Canadian range of this species may favour the growth of the Tiny Cryptanthe relative to other species (CCCSN 2007). Environment Canada (2006f) also suggests that climate change may support an expansion of the Canadian range of this species if suitable connective habitat exists; findings by Wood (2007) support this on a broad scale, as the grassland biome in which the Tiny Cryptanthe currently grows is projected to expand in the prairie region under climate change.

Toothcup (*Rotala ramosior*)

Taxonomic Group: Vascular Plants

Province: British Columbia, Ontario

Climate Change Impact: Insufficient Information

The Toothcup is distributed across much of the eastern and western United States, and in Canada, occurs in southeastern Ontario and southern British Columbia (SARA Public Registry 2008oo). Canadian populations of this species occur along the shorelines of lakes, where they are subject to seasonal spring flooding that is critical to the germination process (SARA Public Registry 2008oo). Given that this species is at the northern extent of its North American range, climate change may favour the growth of this species in Canada if its climatic growing range shifts northward. However, climate-related changes in water flows and lake levels, as well as changes in the timing and magnitude of spring flood events are likely to affect the Toothcup, but more localized information is needed to understand the overall direction of potential impacts (Bruce *et al.* 2003; AMEC Earth & Environmental 2006; Lemmen *et al.* 2008). The small and isolated nature of Canadian populations also makes them vulnerable to increased variability of extreme events such as severe spring floods or summer droughts.

Townsend's Mole (*Scapanus townsendii*)

Taxonomic Group: Mammals (Terrestrial)

Province: British Columbia

Climate Change Impact: Insufficient Information

The range of Townsend's Mole extends along the west coast of North America from northern California to southwestern British Columbia in areas that are nearby or adjacent to the U.S. border (COSEWIC 2003h). This species is at the northern extent of its range in Canada; however, although some cross-border migration from the United States has potential to increase Canadian populations, northward migration under climate change will be relatively limited by current and future development (which acts as a barrier to dispersal) (COSEWIC 2003h). Climate change in southwestern BC is unlikely to have a significant impact on the general lifestyle and survival of the Townsend's Mole, but winter flooding, which is currently a known threat to this species, may be exacerbated by increased fall and winter precipitation in this region under climate change (COSEWIC 2003h; CCCSN 2007). Warmer summers and drought periods may affect soil moisture levels in the underground habitat of Townsend's Mole, but more study is needed on if and how this may affect individual animals (COSEWIC 2003h; CCCSN 2007).

Vancouver Island Marmot (*Marmota vancouverensis*)

Taxonomic Group: Mammals (Terrestrial)

Province: British Columbia

Climate Change Impact: Negative

The Vancouver Island Marmot is endemic to sub-alpine and alpine areas of Vancouver Island (Bryant 2000). This species has declined significantly over the past two decades, which is theorized to have been caused by a combination of recent climate change impacts to habitat, local anthropogenic habitat disturbance and increased predation rates (Bryant 2000; Sinclair & Byrom 2006). In keeping with historical climate-ecological trends, the Vancouver Island treeline has been encroaching on the subalpine meadow habitat of the Marmot over the past several decades (Hebda 1998; Milko 1984 and Nagorsen *et al.* 1996 as cited in Bryant 2000; Sinclair & Byrom 2006). As a result, Vancouver Island Marmot habitat is being confined to a shrinking geographic area. If such trends continue, further long-term climate change may eliminate sufficiently large areas of suitable climate and ecological conditions required to sustain viable populations of the Marmot, and the isolation of this species on Vancouver Island means that northward migration is not a feasible adaptation measure for this species.

Virginia Goat's-rue (*Tephrosia virginiana*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

Virginia Goat's Rue is a perennial herb that is common across parts of its range in the eastern United States, but in Canada, it only occurs as several small and isolated populations in southern Ontario (SARA Public Registry 2008pp). The species is at the northern extent of its range and therefore may benefit from climate change if its growing range shifts northward, although habitat availability may limit potential opportunities for dispersal. Virginia Goat's-rue lives in open woods and other open, low vegetation habitats (SARA Public Registry 2008pp); climate change may not threaten the broad occurrence of this type of ecological landscape in southern Ontario (i.e., Wood 2007), but more information is needed on local climate change impacts.

Water-plantain Buttercup (*Ranunculus alismifolius* var. *alismifolius*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Negative

The Water-plantain Buttercup occurs in areas of northwestern United States and in two locations on southeastern Vancouver Island in British Columbia (Parks Canada Agency 2006b). This species is one of several endangered species dependent on ephemeral wet areas in the Garry Oak ecosystem, which are known to be very sensitive to changes in temperature and precipitation and are likely to be significantly influenced by climate change (see also Bog Bird's-foot Trefoil, Dwarf Sandwort, Kellogg's Rush, Rosy Owl-clover and Tall Woolly-heads) (Parks Canada Agency 2006b). The projected climate shift towards warmer temperatures and drier summer conditions over the next century will likely cause earlier and more rapid drying of the Water-plantain Buttercup's vernal seep habitat, which can result in a shortened growing season and lower seed production (M. Fairbarns, pers. comm., 2005 as cited in Parks Canada Agency 2006b; CCCSN 2007). Moreover, the small population size of this species means that it is very sensitive to more extreme environmental events (i.e., drought) and if climate change gradually renders its current Canadian growing range unsuitable the ability of the Water-plantain Buttercup to colonize new habitat is limited by the fragmented nature of its habitat and its isolation from mainland ecosystems (Parks Canada Agency 2006b). Furthermore, the current threat of disturbance from human recreation activities will likely be exacerbated by climate change as recreation periods become warmer and lengthened (Parks Canada Agency 2006b; Scott & Jones 2006).

Wavy-rayed Lampmussel (*Lampsilis fasciola*)

Taxonomic Group: Molluscs

Province: Ontario

Climate Change Impact: Negative

The Wavy-rayed Lampmussel is a medium-sized freshwater mussel species that can be found in the Ohio and Mississippi river basins in the United States, but the species has declined significantly in recent years: in Canada, the species has always been uncommon, but declining populations exist in several rivers and Lake St. Clair in southern Ontario (Morris 2006b). Competition with the zebra mussel has decimated other freshwater mussel populations in Ontario and, given that zebra mussel are warm water adapted, their competitive edge may be enhanced by climate change, although areas not currently infested (the Sydenham River) will likely remained protected from zebra mussel in future (Schindler 2001; Morris 2006b). Other primary threats to the Wavy-rayed Lampmussel in Ontario, namely pollution, eutrophication, and siltation, are likely to be exacerbated under climate change as a result of projected long-term declines in water levels of rivers and lakes in southern Ontario during summer periods (Bruce *et al.* 2003; Lemmen & Warren 2004; AMEC Earth & Environmental; Morris 2006a; Morris 2006b; Morris & Burrige 2006; Lemmen *et al.* 2008). More information is needed on how climate change will influence the patterns of fish species that act as hosts during the larval stage of mussel development and how adaptable the Wavy-rayed Lampmussel is to increased water temperatures (Morris 2006b). This species is also known to be disrupted by recreational canoeing in certain regions (Morris 2006b); although this is a minor threat to this species, it may

be exacerbated my climate change due to warmer temperatures and a longer recreational period (Scott & Jones 2006).

Western Prairie Fringed-orchid (*Platanthera praeclara*)

Taxonomic Group: Vascular Plants

Province: Manitoba

Climate Change Impact: Insufficient Information

The Western Prairie Fringed-orchid occurs rarely throughout its range in central United States and southern Manitoba and the one remaining Canadian population in Manitoba represents approximately 50% of the total North American population (Environment Canada 2006g). This species has become endangered primarily because of the loss and modification of its wet prairie grass habitat, but the range of this species is believed to be naturally limited in Canada because it is at the northern extreme of its range and the colder climate may play a role in limiting seed production (Environment Canada 2006g). The Western Prairie Fringed Orchid may therefore stand to benefit from potential northward shifts in its growing range as annual temperatures increase across its growing range under climate change (CCCSN 2007). Environment Canada (2006g) also notes that late spring frosts cause damage to flowers and low temperatures are known to reduce the activity of pollinators (primarily moths), which can both have a negative impact on reproduction; warmer spring temperatures projected under climate change in southern Manitoba may lessen these threats (CCCSN 2007). However, the Western Prairie Fringed Orchid lives primarily in wet prairie and fen environments and is known to be sensitive to changes in the local hydrologic regime (SARA Public Registry 2008qq). Changes to precipitation and soil moisture patterns in both spring and summer in this region may affect the Western Prairie Fringed Orchid, but the potential net result of climate change-related impacts requires further investigation.

Western Screech-Owl *macfarlanei* subspecies (*Megascops kennicottii macfarlanei*)

Taxonomic Group: Birds

Province: British Columbia

Climate Change Impact: Insufficient Information

The Western Screech-Owl is a non-migratory, predatory bird with two different subspecies that occur in Canada: (i) the *kennicottii* subspecies is considered relatively common and occurs along the western coast of British Columbia and on Vancouver Island; and (ii) the endangered *macfarlanei* subspecies, which occurs in a non-overlapping range in the Okanagan Valley of the interior of British Columbia (COSEWIC 2002k). The Western Screech-Owl is known to occur in a wide variety of habitats, ranging from deserts to forest and including some treed urban areas, but much of the deciduous and mixed wood forest habitat used by the *macfarlanei* subspecies in Canada has been lost or disturbed (COSEWIC 2002k). This is particularly problematic for the nesting habits of the *macfarlanei* subspecies, which is known to lay eggs in the cavities of large, mature trees that require substantial time to regrowth following disturbance (COSEWIC 2002k). The very small population size of the *macfarlanei* subspecies makes it susceptible to negative impacts from stochastic climate change-related events. The interior of British Columbia is expected to be at greater risk of forest fires and pests that could further reduce the already limited forested habitat areas of sufficient maturity to support nesting preferences (COSEWIC 2002k;

Lemmen & Warren 2004; Lemmen *et al.* 2008). However, because the species as a whole is at the northern extent of its range in Canada and is capable of existing in a variety of habitats and on a variety of food sources, it is possible that northward shifts U.S. populations of this species may play a role in repopulating Canadian populations.

White Flower Moth (*Schinia bimatrix*)

Taxonomic Group: Arthropods

Province: Manitoba

Climate Change Impact: Insufficient Information

The White Flower Moth occurs at only one site in southwestern Manitoba and in scattered, isolated locations throughout its range in central United States (COSEWIC 2005h). In Canada, the species is known to live near active sand dunes that are not stabilized by vegetation and the availability of this habitat limits the species' abundance (COSEWIC 2005h). COSEWIC (2005h) has speculated that the shift towards warmer and drier conditions in southern Manitoba as a result of climate change may be responsible for re-activating sand dunes that were becoming stabilized. However, it is unclear whether the availability of more active dune habitat will positively benefit the White Flower Moth in Canada. The species traditionally exists in humid conditions, and further study is needed to understand how climate change may affect humidity in current and potential future habitat areas (COSEWIC 2005h).

White Meconella (*Meconella oregana*)

Taxonomic Group: Vascular Plants

Province: British Columbia

Climate Change Impact: Negative

Scattered and isolated populations of the White Meconella occur in the western United States and on southeastern Vancouver Island in British Columbia (COSEWIC 2005i). This species lives on hillsides with shallow soils and depends on seepage for soil moisture. The White Meconella is an annual species that is known to fluctuate from year-to-year with variable precipitation (COSEWIC 2005i). As a result, this species is likely to be affected by more frequent periods of drought projected in this region in the summer, and may also be vulnerable to extreme precipitation events and disturbance in the early spring (Lemmen *et al.* 2008). Because seeds have a limited lifespan, repeated years of unfavourable conditions for seed germination may limit the species' ability to reproduce (COSEWIC 2005i).

White Prairie Gentian (*Gentiana alba*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Neutral

The range of the White Prairie Gentian occurs in the central United States and on Walpole Island at the tip of southern Ontario in Canada, where only a single plant remains (Waldron 2001). This species lives in oak-hickory savannah habitat and has been severely threatened by habitat loss and modification (Waldron 2001). While some projections indicated that climate change may favour the growth of savannah type landscapes in southern Ontario (Wood 2007), habitat

availability will still remain a consistent threat due to the highly developed nature of this region. Although more information is needed on the potential impact of temperature and precipitation change on the White Prairie Gentian, any potential climate change-related impacts are likely to be negligible relative to this species' extremely small population and limited habitat.

White Sturgeon (*Acipenser transmontanus*)

Taxonomic Group: Fishes (Freshwater)

Province: British Columbia

Climate Change Impact: Negative

Canadian populations of the White Sturgeon are known to occur in southern British Columbia in the Fraser and Columbia River watersheds and in the Kootenay River and Kootenay Lake near the U.S. border (Ptolemy & Vennesland 2003). This species has declined significantly since the late 19th century and the small remaining populations coupled with the species' long lifespan and high age of sexual maturity mean that the White Sturgeon is vulnerable to rapid environmental changes (Ptolemy & Vennesland 2003). The spawning period and reproductive success of the White Sturgeon is closely linked to river flow and temperature (Ptolemy & Vennesland 2003). Morrison *et al.* (2002) modeled the Fraser River basin under climate change and project that, although average annual river flow may increase slightly, average flow rate during the time of peak flow (which coincides with White Sturgeon spawning) will decrease by 18% by the 2080s. In the Columbia River basin, similar trends of increased annual flow but decreased peak flow have already been observed over the past several decades, but Bruce *et al.* (2003) project that peak flow will begin to decline as climate change progresses. In the Fraser River basin, Morrison *et al.* (2002) also project that average summer water temperature is will increase by 1.9°C by the 2080s. Although specific impacts of reduced peak or annual flows on White Sturgeon are difficult to predict and may be localized, Morrison *et al.* (2002) predict that risk of exposure of salmon to waters above 20°C (which is known to degrade spawning success) will increase by a factor of 10 under climate change. Impacts of water temperatures specific to the White Sturgeon were not predicted, but the increased rate of risk to spawning success is likely similar. Optimum water temperatures for the spawning and larval stages of the White Sturgeon generally occur below 20°C, but can reach as high as 21°C in parts of the Columbia River watershed (Ptolemy & Vennesland 2003); however, studies have suggested that water temperatures higher than 18°C cause increased abnormalities and mortality in the White Sturgeon (Conte *et al.* 1988; Hildebrand *et al.* 1999 as cited in Ptolemy & Vennesland 2003).

White-headed Woodpecker (*Picoides albolarvatus*)

Taxonomic Group: Birds

Province: British Columbia

Climate Change Impact: Insufficient Information

The White-headed Woodpecker occurs in mature conifer forests in the western United States and as far north as the southern interior of British Columbia (Cannings 1995a; SARA Public Registry 2008rr). Biome models project varying responses of conifer forests to climate change in British Columbia and more information is needed on the specific response of pine species favoured by the White-headed woodpecker (Wood 2007). Increased risk of climate change-related forest fire or pests/disease in southern British Columbia as a result of drier summer periods and warmer

winter may also have a negative impact on White-headed Woodpecker habitat (CCCSN 2007; Lemmen *et al.* 2008). However, because the White-headed Woodpecker is naturally rare at the northern limit of its range, the Canadian population of this species could benefit from climate change if climatic conditions similar to its core range shift northward and sufficient suitable habitat exists for the White-headed Woodpecker within its range (SARA Public Registry 2008rr).

Whooping Crane (*Grus americana*)

Taxonomic Group: Birds

Province: Northwest Territories, Alberta

Climate Change Impact: Negative

The breeding range of the Whooping Crane has been severely reduced in Canada and the only self-sustaining population is currently restricted to areas in and adjacent to Wood Buffalo National Park in Alberta and the Northwest Territories (Wapple 2000). Via recent recovery efforts in both Canada and in the United States (where the species overwinters in Aransas National Wildlife Refuge along the Gulf Coast of Texas), Whooping Crane populations have increased and the species' probability of extinction has been significantly reduced (Environment Canada 2007). Recent reports have cited warmer springs as a contributing factor to the higher survival rate of hatchlings, but future climate change is expected to have negative consequences for the Whooping Crane (Environment Canada 2007e). Although more detailed models are needed on the potential impact of climate change on the hydrological regime of wetlands in the Canadian breeding grounds of the Whooping Crane, Wrona *et al.* (2006) suggest that warmer temperatures may contribute to drying of the wetland habitats used by the Whooping Crane and lower water depths are correlated with smaller production rates of juvenile Whooping Cranes. Climate change is also likely to alter the ecological landscape of Wood Buffalo National Park. Wood Buffalo National Park exists in the boreal forest near the zone of transition to taiga, and Scott & Suffling (2000) suggest that the spruce dominated forests at the northern edge of the park where the majority of Whooping Crane habitat exists may begin to shift in favour of denser spruce-mix forests and eventually more warm tolerant tree species as the northern edge of the boreal zone shifts northward. Biome projections by Wood (2007) indicate similar northward shifts of the boreal forest biome, although all scenarios also project the development of isolated areas of savannah/woodland biome in parts of the Whooping Crane's current Canadian range. The restricted range of this species within a national park means that it could become more vulnerable to anthropogenic disturbance if new climatic and ecological conditions force the Whooping Crane to shift its range outside of park boundaries (though current influences from human disturbance in regions surrounding Wood Buffalo National Park are minimal). Climate change may be a more particular threat in the overwintering grounds of the Whooping Crane in Texas, where coastal wetland habitat may be vulnerable to sea level rise and more intense storm activity projected under climate change (Wapple 2000; IPCC 2007a).

Williamson's Sapsucker (*Sphyrapicus thyroideus*)

Taxonomic Group: Birds

Province: British Columbia

Climate Change Impact: Insufficient Information

The breeding range of Williamson's Sapsucker occurs in mature coniferous forests of mountainous areas in the western United States and in southern and southeastern British Columbia in Canada (COSEWIC 2005j). Although this species is at the northern extent of its range, there is potential for significant biome change exists across the current Williamson's Sapsucker range and more specific information is needed on the potential impact of climate change on the individual tree species favoured by this species to understand if suitable habitat will be available if its range expands further into Canada (COSEWIC 2005j; Wood 2007). Williamson's Sapsucker lives in coniferous or mixed wood forests and has demonstrated preferences for Western Larch, interior Douglas Fir and Ponderosa Pine forest types (COSEWIC 2005j). However, according to COSEWIC (2005j), further study is required to understand why Williamson's Sapsucker does not occur in some areas of apparently suitable habitat. The mature forests preferred for nesting by this species may also be vulnerable to climate change-related impacts from fire and disease/pests in southern British Columbia as summer conditions become drier and winters become warmer (Lemmen & Warren 2004; CCCSN 2007; Lemmen *et al.* 2008). More information is also needed on the influence of climate change on the overwintering habitat of Williamson's Sapsucker in the southern United States and Mexico.

Wolverine (Eastern Population) (*Gulo gulo*)

Taxonomic Group: Mammals (Terrestrial)

Province: Quebec, Newfoundland

Climate Change Impact: Negative

The Wolverine exists across much of Canada, but only the eastern population that lives in northern Quebec and Labrador has been designated as endangered and the population is believed to be extremely low (COSEWIC 2003i). The Wolverine exists in northern forests and alpine and arctic tundra, and adaptation to climate change via northward migration is limited by geographic boundaries both in eastern Canada and in the Arctic (Kerr & Packer 1998). Biome projections across the current range of the eastern population of Wolverine indicate that much of the taiga and tundra biomes will be lost across northern Quebec and Labrador as the boreal forest biome moves northward, which may result in substantial habitat changes for the Wolverine (Wood 2007). Climate change has also been listed as a potential limiting factor of the Woodland Caribou, which ranges across central and northern Quebec (Thomas & Gray 2002); this species is a primary food source of the Wolverine and the abundance of the Wolverine and the abundance of large ungulates like caribou are closely related (COSEWIC 2003i). Furthermore, the Wolverine is known to have low reproduction rates and slow recovery time after population declines (COSEWIC 2003i). The eastern population of Wolverine is currently very small, and it is likely that any added stressors due to climate change could have serious implications for the survival of the species across its eastern range.

Woodland Caribou (Atlantic-Gaspésie population) (*Rangifer tarandus caribou*)

Taxonomic Group: Mammals (Terrestrial)

Province: Quebec

Climate Change Impact: Negative

Woodland Caribou live across the boreal zone of Canada and Alaska and have been designated as a threatened species in much of this area; the Atlantic-Gaspésie population occurs in eastern

Quebec, south of the St. Lawrence and has been designated as endangered because it is a small and isolated population that has significantly declined since the 1970s as a result of predation and habitat loss (Thomas & Gray 2002). The Atlantic-Gaspésie population of the Woodland Caribou migrates between alpine tundra and sup-alpine forests in mountainous areas of southeastern Quebec (Gaspésie Woodland Caribou Recovery Team 2006). Climate change is of significant concern for most species of caribou, including the Woodland Caribou and research suggests that species in the Arctic are already being negatively affected by climate change (Thomas & Gray 2002; Anisimov *et al.* 2007; Field *et al.* 2007). The very restricted range of the Atlantic-Gaspésie population of the Woodland Caribou, its tendency for elevational rather than latitudinal migration, and its limited genetic diversity suggest that it will be difficult for this population to adapt to climate change. Biome projections indicate that the current range of the Atlantic-Gaspésie population will shift from boreal forest to temperate evergreen and mixed forest biomes (Wood 2007). Furthermore, according to Thomas and Gray (2002), isolated southern populations like the Atlantic-Gaspésie population of Woodland Caribou are susceptible to impacts of variable weather and local climate change impacts, which could include more freezing rain and thaw periods during the winter, as well as loss of snow banks and hot weather in the summer, and change in access to food supplies.

Wood-poppy (*Stylophorum diphyllum*)

Taxonomic Group: Vascular Plants

Province: Ontario

Climate Change Impact: Insufficient Information

The Wood-poppy is a perennial flowering plant that occurs in parts of central and eastern United States, but has always been considered rare in Canada and occurs as only three populations near London in southern Ontario (Bowles 2007). This species is thought to be limited in by Canada's colder climate, which means that climate change may favour the growth of this species provided sufficient habitat is maintained (Bowles 2007). In fact, Bowles (2007) notes that Canadian populations have flourished in the past decade and suggests that this may be attributable to higher temperatures during these years. Climate change may reduce the threat of cold springs and late spring frosts, which can affect flowering, but other climate change-related impacts such as drought or extreme precipitation/storm events that may become more common in southern Ontario under climate change may have negative implications for current populations, particularly given their small size and limited, isolated Canadian range (AMEC Earth & Environmental 2006; Bowles 2007; Lemmen *et al.* 2008).

Yellow-breasted Chat *auricollis* subspecies (British Columbia Population) (*Icteria virens auricollis*)

Taxonomic Group: Birds

Province: British Columbia

Climate Change Impact: Insufficient Information

The breeding range Yellow-breasted Chat is widely distributed in North America. In Canada, the threatened *virens* subspecies occurs in southern Ontario and the *auricollis* subspecies occurs as a threatened prairie population in southern Alberta and Saskatchewan and as an endangered British Columbia population in the southern interior of British Columbia (SARA Public Registry

2008ss). Several studies have examined the response of the Yellow-breasted Chat in the United States to climate change. Butler (2003) and Marra *et al.* (2005) examined the impact of recent climate change on the spring arrival time of the Yellow-breasted Chat, but did not detect any significant change in arrival time in response to warming. Matthews *et al.* (2004) project that the range of eastern populations of this species will expand northward and contract across the southern United States under future climate change (2 x CO₂ conditions), suggesting that populations in Canada may increase. The British Columbia population of the Yellow-breasted Chat *auricollis* subspecies returns to Canada in mid-May and lives in areas of low, dense vegetation in riparian zones and may be affected by changes in stream and wetland dynamics under climate change, but the direct impact of climate change on local habitat is unknown in British Columbia (Cannings 1995b; BC Ministry of Sustainable Resource Management 2004; SARA Public Registry 2008ss). More information is also needed on the potential impact of climate change on the overwintering habitat of this species in the southern United States south to Panama (Cannings 1995b).

Yucca Moth (*Tegeticula yuccasella*)

Taxonomic Group: Arthropods

Province: Alberta

Climate Change Impact: Insufficient Information

The Yucca Moth is a small white moth species that lives in warm, dry prairie grassland and sparsely vegetated areas in the central and eastern United States and in the southeastern corner of Alberta (COSEWIC 2002). The Yucca Moth exists in a close, mutualistic relationship with the Soapweed (a threatened species in Canada), whereby the Yucca Moth is the primary pollinator of the Soapweed and uses Soapweed flower to lay eggs and feed its larvae (COSEWIC 2002). Given that the Yucca Moth and the Soapweed prefer warm, dry conditions and exist at the northern extent of their range in Alberta, it may be possible for the growing range of both species to expand in Canada under climate change. Biome projections indicate that the grassland biome, and other types of open vegetated landscape (i.e., savannah) may expand across Alberta and the prairie region under climate change (Wood 2007), but more information is needed the specific response of the Soapweed, especially since it may face increasing pressure from invasive species under climate change. The existence of transplanted Soapweed populations in areas slightly farther north of core Canadian populations that have not been colonized by the Yucca Moth suggest that existence of the Yucca Moth in more northern areas is may be possible if facilitated via management to overcome the isolation of current populations (COSEWIC 2002).

CHAPTER 5: IMPLICATIONS OF CLIMATE CHANGE FOR SPECIES AT RISK MANAGEMENT AND POLICY

Based on the results of the screening level assessment (Chapter 4), climate change has the potential to cause a predominantly negative influence on the survival of a considerable portion of species at risk, while potential positive influences from climate change remain largely uncertain due to insufficient information concerning the interaction of climate change with other limiting factors. The following sections outline key climate change-related issues that were common among the endangered species assessed in this study and that have implications for species at risk management and policy. SARA is also analyzed for threats and opportunities in the context of future climate change.

5.1. Key issues relating to climate change and species at risk in Canada

5.1.1. Inherent vulnerability of species at risk to climate change

The characteristics that define a species as ‘at risk’, such as a small and/or isolated populations, biological traits that limit the species abundance, and prevalent external stressors on the species and its habitat, mean that many species at risk are inherently less resilient to periods of rapid environmental change. Although climate change has the potential to ameliorate the climatic growing conditions for some species at risk in Canada that are in part restricted by colder climates, the factors already limiting these species (particularly anthropogenic threats to habitat) may prevent species from capitalizing on emerging opportunities.

Furthermore, some impacts of climate change may be a common threat to all species at risk. The potential for increased variability, frequency and magnitude of extreme environmental events under climate change, such as storms, flooding or drought, are likely to have negative impacts on small populations of species at risk unless they are very well-adapted to such

conditions. Similarly, while the role of climate change-related ecological disturbance, such as insect and pathogen outbreaks and forest fire, was not discussed extensively throughout the screening level assessment of endangered species due to the inability of existing information to make projections relevant to the species scale, disturbances that afflict areas of species at risk inhabitation could have very significant impacts on the survival of populations. In Canada as a whole, forest fire frequency is projected to increase and fire season is expected to lengthen, but impacts are projected to be most severe in western Canada and research suggests that some parts of Ontario and Quebec may experience slight declines in fire activity (Bergeron & Flannigan 1995; Flannigan *et al.* 2001; Lemmen & Warren 2004; Lemmen *et al.* 2008). The impacts of insects and pathogens are also expected to increase in Canada under climate change, as warmer temperatures are projected to aid the survival and dispersal of many of these organisms (Ayres & Lombardero 2000; Volney & Fleming 2000; Dale *et al.* 2001; Lemmen & Warren 2004; Lemmen *et al.* 2008). Although it is not possible to exactly determine if or how disturbance will play a role in the vicinity of most species at risk populations across Canada, at a broader scale it is clear that climate change-related increases in disturbances are likely to cause changes in the structure of many ecosystems across Canada and therefore may directly or indirectly affect the persistence of species at risk populations.

5.1.1.1. Invasive species

Current definitions of invasive species vary by management jurisdiction and are often interchanged by non-science communities with terms such as exotic, introduced and alien. However, for the purposes of this discussion, the term invasive refers to a species anthropogenically introduced outside its current or historic distribution causing negative

environmental, social or economic impacts¹⁵. Research suggests that climate change and, in some cases, increased atmospheric CO₂ concentrations, will facilitate the success of many invasive species (Dukes & Mooney 1999; Fischlin *et al.* 2007). Common characteristics among invasive species are their ability to tolerate a wide range of environmental conditions and to rapidly disperse to new regions, meaning that they may be more capable of capitalizing on transitioning ecosystems under climate change than some native species (Dukes & Mooney 1999). Many species at risk in Canada are already threatened by invasive species and climate change may enhance existing invasive species' ability to compete with native species at risk or further alter the ecological conditions preferred by species at risk, as well as to disperse into regions where invasion was previously limited by climatic factors.

Furthermore, as discussed in section 2.3, migration is likely to be a primary adaptive response of species to climate change and native species with high capacity for dispersal may begin to rapidly colonize regions outside their historic range (Kutner & Morse 1996). However, these species may also begin to compete with species at risk populations in the same way as invasive species that are considered anthropogenic threats. For example, Long's Braya is an endangered vascular plant located along the northwest coast of Newfoundland; this species is adapted to a cold climate and regular disturbance from cryoturbation processes that limit the ability of other plant species to compete with it. Tilley *et al.* (2005) suggest that warmer conditions projected under climate change may facilitate the migration of plant species into Long's Braya's current range, which will increase competition in a region that was formerly very specialized. Based on the potential for northward migration and competition by plant species that are native to North America, some authors have begun to question the appropriate definition

¹⁵ This definition is adapted from the definition used by the United Nations Convention on Biological Diversity (1992) and Environment Canada's (2004) definition of the more accurate term, 'invasive alien species'.

of an invasive species under climate change (Kutner & Morse 1996; Scott & Lemieux 2005). From a management perspective, it is unclear whether such species should be interpreted as anthropogenically-driven threats to species at risk that require mitigation or if they represent natural, autonomous adaptations of species and subsequently ecosystems to anthropogenic climate change and do not necessitate a management response. Scott and Lemieux (2005) suggest revised definitions and management guidelines are required to reflect these complexities introduced by climate change and to ensure consistent interpretations across jurisdictions and land managers (see also Recommendation 6.1.5).

A number of authors take a different approach to this issue in the context of species threatened by climate change and question the potential necessity and ethics of utilizing the introduction of species into regions outside their historic range as a potential conservation strategy (termed assisted colonization, assisted migration or ex-situ introduction) (Kutner and Morse 1996; Hunter 2007; McLachlan *et al.* 2007; Hoegh-Guldberg *et al.* 2008). While such strategies may become increasingly important to ensure the survival of species threatened by climate change, deliberate human introduction of species into non-native regions could have unforeseeable impacts on existing ecosystems if deliberately introduced species begin to act in an invasive manner or if they inadvertently carry disease, parasites or other pests. In this situation, the ‘worth’ of species being considered for assisted colonization must be weighed against the risk of negative impacts and the socio-economic costs associated with deliberate introduction (see also Recommendation 6.2.4) (Hoegh-Guldberg *et al.* 2008).

5.1.2. Species at risk at the northern periphery of their range in Canada

The devotion of increasingly scarce resources to the conservation of peripheral populations, which exist at the margins of species’ ranges, is the subject of considerable debate

(i.e., Hunter & Hutchinson 1994; Lesica & Allendorf 1995; Bunnell *et al.* 2004). Due to their distance or isolation from the core species range, peripheral populations tend to live in environmental conditions that are less than ideal relative to the species' preferences and research suggests that the existence of peripheral populations in more extreme environmental conditions gives rise to increased genetic divergence among populations and potentially results in distinct evolutionary adaptations (Hunter & Hutchinson 1994; Lesica & Allendorf 1995). However, peripheral populations tend to be small and often have decreased genetic variability within the population, which means that peripheral populations have a naturally higher risk of extirpation and are often deemed rare or at risk by local political jurisdictions, regardless of the species' status across its full geographic range (Hunter & Hutchinson 1994; Lesica & Allendorf 1995).

It has been argued that the distinctive qualities of peripheral populations, as well as the roles they play in local ecosystems and cultures, make them important targets for conservation and this may be particularly true in the era of climate change (Hunter & Hutchinson 1994; Safriel *et al.* 1994; Hampe & Petit 2005; Yakimowski & Eckert 2007). Under climate change, peripheral populations may be better able to adapt to increased environmental variability and research suggests that peripheral populations often persist during events where core populations are extirpated (Safriel *et al.* 1994; Channell & Lomolino 2000a & b; Venter *et al.* 2006). Peripheral populations at the poleward-edge of species' distributions will also be critical to facilitating shifts in habitat range to track climate change (Hunter & Hutchinson 1994; Davis & Shaw 2001)

In Canada, a large portion of species at risk occur as peripheral populations at the northern extent of their range along the southern borders of the country (some examples include Barn Owl, Night Snake, Northern Bobwhite, Silver Hair Moss, Small-flowered Sand-verbena,

Tiny Cryptanthe, Townsend's Mole). Given that these populations are at the expected leading edge for northward range expansions under climate change, the conservation of Canadian peripheral populations of species at risk may become increasingly critical for the conservation of these species as a whole within North America. The potential for such range shifts calls into question the relative responsibility of Canada in the conservation of these species. If the climatic habitat range and core populations shift further into Canada and if habitat conditions become unsuitable in southern regions, populations currently deemed as peripheral may require reassessment in terms of conservation priority to take into account the new proportion of the species range that falls within Canada.

Another important consideration for the conservation of peripheral species at risk populations is their suitability for restoration or reintroduction programs. Both Safriel *et al.* (1994) and Channell and Lomolino (2000b) have cited the importance of peripheral populations in determining potential sites for ecological restoration and as a source for individuals that can be translocated to other sites. According to a study by Yakimowski and Eckert (2007), peripheral populations of the threatened vascular plant, Deerberry (*Vaccinium stamineum*), in southern Ontario may be well-suited to adapt to climate change-related shifts in growing conditions. Yakimowski and Eckert (2007) examined the population and reproductive characteristics of this species across its full geographic range and found that, although population size and occurrence of Deerberry are low in Ontario, these peripheral populations exhibit reproductive success equal to core populations. For this reason, Yakimowski and Eckert (2007) suggest that the preservation of these populations may serve as an important conservation tool in the era of climate change.

The targeted conservation of northern peripheral populations in southern Canada may also constitute a valuable investment in terms of the likelihood of successful recovery. Given a less restrictive warmer climate, Canadian peripheral populations could potentially become more prolific in Canada as climate change progresses, particularly in cases where populations in the core growing range of the species are more robust due to more suitable climatic growing conditions. For example, Bowles (2007) noted that northern peripheral populations of the endangered Wood-Poppy in southern Ontario have increased during the past decade and suggests that this trend may be linked to warmer temperatures. Although the Wood-Poppy has been most recently threatened by habitat loss and degradation, this species has always been considered naturally rare in Canada and is disjunct from the more stable core populations of the species in Virginia, Kentucky and southern Illinois. The theorized response of the Wood-Poppy to warmer temperatures over the past decade may therefore be indicative of a typical response to climate change by peripheral populations limited by Canada's colder growing conditions.

However, many northern peripheral species at risk populations are clustered in areas of Canadian 'biodiversity hotspots' where climatic conditions are the warmest, namely southwestern British Columbia and southern Ontario, and have become endangered because of the co-incidence of these regions with high levels of anthropogenic land-use. As a result, the potential for range expansions in these regions may be severely diminished due to lack of habitat availability and connectivity and the inability of remaining small populations to effectively disperse northward. It is for these reasons that many of the endangered species existing as northern peripheral species in Canada were classified as "insufficient information" throughout the screening level assessment process, as it is unclear if current threats to habitat will be sufficiently mitigated to allow for climate change-related dispersal.

5.1.3. Protected areas and shifts in species range

Many remaining populations of endangered species occur in protected areas where threats from human disturbance are at a relative minimum. Under climate change, species that respond to changing conditions by shifting their range will potentially move out of protected areas boundaries and, in the case of national parks and other protected areas under federal jurisdiction, may lose the direct protection afforded by SARA to conserve these species' critical habitat¹⁶.

Species that are highly mobile may be most likely to shift their range in response to climate change and may be among the earliest species to be influenced by loss of protection from protected areas. For example, the Swift Fox is an endangered species that was extirpated in Canada and has been reintroduced via captive-bred populations into designated areas of suitable habitat in the southern prairies, including Grasslands National Park (Carbyn 1998; Pruss *et al.* 2008). While these reintroduced populations have achieved success in their reestablishment into the wild, they are still small in number and exist in isolation from the core Swift Fox range in the south-central United States. As a result, both long-term and short-term (during unfavourable years) climate change-related shifts that move reintroduced populations away from the protection of park boundaries may increase the impact of anthropogenic threats to individuals and their habitat, and populations across current Canadian Swift Fox range are unlikely to be bolstered by influxes of individuals from the disjointed population in the south. In the case of the Grasslands National Park population, the preservation of suitable natural areas northward of the park boundaries could be critical to sustaining this population in Canada. The potential for range

¹⁶ Excepting species listed under the Migratory Birds Convention Act or aquatic species

shifts among the Swift Fox and other species at risk highlight the need to plan for climate change-induced migration among and between protected areas.

Several studies have identified the challenge that climate change may pose for protected areas management and policy in Canada (Scott & Suffling 2000; Scott *et al.* 2002; Lemieux & Scott 2005; Scott & Lemieux 2005; Welch 2005) and Scott and Lemieux (2005) have identified broad strategies to facilitate climate change planning and adaptation within Canada’s protected areas system (summarized in Table 5.1). Given that protected areas are the foremost tools of biodiversity conservation, most of these strategies have direct benefits for species at risk conservation under climate change (see also Recommendation 6.1.6.).

Table 5.1. Climate change-related management and policy strategies for protected areas agencies (Adapted from Scott & Lemieux 2005)

System Planning and Policy	Expand the protected areas network and individual protected areas where possible
	Improve natural resource planning and management to focus on preserving and restoring ecosystem functionality and processes across regional landscapes
	Selection of redundant reserves
	Selection of new protected areas on ecotones ¹⁷
	Selection of new protected areas in close proximity to existing reserves
	Improve connectivity of protected area systems
	Regularly assess protected areas legislation and regulation in relation to past, anticipated or observed impacts of climate change
Management	Include adaptation to climate change in the management objectives of protected areas
	Implement adaptive management
	Enhance the resiliency of protected areas to allow for the management of ecosystems and their processes and services, in addition to certain species
	Minimize external stresses to facilitate autonomous adaptation
	Eliminate non-climatic internal threats
	Create and restore buffer zones around protected area cores
	Implement ex-situ conservation and translocation strategies if appropriate
	Increase management of the matrix for conservation
	Mimic natural disturbance regimes where appropriate
Revise protected area objectives to reflect dynamic biogeography	
Research and Monitoring	Make further resources available to aid research on the impacts of past and future climate change
	Utilize parks as long-term integrated monitoring sites for climate change
	Identify specific values at risk to climate change

¹⁷ An ecotone is a zone of transition between two distinct ecosystem types that is known to be ecologically responsive to small changes in climate.

	Regional modeling of biodiversity response to climate change
	Incorporate climate change impacts into state-of-the-environment reporting
Capacity Building and Awareness	Strengthen professional training and research capacity of protected area staff with regards to climate change
	Capacity building and awareness should proceed with the goal of securing public acceptance for climate change adaptation
	Foster partnerships/collaboration with greater (regional) park ecosystem stakeholders
	Improve collaboration/stewardship from local to international scales
	Make resources available for investing in active, adaptive management
	Develop precautionary approaches (such as disaster preparedness and recovery systems) through forecasting, early warning and rapid response measures, where appropriate

5.1.4. Potential for increasing number of species at risk under climate change

In addition to potentially exacerbating threats to current species at risk, research suggests that climate change will increase the number of species facing extinction globally (Thomas *et al.* 2004; IPCC 2007a). In her review of U.S. endangered species policy, Bloomgarden (1995) suggests that an increasing number of species being imperiled by climate change will undermine the effectiveness of the U.S. Endangered Species Act to protect both individual species and biodiversity as a whole. Species at risk management and policy in Canada may face a similar fate if species not previously at risk become rapidly threatened as their environment changes (see also Recommendation 6.1.4).

The projected imperilment of Arctic species under climate change (Arctic Climate Impact Assessment [ACIA] 2004; Fischlin *et al.* 2007) may present the greatest challenge to conservation in Canada. As reviewed in Huntley (2005), historical evidence suggests that in cases where the persistence of an entire biome is threatened by climate change the extinction of species associated specifically with that biome is likely. Although the entire disappearance of arctic and subarctic biomes in Canada is not projected under 21st century climate change, these biomes are expected to shift substantially northward and present-day arctic and subarctic regions will transition to boreal forest (Rizzo & Wiken 1992; Lenihan & Neilson 1995; Lemieux & Scott

2005; Wood 2007). According to the IPCC (Fischlin *et al.* 2007), arctic and subarctic ecosystems are globally the most vulnerable ecosystems to climate change and, in Canada, the capacity for range shifts of many species may be further limited by the terrestrial discontinuity between mainland Canada and the high Arctic islands (Kerr & Packer 1998). Consequently, although species in this region are relatively less threatened by local anthropogenic stressors than southern ecosystems, Arctic species are likely to have the highest rates of imperilment in Canada over the next several decades. An emerging species at risk management issue is if and how to provide for the protection of these species.

The Polar Bear is among the most publicly recognizable Arctic species and the potential impact of climate change on the Polar Bear has been the subject of significant media attention in recent years (i.e., Broder & Revkin 2007; Savory 2008). Under climate change, the Polar Bear is theorized to be threatened by projected reductions in sea ice and changes in the marine trophic structure that will limit the accessibility and availability of its food sources (Derocher *et al.* 2004; Stirling & Parkinson 2006). Preliminary evidence indicates that the Polar Bear population in the western Hudson Bay region near the southern periphery of the species range has experienced recent climate change-related population declines (Stirling & Parkinson 2006; Fischlin *et al.* 2007).

The conservation status of the Polar Bear has been debated both in Canada and internationally over the past several years. In 2006, the IUCN added the Polar Bear to its *Red List of Threatened Species* and in May 2008, after extensive consultation, the U.S. Fish and Wildlife Service (2008a) listed the Polar Bear as a threatened species¹⁸ under the U.S.

¹⁸ Under the U.S. Endangered Species Act (1973), a threatened species is defined as “any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range (s. 4 [20], p. 4).”

Endangered Species Act. In Canada, COSEWIC first assessed the status of the Polar Bear as not at risk in 1986; this status was upgraded to special concern in 1991, which has been subsequently reconfirmed by COSEWIC assessments in 1999 and 2002 (COSEWIC 2002m). The listing of the Polar Bear under Schedule 1 of SARA was delayed for consultation with the Nunavut Wildlife Management Board and has currently been referred back to COSEWIC for further assessment to incorporate traditional knowledge as well as new scientific knowledge (Government of Canada 2005). The listing of the Polar Bear in both Canada and the United States is controversial because it calls into question the legal obligations of the federal government to respond to the identified threat of climate change for this species and its critical habitat (see section 5.2 for further discussion of the legal implications of Polar Bear listing with respect to Canadian and American legislation). Decisions to list the Polar Bear or other large Arctic mammals such as the Peary Caribou under Schedule 1 of SARA may therefore set precedent for the protection and management of all species at risk threatened by climate change in Canada.

5.1.5. Protection of species unlikely to survive under projected future climate change

As discussed in section 5.1.1 above, all species at risk may be inherently vulnerable to impacts associated with rapid climate change. However, it should also be noted that many species at risk may be on a path to extinction due to natural, biological factors; while these species' situations may be exacerbated by human influences, it is important to make distinctions between these species and those that are particularly at risk from non-natural stressors. The screening level assessment approach used in this study examines species on a case by case basis and allows for the identification of species that exhibit considerable sensitivity to climate change and that may be important targets for further research or for key management decisions. Via the

screening level assessment of endangered species, clear cases emerged in which climate change impacts would make the survival and recovery of a species across its current range very challenging.

Under climate change, species at risk managers may be faced with difficult ethical and legal questions regarding the appropriate level of managerial intervention to preserve species at risk. In cases where a species' habitat is currently or projected to be significantly altered across its distribution and where the species is unlikely or unable to adapt to changing conditions, a possible management option is to abandon recovery efforts. By abandoning species' recovery programs with little chance of success, scarce resources for species at risk management can be strategically directed in a manner that will maximize the preservation of biodiversity as a whole.

For example, current evidence suggests that the endangered Atlantic-Gaspésie population of the Woodland Caribou and the Vancouver Island Marmot are already being negatively affected by climate change impacts and, unless radical measures are taken, climate change will virtually eliminate the potential for these species' recovery across their current range. In the case of the Woodland Caribou, the species ranges across much of Canada and the designations of different populations range from not at risk, special concern, threatened and finally the endangered Atlantic-Gaspésie population (Thomas & Gray 2002). Although climate change may negatively impact all Woodland Caribou populations, the existence of the Atlantic-Gaspésie population at the southern periphery of its range, its small and isolated populations and threats to the species' habitat due to climate change and other stressors greatly reduce this population's recovery potential. In contrast, the Vancouver Island Marmot is a species endemic only to Vancouver Island. Climate change-related shifts in treeline are thought to have already played a significant role in the loss of this species' sub-alpine meadow habitat, and future projections

suggest that continued encroachment of the treeline will diminish suitable habitat area to a size that will be unable to support a self-sustaining population of this species (Hebda 1998; Milko 1984 and Nagorsen *et al.* 1996 as cited in Bryant 2000; Sinclair & Byrom 2006). If abandoning the recovery of species unlikely to survive under climate change is considered an acceptable management option, these two examples illustrate the need for established priorities by which the value (or alternately the expendability) of a species can be determined as well as the acceptable level of management allowed to facilitate species recovery (see also recommendation 6.1.4).

5.2. Analysis of the Species at Risk Act in the context of future climate change

While the United Nations CBD does not explicitly address climate change in its framework, it operates in an interrelated and mutually supportive manner with the UNFCCC. Canada's response to the United Nations CBD, the Canadian Biodiversity Strategy (1995), explicitly acknowledges climate change and identifies strategic directions to improve the assessment of the potential impacts of climate change on biodiversity and to implement measures to reduce negative climate-related impacts (see Table 2.5 above). SARA was created to assist in fulfilling Canada's obligations under the United Nations CBD and the Canadian Biodiversity Strategy. With this in mind, the following section examines SARA in the context of future climate change and identifies key limitations and opportunities.

The purpose of SARA (2002, s. 6) is “to prevent wildlife species from being extirpated or becoming extinct, to provide for the recovery of wildlife species that are extirpated, endangered or threatened as a result of human activity and to manage species of special concern to prevent them from becoming endangered or threatened (p. 8).” The Act later goes on to state that in addressing threats to species at risk, the competent minister is mandated to consider the Government of Canada's commitment to “conserving biological diversity and to the principle

that, if there are threats of serious or irreversible damage to a wildlife species, cost-effective measures to prevent the reduction or loss of the species should not be postponed for a lack of full scientific certainty (SARA 2002, s. 38, p.21-22).”

Based on these statements, a fundamental first question is whether climate change qualifies as a human activity that puts species at risk under SARA. Given that the IPCC (2007a & b) has concluded that warming of the climate system is attributable¹⁹ to human activities over the past several centuries and that climate change has already had a discernable impact on both biological and physical systems in recent decades, it is now generally accepted that humans are the primary cause of ongoing climate change and as such must assume responsibility for its impacts. So far, none of the endangered species listed on Schedule 1 of SARA and assessed in this screening level assessment have become endangered primarily as a result of climate change²⁰. While climate change is expected to become a leading stressor of biodiversity over the next century (Sala *et al.* 2000; Thomas *et al.* 2004; Thuiller 2007) and, based on the results of this screening level assessment, is likely to have an overall negative impact on the majority of endangered species in Canada, significant uncertainty remains in delineating climate change as a direct or indirect threat to individual species at risk. Therefore, a critical interpretation of SARA in the context of future climate change will be when the scientific evidence for the link between climate change and the imperilment of individual species is sufficiently established to justify measures to prevent species loss from climate change. However, as discussed in section 5.1.4., species in the Arctic regions of Canada are expected to become rapidly imperiled as climate change progresses. The more minimal influence of other anthropogenic stressors in this region relative to southern Canada means that the link between climate change and the imperilment of

¹⁹ The IPCC (2007a) concluded that global temperature increases since the mid-20th century are very likely (>90% confidence) due to increases in anthropogenic GHG emissions

²⁰ A possible exception being the Vancouver Island Marmot

Arctic species will be less ambiguous should Arctic species such as the Polar Bear or Peary Caribou be listed under Schedule 1 of SARA.

If actions to reduce the threat of climate change to listed species at risk are deemed warranted, it is unclear what constitutes “cost-effective” measures to reduce this threat. Climate change mitigation via atmospheric greenhouse gas reductions is likely the most effective means of reducing the threat of climate change to all species at risk. While the costs of this activity may be considered very much disproportional to the value of a single species protected individually under SARA, the costs of climate change mitigation may become more fitting if species losses are considered en masse in terms of overall impact on biodiversity. However, since some climate change is projected to occur over the next century in spite of any current or future mitigation efforts, climate change adaptation measures will need to be used in conjunction with or instead of mitigation to facilitate the adjustment of species to climate change. Climate change adaptation efforts can be implemented at more targeted species or regional scales and should have current as well as future benefits under climate change; when seen in this way, adaptation may be considered a more desirable or suitable option as a “cost-effective measure” to prevent species loss under SARA’s mandates.

The protection of critical habitat is of interest in the context of climate change for both American and Canadian species at risk legislation. Under SARA (2002, s. 2[1]) critical habitat is defined as “the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species’ critical habitat in the recovery strategy or in an action plan for the species (p.4).” SARA (2002, s. 41[1c]) requires that in the preparation of recovery strategies the species critical habitat be identified to the extent possible and based on best available information. If the critical habitat is located on federal land, or pertains to any aquatic

species or migratory birds listed under the *Migratory Birds Convention Act*, the destruction of the critical habitat is prohibited under SARA (SARA 2002, s. 58[1]); if the critical habitat is not under federal jurisdiction, SARA provides mechanisms by which the competent minister can order or regulate its protection (SARA 2002, s. 58[4] & 59). The interpretation of this clause has the potential to carry substantial weight in terms of mandating federal action to mitigate climate change in order to prevent the destruction of critical habitat threatened by climate change. Unlike the protection of individuals, where the direct influence of climate change is less easily attributed, trends in critical habitat change can be more clearly linked to long-term and larger scale influences such as climate change, particularly in the case of habitats for wide ranging mammals.

Under the U.S. Endangered Species Act, a similar, but more restrictive clause is of significant legal controversy with regard to the listing of the Polar Bear. According to the Act, all U.S. federal agencies must ensure that any action they authorize, fund or carry out is not likely to jeopardize the existence of endangered or threatened species or destroy or adversely modify their critical habitat (U.S. Endangered Species Act 1973, s. 7a[2]). However, the U.S. Fish & Wildlife Service (2008b) asserts that the Endangered Species Act is intended to remove threats that target individuals of a species, and cannot be used to regulate broad-based activities that contribute to global climate change due to a lack of a direct cause and effect link between local climate change inducing activities and the imperilment of individual polar bears. Moreover, although the Polar Bear was recently listed as a threatened species under the U.S. Endangered Species Act, the U.S. Fish & Wildlife Service (2008b) did not define its critical

habitat due to the variability and instability of the sea ice utilized by the Polar Bear and an inability to prevent the loss of sea ice within a reasonable time period²¹.

In Canada, it remains unclear if the listing and protection of the critical habitat of species such as the Polar Bear will have ramifications for the responsibility of Canada to mitigate climate change. Although the relationship between Polar Bear sea ice habitat identified by COSEWIC (2002m) and anthropogenic climate change is scientifically well-understood, the Polar Bear is not yet listed under Schedule 1 of SARA, and therefore its critical habitat has not yet been defined within an action plan or recovery strategy. If federally-managed sea ice is identified as critical habitat for this species and if the Polar Bear is listed on Schedule 1 of SARA as a threatened or endangered species²², its critical habitat would be prohibited from destruction. Under SARA, this prohibition is relatively open to interpretation in terms of the appropriate scale of federal action to prevent critical habitat destruction. A decision in Canada to list the Polar Bear (or other wide-ranging Arctic species, such as the Peary Caribou) as a species at risk and the definition and protection of its critical habitat will likely determine if or how threats from climate change will be addressed for all species at risk.

A key weakness in the protection of species under SARA in the context of future climate change is its core definition of a wildlife species. According to SARA (2002, s. 2[1]), a wildlife species is defined as “a species, subspecies, variety or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and (a) is native to Canada; or (b) has extended its range into Canada without human

²¹ According to the U.S. Fish & Wildlife Service (2008b), “There are currently no steps that can be taken to halt the decline in sea ice. Even collective, international action to moderate climate change will take 50-75 years to alter the current trends in sea ice decline (p.4).”

²² Prohibition of the destruction of critical habitat or individuals is not mandated for species of special concern.

intervention and has been present in Canada for at least 50 years²³ (p.7).” Under climate change, Canada may experience an influx of new species from the south as species shift their range northward and, similar to the debate on invasive species (section 5.1.1.1), it is unclear whether species that extend their range into Canada would be considered to have done so via “human intervention” (and are therefore omitted from protection under SARA) or as a natural, autonomous adaptation to a changing environment. If range shifts are considered to be a natural adaptation to climate change, then species will only be eligible for protection under SARA after having dwelt in Canada for 50 years. It is possible that some species that emigrate into Canada already meet the criteria of a species at risk under international jurisdictions or species that shift into Canada may become rapidly threatened across their full range if northward range expansions are insufficient to compensate for southern range contractions. In such instances, the responsibility of managing these species may increasingly fall within Canadian jurisdiction. Given that Thomas *et al.* (2004) determined that 15-37% of the species they assessed on a global scale will be committed to extinction by 2050 under mid-range climate change scenarios, an inability under SARA to protect new species in Canada for 50 years could thwart actions necessary to prevent the eventual extinction of some species (see also Recommendation 6.1.1)

While the appropriate response to address the threat of climate change for individual species at risk listed under SARA requires decision-making beyond the scope of this discussion, parts of SARA make provisions for tools that can be used in the local and regional adaptation of species and ecosystems to climate change. In its preamble, SARA (2002) notes, “Canada’s protected areas, especially national parks, are vital to the protection and recovery of species at risk (p. 2)” and the Act makes provisions for cooperation and compensation among private

²³ The Act goes on to say, “a species, subspecies, variety or geographically or genetically distinct population is, in the absence of evidence to the contrary, presumed to have been present in Canada for at least 50 years (SARA 2002, s. 2 [1] (2), p. 7).”

landholders and interested parties in the protection and recovery of species and their critical habitat (i.e., SARA 2002, s. 10 – 13). In this way, SARA provides a legislative base by which some climate change adaptation strategies can be rationalized and implemented, such as the creation of connective corridors of natural spaces that allow for migration and dispersal of species under climate change (see also Recommendation 6.1.6[i]). SARA also allows for a multi-species or ecosystem approach to be taken when planning the recovery of a species, if appropriate to do so (SARA 2002, s. 41[3]). In most cases, ecosystem scale management, rather than the management of individual species, is considered to be a more effective means of conserving biodiversity under climate change, particularly if large numbers of species become increasingly threatened (Bloomgarden 1995; Lovejoy & Hannah 2005; Scott & Lemieux 2005). While SARA protects species individually, its allowance of larger scale management approaches may be critical for effective management under future climate change if rates of species imperilment continue to increase (see also Recommendation 6.1.6.[ii]). Furthermore, in the preparation of species recovery strategies, SARA states that the competent minister must determine whether the recovery of a listed wildlife species is technically and biologically feasible (SARA 2002, 40). As discussed in section 5.1.5, a possible strategy to maximize the efficiency and success rate of resources allotted for species at risk protection may be to abandon management efforts for species with minimal chances of survival under climate change. This clause provides a possible mechanism under SARA for such decisions to be made once best available information is amassed and possible recovery actions, costs and priorities are explored.

CHAPTER 6: RECOMMENDATIONS AND CONCLUSIONS

Through the identification of climate change related impacts common to many species at risk and the analysis of SARA, a number of potential adaptation options emerged by which climate change can be better incorporated into species at risk conservation practices. The following section presents recommendations for species at risk management and policy and for further research in this area. The section concludes with a summary of key messages and an overview of recurrent themes throughout this thesis.

6.1. Recommendations for management and policy

6.1.1. Revise the definition of wildlife species under SARA

As discussed in section 5.2, the current definition of a wildlife species under SARA that requires species to reside in Canada for 50 years before they are eligible for protection fails to make allowances for rapidly shifting species ranges under climate change and for the potential emigration of southern species requiring protection. An example of an alternate criteria for duration of residence in Canada in the era of climate change is COSEWIC's timeframe for assessing population trends among species at risk candidates. COSEWIC (2007a) establishes population trends after they have been measured for three consecutive generations of the species or for ten years, whichever is longer. A similar timeframe to measure newly established, reproducing species in Canada would allow for species that emigrate northward in response to climate change to become eligible for protection under SARA in a timely manner, but would omit individuals that migrate temporarily during favourable or unfavourable years.

6.1.2. Consider the potential impact of climate change in all COSEWIC status assessments

COSEWIC status reports follow a standard format and according to COSEWIC instructions climate change can be listed under the heading of “limiting factors and threats” if experimental data indicates that the species has demonstrated a particular sensitivity to changes in climate (COSEWIC 2007g). This overlooks the potentially positive impacts of climate change that may be relevant to classification and listing decisions and undermines the broader role in which climate change has on ecosystem structure and functioning. Instead, it is recommended that the potential impacts of climate change (positive or negative) be assessed for each species at risk across its full geographic range in order to better inform listing decisions and to identify multi-scale impacts of climate change that may influence species and their habitat.

6.1.3. Incorporate climate change into species at risk recovery strategies and management plans

Information from the assessment of climate change in COSEWIC status reports should be considered and incorporated into the species recovery strategies and management plans that are prepared by the responsible federal department once a species is listed under SARA. Climate change may have a large influence on the effectiveness of a species recovery strategy or management plan over the long-term and should be a determinant when evaluating the suitability and feasibility of a species for recovery action, particularly when strategies such as species reintroductions are being considered.

6.1.4. Identify important species at risk values to guide decisions regarding the priority of a species for conservation

In her analysis of the U.S. Endangered Species Act, Bloomgarden (1995) recommends that higher priority be given to more “critical” species that play greater roles in ecosystem processes and services. The adoption of a similar policy in Canada may be required to

compensate for increasing rates of species imperilment under climate change. While questions beyond the scope of this thesis may be raised regarding the ethics and legality of assigning priority and resources to the protection of certain species above others, the limited resources allotted for species at risk management mean that such a strategy may be a more effective means of maximizing overall biodiversity. Bloomgarden (1995) recommends that keystone²⁴, umbrella²⁵ and indicator²⁶ species be priority targets for conservation under climate change. Other factors that may influence the priority of a wildlife species can be drawn from the criteria for COSEWIC status assessments and species recovery strategies/management plans and could include the species' taxonomic level, its endemism in Canada, its relative social and economic value and the feasibility and costs associated with the species' management and recovery.

6.1.5. Clarify the definition of an invasive species under climate change

As discussed in section 5.1.1.1, climate change will facilitate the success of existing invasive species in Canada, as well as facilitate the northward migration of native species that may compete with current species at risk populations. The potential for northward migrating species to negatively impact species at risk, calls into question the definition of an invasive species in the context of future climate change. While no specific reference is made to invasive species in SARA, Environment Canada (2004) recently produced a national strategy to remove and manage threats from "invasive alien species". According to the strategy, "alien" refers to species that are introduced by human action outside their current or historic distribution whereas the definition of "invasive alien species" is narrowed to include only alien species that cause

²⁴ A keystone species refers to a species that exerts significant influence on the ecological assemblage in which it is associated (Paine 1995).

²⁵ An umbrella species refers to a species whose preservation confers protection to a large number of co-occurring species (Roberge & Angelstam 2004).

²⁶ An indicator species refers to a species that can be used to monitor and assess conditions of the ecological assemblage in which it is associated (Noss 1990).

harm or threaten the environment, the economy, or society (Environment Canada 2004). While this definition justifies managerial action to control the threat of existing invasive alien species in Canada if they proliferate under anthropogenic climate change, the managerial response to native North American species that extend their range as a result of climate change and have a invasive (harmful) effect on species at risk is unclear. Guidelines are needed to address cases of “invasion” by southern species moving autonomously northward in response to anthropogenic climate change; similar to recommendation 6.1.4 above, such guidelines may require difficult decisions regarding the relative values and controls placed on species and ecosystems under climate change and the responsibility of humans to assist species adversely affected by anthropogenic climate change impacts.

6.1.6. Implement protected areas’ climate change adaptation strategies with broad focus on biodiversity conservation

Protected areas are Canada’s foremost tools for conservation and operate in conjunction with SARA to manage species at risk populations. Climate change adaptation strategies outlined by Scott and Lemieux (2005) (Table 5.1) for Canada’s protected areas system are broadly applicable to the conservation of species at risk and biodiversity as a whole. It is recommended that the following core strategies drawn from Scott and Lemieux (2005) be utilized as a focus for facilitating ecological adaptation to climate change among species at risk in Canada:

(i) Strategically facilitate connective ecological corridors for species migration

Scott and Lemieux (2005) list several means by which connective ecological corridors can be facilitated, including expanding the protected areas network, increasing management of the matrix of land between protected areas and strengthening cross-jurisdictional ecological management. Emphasis on stewardship and collaboration and the protection of critical habitat under SARA provide a base by which activities relating

to the development of connective corridors can be pursued. Priority species at risk should be considered in the planning of ecological corridors.

(ii) Implement adaptive ecosystem based management in addition to protecting priority species at risk

A point of contention among climate change adaptation for protected areas and species at risk policy is the concept of ecosystem management, in which the focus of management is on the integrity of the whole ecosystem rather than on individual species.

Bloomgarden (1995) and Scott and Lemieux (2005) identify the need for a conservation approach under climate change that emphasizes the management of ecosystems in addition to focusing on priority species. Utilizing an ongoing, adaptive ecosystem approach to conservation is the best means of preserving biodiversity and ecological processes and services under climate change, while targeting individual species management efforts at priority species at risk ensures that species that are vital to Canadian heritage and ecosystem integrity are preserved.

(iii) Minimize other stressors

While the mitigation of the anthropogenic causes of climate change is the best means of removing the threat of climate change itself, it requires costs that may be disproportionate to the value of a single species. More local threats to species at risk are easier and less costly to mitigate. Minimization of non climate change-related stressors will improve the resilience of species and ecosystems and will enhance their capacity to adapt to climate change autonomously.

6.2. Recommendations for research

6.2.1. Conduct screening level assessment for threatened species and species of special concern

Due to time constraints, this study focused only on assessing the potential impact of climate change on endangered species in Canada. Species classified as threatened and special concern should also be screened in a similar manner to help identify priority species for further in-depth assessment and to better understand the management and policy needs of these species. Threatened species and species of special concern have larger populations and significantly more potential for recovery/preservation and therefore may benefit from different climate change impact studies or adaptation strategies than endangered species.

6.2.2. Conduct in-depth climate change analyses for priority species at risk

As discussed in section 3.2, formal consultation with a panel of species experts to examine potential species responses to the projected impacts of climate change was an approach considered as a second phase of this thesis. While this phase was not realized due to resource and time constraints, it is recommended as a next step in advancing understanding of the implications of climate change for species at risk and in connecting the results of this thesis with species at risk managers and policymakers.

Furthermore, based on values identified for priority species at risk (per recommendation 6.1.4 above), species can be selected for more in-depth climate change assessment and modeling, which require more time and resources, but also provide more detailed information and scenarios. Good candidates for more in-depth assessment would include species with known sensitivities to climate change that can serve as representative examples of species at risk across Canada. Further in-depth assessment will also help to guide difficult decisions regarding the

feasibility and suitability of continued recovery efforts for certain species at risk under climate change and longer-term habitat responses.

6.2.3. Improve modeling capabilities to better incorporate species and ecosystem processes with stressors that operate at multiple spatial and temporal scales

The difficulty in reconciling the scales at which climate, other stressors and ecological processes operate is an ongoing point of contention among the research community, particularly when considering the usability of climate-ecological projections to guide management and policy decisions (i.e., Schmitz *et al.* 2003). While climate envelope modeling currently provides the best means of quantitatively projecting the future impacts of climate change at the individual species level, integrated models are needed that can provide more comprehensive projections of the influence of climate change and other stressors on species and ecosystems. As new modeling technologies emerge, they may be a critical resource in better informing decisions regarding the prioritization and conservation of species at risk.

6.2.4. Explore assisted colonization of species at risk under climate change

While current species at risk recovery practices stress that the introduction of species should align with remaining populations and historically known ranges, a number of authors suggest that assisted colonization of species in regions outside of known ranges may become an increasingly relevant species conservation practice under climate change (Kutner and Morse 1996; Hunter 2007; McLachlan *et al.* 2007; Hoegh-Guldberg 2008). However, conservation policies that incorporate climate change are still in the process of being developed and need to be better informed with respect to the feasibility and suitability of assisted colonization as an adaptation strategy to prevent species extinctions under climate change. Hunter (2007) and McLachlan *et al.* (2007) outline a number of areas for further research that can inform

conservation policies with respect to assisted colonization, including the assessment of appropriate thresholds to trigger assisted colonization, the design of assisted colonization programs to minimize potentially adverse impacts, and the public perception and acceptance of assisted colonization practices. Furthermore, per recommendations 6.2.2 and 6.2.3 above, improved modeling capabilities and more in-depth understanding of individual species threatened by climate change are needed to better identify suitable candidate species and candidate sites for assisted colonization (Kutner and Morse 1996; Hunter 2007; McLachlan *et al.* 2007). By initiating research now, a more sound scientific basis will be in place to guide decisions to pursue or reject assisted colonization as a viable species at risk management practice under climate change.

6.3. Conclusions

Climate plays an overarching role in the distribution of species and ecosystems, but the rapidity with which climate change is projected to occur over the 21st century may push the limits of ecological adaptability, to the detriment of global biodiversity. In Canada, the impact of climate change on national parks and protected areas has been the subject of recent research and policy attention, but the vulnerabilities and needs specific to species at risk in the era of climate change have been largely overlooked.

This screening level assessment evaluated the potential impacts of climate change on endangered species listed under Schedule 1 of SARA by integrating knowledge of the current status and characteristics of each species with projections of climate change and climate change impacts. It was determined that climate change may have a potential overall negative influence on more than half of all endangered species in Canada. However, while relatively few species were predicted to respond in an overall positive or neutral manner to climate change, a large

portion of endangered species were classified as having insufficient information to generate a decision on the net influence of climate change; in many cases, these species had the potential to experience at least some positive benefits under climate change in Canada. Furthermore, it is important to note that these assessments are not definitive prognoses of the fate of endangered species under climate change. These assessments are dependent on the application and interpretation of current information for each species and are subject to change as further information becomes available. As such, they should be considered as a starting point for discussion on species at risk research, management and policy in the context of anthropogenic climate change.

Due to their small populations, limiting biological traits and exposure to external threats, all species at risk are inherently vulnerable to rapid shifts in climate, as well as climate variability and extreme weather and disturbance events. The potential for increasing rates of species imperilment under climate change, particularly in the Arctic regions of Canada, stresses the need for anticipatory planning and strategy to ensure that species at risk management and policy maximizes biodiversity and minimizes species extinctions in an effective and efficient manner. It is recommended that climate change be systematically considered in all COSEWIC status assessments and species recovery strategies and management plans; this will guide the establishment of values and priorities for species at risk research and conservation and will inform the development of adaptive strategies that assist species and ecosystems to adjust to climate change.

While climate change clearly represents a significant challenge to species at risk conservation, it should also be noted that climate change simultaneously represents an opportunity for the successful recovery of some species at risk in Canada. Many of the

endangered species listed under Schedule 1 of SARA exist as peripheral populations at the northern extent of their range in warmer regions of Canada. Climate change may aid the survival of these species in Canada, provided that sufficient measures are taken to ensure the resilience of these populations and the availability of their habitat.

Considering the UNFCCC's (1997) objective to "prevent dangerous anthropogenic interference with the climate system" within a timeframe to "allow ecosystems to adapt naturally," a particularly relevant theme that recurred throughout this thesis was the ethics of conservation in a changing climate. With the onset of global climate change, the influence of anthropogenic activities on ecological systems is now pervasive and calls into question the acceptability of ecological impacts from climate change and the appropriate limits of managerial actions to manage these impacts. It can be argued that climate change obligates increased management to mediate or counteract the ecological impacts of climate change, which, in this context, would be considered anthropogenically-derived rather than natural responses to a changing environment. On the other hand, imposing further anthropogenic control over ecological systems to manage climate change impacts could be seen as exacerbating the issue of human dominance over the natural environment, especially if the root causes of climate change itself have not been addressed. The ethicality of the recommendations outlined above to set "values" for species conservation under climate change, to reassess definitions of native wildlife species and invasive species and to explore assisted colonization as a conservation practice may be key points of contention in the debate regarding the appropriate response to the threat of climate change for species at risk.

It is hoped that the discussion presented here will encourage a more formal dialogue amongst the conservation community and amongst Canadians in general on the management and

policy needs of species at risk in the era of climate change. Such a dialogue will be complex and wrought with issues of uncertainty and ethicality, but it is urgently needed to guide the development of anticipatory and precautionary measures that can equip individual species and biodiversity as a whole with the best possible means of adapting to a rapidly changing environment.

APPENDIX 1

a) Projected annual mean temperature change in Canada according to CCCSN (2007) data using CGCM3T47, CSIROm3, GFDLCM2.1, GISSE-R, HADCM3, NCARCCSM3 in compliance with the IPCC's Fourth Assessment Report emissions scenarios and a baseline period of 1961-1990

Experiment	Annual Mean Temperature Change (°C)		
	Year 2025	Year 2055	Year 2085
AR4.CGCM3T47	1.141	1.081	N/A
AR4.CGCM3T47.1PTO4X	3.405	3.503	3.443
AR4.CGCM3T47.SR-A1B	0.896	1.45	2.054
AR4.CGCM3T47.SR-A2	0.744	1.6	2.594
AR4.CGCM3T47.SR-B1	0.667	0.945	1.286
AR4.CSIROMk3.1PTO2X	0.739	0.896	N/A
AR4.CSIROMk3.SR-A2	0.359	0.725	1.386
AR4.CSIROMk3.SR-B1	-0.004	0.28	0.628
AR4.GFDLCM2.1.SR-A1B	0.926	2.436	2.92
AR4.GFDLCM2.1.SR-A2	0.804	1.886	3.198
AR4.GFDLCM2.1.SR-B1	1.123	1.32	2.186
AR4.GISSE-R.1PTO2X	0.953	1.19	1.303
AR4.GISSE-R.1PTO4X	1.932	2.059	1.887
AR4.GISSE-R.SR-A2	0.314	0.671	0.993
AR4.GISSE-R.SR-B1	0.169	0.416	0.63
AR4.HADCM3.SR-A1B	1.071	2.42	3.88
AR4.HADCM3.SR-A2	1.183	2.251	3.754
AR4.HADCM3.SR-B1	1.113	1.85	2.457
AR4.NCARCCSM3.SR-A1B	1.442	2.188	2.677
AR4.NCARCCSM3.SR-A2	0.928	1.986	3.675
AR4.NCARCCSM3.SR-B1	0.999	1.632	1.979

b) Projected annual mean precipitation change in Canada according to CCCSN (2007) data using CGCM3T47, CSIROm3, GFDLCM2.1, GISSE-R, HADCM3, NCARCCSM3 in compliance with the IPCC's Fourth Assessment Report emissions scenarios and a baseline period of 1961-1990

Experiment	Annual Mean Precipitation Change (%)		
	Year 2025	Year 2055	Year 2085
AR4.CGCM3T47.1PTO2X	12.883	9.121	N/A
AR4.CGCM3T47.1PTO4X	10.17	17.064	21.517
AR4.CGCM3T47.SR-A1B	6.771	11.36	5.504
AR4.CGCM3T47.SR-A2	6.514	6.908	8.477
AR4.CGCM3T47.SR-B1	10.017	6.188	8.58

AR4.CSIROMk3.1PTO2X	3.473	6.158	N/A
AR4.CSIROMk3.SR-A2	7.456	9.903	19.801
AR4.CSIROMk3.SR-B1	8.087	9.863	7.825
AR4.GFDLCM2.1.SR-A1B	-0.303	-1.448	3.118
AR4.GFDLCM2.1.SR-A2	-1.941	-4.069	-1.254
AR4.GFDLCM2.1.SR-B1	-1.809	-0.244	-1.303
AR4.GISSE-R.1PTO2X	-3.569	-6.293	-4.801
AR4.GISSE-R.1PTO4X	-9.307	-17.737	-20.199
AR4.GISSE-R.SR-A2	-4.772	-7.213	-11.273
AR4.GISSE-R.SR-B1	-5.479	-7.134	-2.925
AR4.HADCM3.SR-A1B	-1.832	0.393	-1.684
AR4.HADCM3.SR-A2	-1.867	-4.526	-3.183
AR4.HADCM3.SR-B1	0.574	-5.817	0.251
AR4.NCARCCSM3.SR-A1B	-0.579	4.029	7.575
AR4.NCARCCSM3.SR-A2	2.204	0.376	8.236
AR4.NCARCCSM3.SR-B1	-1.443	1.226	2.868

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