Climate change vulnerability of Alberta's terrestrial biodiversity: A preliminary assessment

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Preface

The Alberta Biodiversity Monitoring Institute (ABMI) is an arm's-length, not-for-profit scientific organization. The primary goal of the ABMI is to provide relevant scientific information on the state of Alberta's biodiversity to support natural resource and land-use decision making in the province.

In the course of monitoring terrestrial and wetland ecosystems across the province, the ABMI has assembled a massive biodiversity database, developed reliable measurement protocols, and found innovative ways to summarize complex ecological information.

The ABMI undertakes focused projects to apply this capacity to specific management challenges, and demonstrate the value of the ABMI's long-term monitoring data to addressing these challenges. In some cases, these applied research projects also evaluate potential solutions to pressing management challenges. In doing so, the ABMI has extended its relevance beyond its original vision.

The ABMI continues to be guided by a core set of principles – we are independent, objective, credible, accessible, transparent and relevant.

This report was produced in support of the ABMI's Biodiversity Management and Climate Change Adaptation project, which is developing knowledge and tools to support the management of Alberta's biodiversity in a changing climate.

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Executive Summary

This report provides a broad overview of how Alberta species are likely to be affected by climate change by the 2050s. We used NatureServe's Climate Change Vulnerability Index (CCVI) to assess the relative vulnerability to climate change of 173 Alberta amphibian, bird, insect, mammal and vascular plant species.

Climate change vulnerability is the integration of a) exposure to expected climate change, b) inherent sensitivity of a species to altered climate, and c) the capacity of a species to adapt to possible change. We calculated exposure based on climate change projections calculated as the mean of 16 well-accepted global circulation models. Sensitivity and adaptive capacity were based on 24 factors derived from literature review, historical climate analysis and species distribution modeling. Exposure and sensitivity were integrated into a vulnerability score for each species. For each species assessed, sensitivity and exposure scores, relevant literature and results are available at http://www.biodiversityandclimate.abmi.ca/vulnerability-assessments/.

Amphibians were consistently found to be the taxonomic group having the greatest vulnerability to climate change of the six taxonomic groups assessed. Amphibians are vulnerable to climate change largely as a result of anthropogenic barriers to dispersal, narrow thermal and hydrological niches, and dependence on specific moisture conditions. Birds are the least vulnerable taxonomic group largely as a result of their excellent dispersal abilities. Comparisons among Natural Regions are more complex, however, with no distinct pattern emerging.

The CCVI does not explicitly incorporate species-at-risk criteria in its analysis, but nevertheless, vulnerability is highly correlated with at-risk status. This may be partly attributable to species-at-risk generally having small range sizes.

Of the 173 species assessed, most can be expected to expand or shift their ranges in response to climate change, if suitable habitat exists. Amphibians and reptiles are most likely to have difficulty in shifting their ranges as a result of dispersal barriers. Population movements by many vascular plants are limited primarily by poor dispersal ability.

The CCVI provides a useful overview of the vulnerability of Alberta species to climate change, but it does not provide the complete picture. One of the major uncertainties not addressed by the CCVI is the availability of suitable habitat in the future as species move and habitats change.

The analysis points to the importance of including climate change into management of species at risk, addressing barriers to dispersal, long-term monitoring of species distribution and abundance, and more detailed vulnerability analysis including prediction of potential future habitat.

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1 Introduction

The distribution, abundance and variety of Alberta's plants and animals have been shaped by the province's complex and diverse climates. Alberta's grasslands are inhabited by plants and animals evolved to endure hot, dry conditions. In the Rocky Mountains, steep elevation gradients result in large change in precipitation and temperature over short distances resulting in abrupt shifts in the plant and animal communities. In the boreal forest, resident species must be capable of withstanding seasonal temperature differences of more than 70°C.

But, Alberta's climate has been changing. Over the past 100 years Alberta's mean temperature has increased by 1.4°C with most of the increase occurring since 1970 (Schneider 2013). Between 1912 and 2011, the average annual temperature increased by 1.1°C (0.1 per decade) in the southern half of the province and double that (2.3°C or 0.2 per decade) in the north (Figure 1). Since 1970 the pace of warming has intensified with temperatures increasing at a rate of 0.3°C per decade in both the north and the south (Figure 1). Over the past ca. 100 years (1900 – 2004), precipitation has declined in central Alberta by 5% but has increased in the north by as much as 20% (Rodenhuis et al. 2007).

The recent changes in Alberta's climate are the likely cause of recent changes in distribution, phenology and demography of Alberta plants and animals that are just now beginning to be documented. Beaubien and Freeland (2000) and Beaubien and Hamann (2011) documented earlier blooming dates for several Alberta plants species over a period of 71 years. Brown (2013) concluded that climate warming is driving alpine treeline ecotones to high elevations in the Kananaskis Valley. Landhäusser et al. (2010) suggest that aspen is replacing coniferous forest in the mountains of west-central Alberta as a result of forest management practices in conjunction with a warming climate. Dawe (2011) and Dawe et al. (2014) identify warmer, shorter winters as the predominant factor explaining expansion of white-tailed deer (*Odocoileus virginianus*) in Alberta. Lane et al. (2012) show that female Columbian ground squirrels are emerging from hibernation later as a result of the increasing prevalence of late-spring snowstorms in the Alberta foothills.

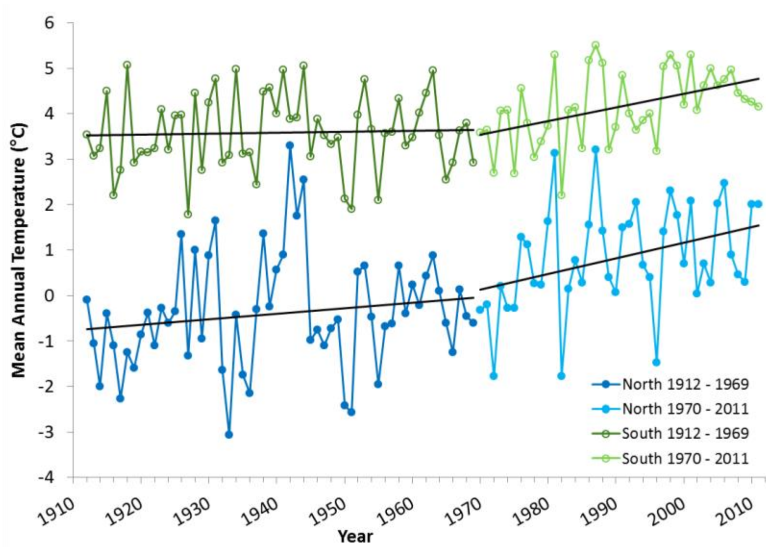

Figure 1. Mean annual temperature averaged over five northern Alberta weather stations (Beaverlodge, Fort Chipewyan, Fort McMurray, Fort Vermilion and Peace River) and five southern Alberta weather stations (Calgary, Camrose, Lacombe, Olds and Pincher Creek) from 1912 to 2011. Data from Environment Canada Homogenized Surface Air Temperature Data at http://ec.gc.ca/dccha-ahccd/)

By 2050, Alberta's mean annual temperature is expected to increase by 2.5 – 3.5°C depending upon the climate model and emission scenario considered (Figure 4.3 in (Schneider 2013)). Annual precipitation is expected to increase, but higher temperatures will lead to greater evapotranspiration (Schneider 2013) and a possible doubling in severe drought frequency (Bruce 2011). Alberta species will be required to respond to projected changes in climate by adapting *in situ* or by shifting their ranges to more northerly or higher elevation sites or, at some time in the future, they may become provincially extinct.

The challenge is to understand how society could best respond to these changes in such a way as to protect, maintain and enhance the values and benefits provided by Alberta's biodiversity. To do so, we need a better understanding of how climate change will affect the province's plants and animals.

Here we use NatureServe's Climate Change Vulnerability Index (CCVI)[1] to provide a general overview of how a wide spectrum of terrestrial plants and animals is likely to respond to Alberta's projected climate in the 2050s. This report is intended primarily to assist in developing effective policy responses to changes in Alberta's biodiversity by identifying which species, taxa and regions are most likely to be affected by climate change. We undertook an analysis of ten existing climate change vulnerability assessment approaches and found that the CCVI was the only existing and proven tool that is capable of addressing all elements of biodiversity, includes exposure as well as sensitivity, and does not require large amounts of population and distribution data (Shank 2012). The CCVI has recently been used by a number of agencies and institutions as a means to rapidly assess vulnerability of a wide variety of taxa in several North American jurisdictions (Larrivée and Anions nd, Steel et al. nd, Walk et al. 2010, Zack et al. 2010, Byers and Norris 2011, Dubois et al. 2011, Furedi et al. 2011, Schlesinger et al. 2011, Sperry and Hayden 2011, Anacker and Leidholm 2012, Brinker and Jones 2012, Davison et al. 2012, Johnson 2013, Liebezeit et al. 2013).

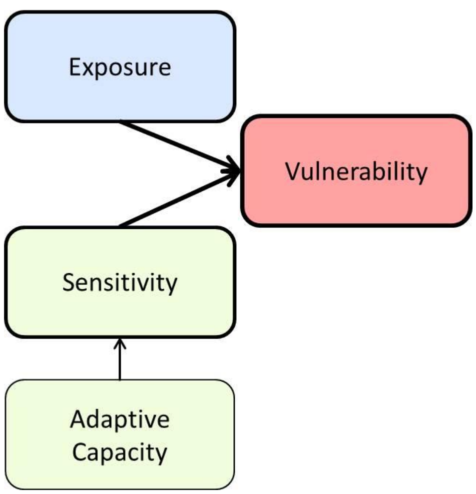

Figure 2. Climate change vulnerability is a synthesis of exposure to future climatic conditions, sensitivity of the species to changes in climate, and ability of the species to adapt.

The key concept is that of "vulnerability", in this context considered to be the degree to which a species is able to cope with the effects of climate change. Vulnerability is comprised of the interaction of exposure, sensitivity and adaptive capacity (Figure 2; Glick et al. 2011). Exposure refers to the amount and rate of climate change (e.g., temperature, moisture, seasonality, etc.) experienced by individuals. Sensitivity relates to the innate tolerances of a species to such climate-related variables as snow-cover, temperature extremes, and number of growing-degree days. And finally, adaptive capacity refers to the ability of a species to behaviourally or genetically change its characteristics to cope with altered conditions, for example by changing its diet or phenology. In practice, the differentiation between sensitivity and adaptive capacity is not always clear and here adaptive capacity is considered as a subset of sensitivity.

[1] Version 2.1, http://www.natureserve.org/conservation-tools/standards-methods/climate-change-vulnerability-index

All means of assessing the vulnerability of species to climate change have their uncertainties and weaknesses, but we chose the CCVI largely because of the breadth of species treated, its wide use and extensive testing (Shank 2012). The method is intended to provide a quick assessment for a large number of species in different taxa and therefore sacrifices some level of precision for broad applicability. A discussion of the advantages and cautions associated with the CCVI is outlined in Section 4.1.

2 Methods

2.1 The CCVI Approach

The CCVI uses a Microsoft Excel 2007 spreadsheet model to calculate vulnerability scores based on place-based predictions of exposure to future climate change and species-specific sensitivity to climate change (Young et al. 2012). Modeled climate data are used to determine the likely changes in temperature and available moisture by the 2050s throughout the species current Alberta range generating an exposure score. To determine a sensitivity score, 24 sensitivity factors are evaluated based on literature review, historical climate analysis and species distribution modeling (if available). The exposure and sensitivity scores are then combined into a synthetic vulnerability score (Figure 3).

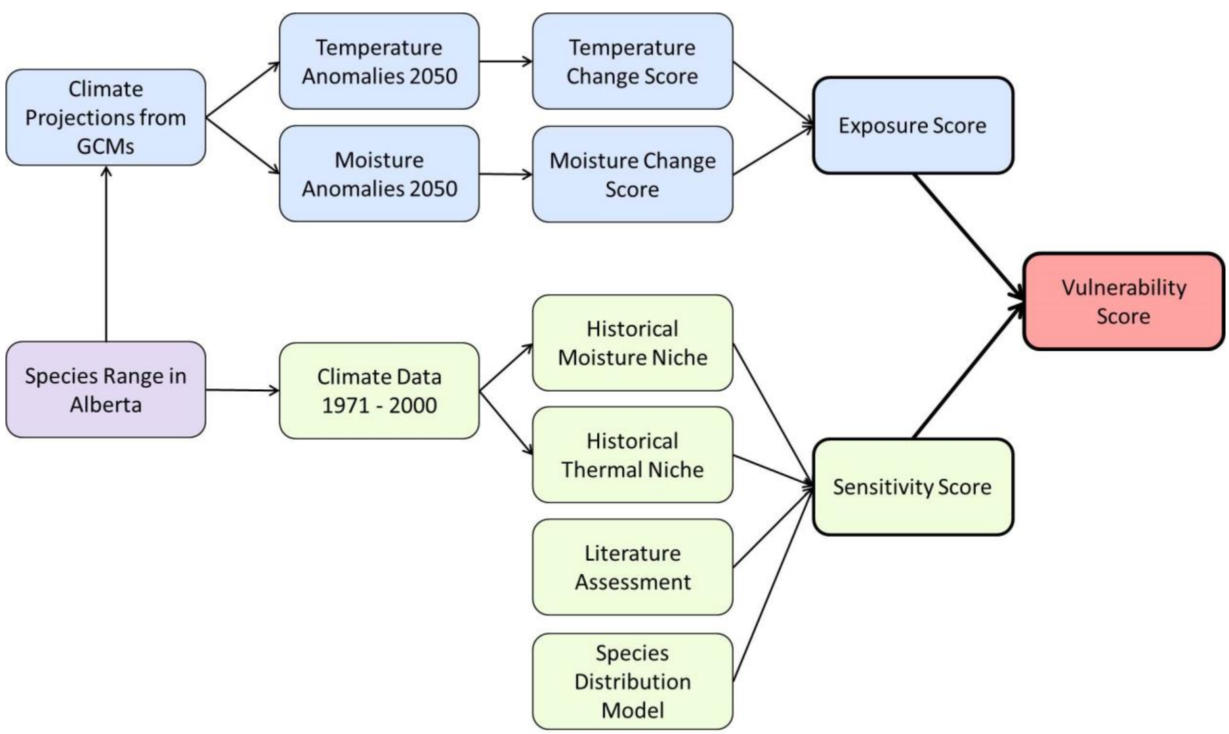

Figure 3. The mechanics of deriving a CCVI vulnerability score.

2.2 Species Examined

In total, 173 species from 6 taxonomic groups limited to the terrestrial realm were assessed (Table 1). Species were selected for analysis based on a number of criteria:

- All amphibians and reptiles,
- Species suggested by experts to be included as terrestrial fine filter indicator species in Alberta's proposed Biodiversity Management Framework (Hugh Norris, pers. comm., 2013),
- Species listed as provincial High Responsibility species (Alberta Biodiversity Monitoring Institute 2009),
- Species suggested by Alberta Environment and Sustainable Resource Development staff,
- Species for which sufficient information exists, and
- Reasonable representation from a variety of taxonomic groups.

Table 1. Number of species assessed in each taxonomic group. Full species list is presented in Appendix 1.

Taxonomic Group	Count
Amphibians	10
Birds	55
Insects	11
Mammals	37
Reptiles	8
Vascular Plants	52
Total	**173**

2.3 Species Assessments

Species assessments were undertaken by ABMI staff and by University of Alberta students using on-line and published information. None of the initial assessors had expert knowledge of the species examined, but all had backgrounds in field biology. Data were recorded on standardized assessment sheets. The authors of this report checked each assessment to ensure thoroughness and consistency in interpretation.

A selection of assessments was sent out to species experts for review. In total, 39 species were reviewed. On average, each initial reviewer's comments resulted in changes to 1.4 factors. The average change in factor score was +0.2 (for example, moving from Somewhat Increase Vulnerability to Increase Vulnerability results in +1 change in scoring) indicating that there was little consistent bias towards more or less vulnerability in the initial reviews. A second expert review was obtained for six species resulting in an average of one additional change per species. One of the most beneficial aspects of engaging experts was their suggestion of literature missed by the initial assessors and calling attention to better range maps.

Species assessments may be found on-line at http://www.biodiversityandclimate.abmi.ca/vulnerability-assessments/. These sheets summarize information used in the CCVI analysis including species range, sensitivity scores for all factors, justification for the scoring and relevant literature for each factor. The species' vulnerability score and the exposure and sensitivity scores upon which it is based are presented as gauges. Species assessment sheets can be downloaded as PDFs.

2.4 Selection of Range Maps

Range maps used in the analysis are intended to reflect the general extent of the species distribution in Alberta. The conceptual model was the IUCN Red List "extent of occurrence" defined as "…the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy"[2].

Range maps were intended, to the extent possible, to reflect species distribution in Alberta over the period 1971 – 2000; the timeframe of the historical climate data used to define each species' historical climate niche. Maps reflecting pre-1970 or post-2000 ranges were avoided, when possible. Throughout this report, the term "range" will refer to a species' distribution in Alberta during the period of ca. 1971 – 2000.

Range maps were collected from a variety of sources. In many cases, maps were digitized from status reports or published papers. Map sources are indicated in the on-line assessment sheets.

2.5 Species Presence in Alberta's Natural Regions

Using ArcGIS v 10.0 (ESRI, Redlands, California) we calculated the percentage overlap of species range with each of Alberta's six Natural Regions[3]. The species was considered "present" in a Region if ≥10% of the Region's area is contained in the species current range. For species with very small ranges in which no Region showed ≥10% overlap with species range, the species was considered present in the single Region with the greatest overlap.

2.6 Climate Data Inputs

The CCVI requires climate inputs from both recent historical records (1971-2000) and future time periods. Recent historical records for seasonal differences in temperature and spatial differences in precipitation are employed as a proxy for the breadth of the species evolved climate niche. Projections of future change in temperature and available moisture are used to predict the level of exposure to changed climate conditions in period 2041 – 2071 which, following Wang et al. (2012), we term "the 2050s".

The CCVI Guidelines (Young et al. 2011) recommend the use of Climate Wizard[4] for easy access to downscaled temperature projections. However, the spatial resolution of Climate Wizard in Canada is 50 km. We considered this to be too coarse and therefore developed our own approach.

2.6.1 Recent Historical Climate Data

Historical climate normals were generated from ClimateWNA software (Wang et al. 2012) using gridded geographic coordinates extracted from a digital elevation model at 1 km resolution and weather station data from 1971 – 2000.

Seasonal range in temperature was calculated as the mean of the annual differences between the maximum and minimum mean monthly temperatures over the period 1971-2000 (Figure 4a). Seasonal differences are greatest in the northeast corner of the province and least in the Rocky Mountains and Foothills.

[2] http://www.iucnredlist.org/static/categories_criteria_2_3
[3] http://www.albertaparks.ca/media/3706579/nsr2005_final_letter.pdf
[4] http://www.climatewizard.org

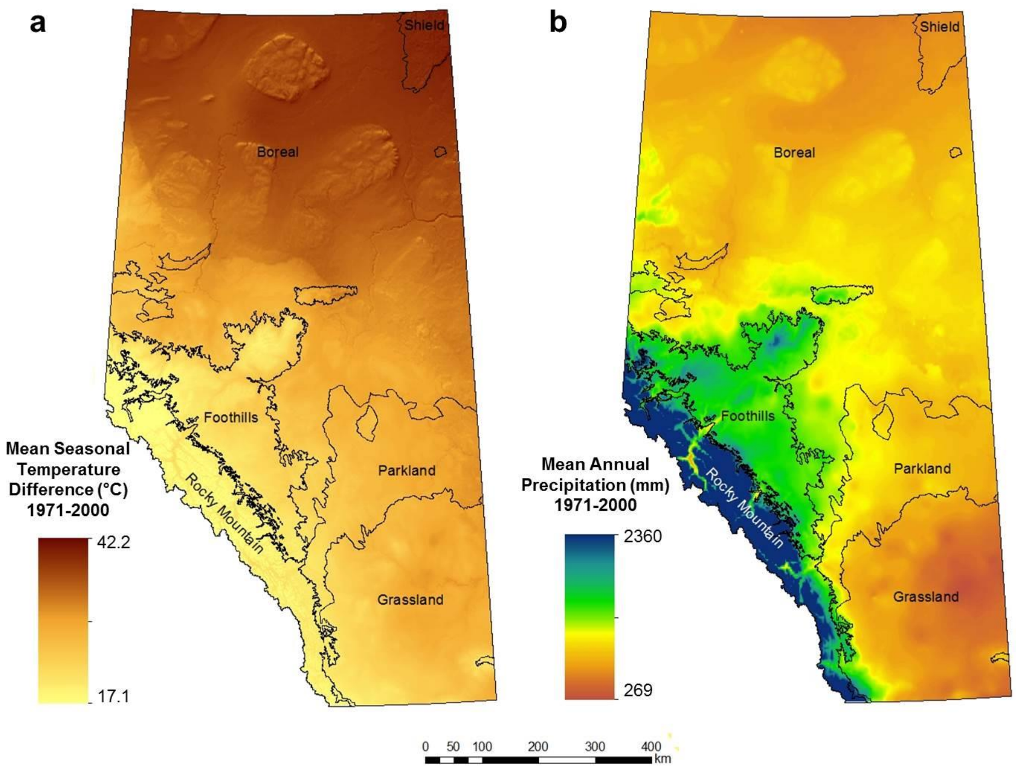

Figure 4. Historical climate data (1971 – 2000) used as inputs to the CCVI: a) the mean difference between winter minimum temperatures and summer maximum temperatures and b) mean annual precipitation. Natural Regions are presented for reference.

Mean annual precipitation was also calculated over the period 1971 – 2000 (Figure 4b). Historically, the greatest amount of precipitation in the province falls at higher elevations in the Rocky Mountains and the least in the northern and southeastern parts of the province. For the period 1971 – 2000, the mean annual precipitation for Alberta was 482 mm with a minimum of 269 mm in the southeast and a maximum of 2360 mm at higher elevations.

2.6.2 Projected Future Climate Data

Future climate projections for the 2050's period were downscaled with ClimateWNA (Wang et al. 2012) from general circulation models (GCM) from the IPCC's 4th Assessment Report (Meehl et al. 2007).

Following advice from NatureServe (Young et al. 2011), we present data for an "Ensemble" dataset. Ensemble projections were generated by using the A2 emission scenario (IPPC 2000) and by averaging climate anomalies from several GCMs prior to downscaling. Included in the Ensemble projections were the following GCMs:

1. INGV-ECHAM4, Italy/Germany
2. CSIRO-Mk3.5, Australia
3. ECHAM5/MPI-OM, Germany
4. CCSM3, USA
5. GFDL-CM2.1, USA
6. GFDL-CM2.0, USA
7. UKMO-HadCM3, UK
8. UKMO-HadGEM1, UK
9. CSIRO-Mk3.0, Australia
10. CGCM3.1(T63), Canada
11. ECHO-G, Germany/Korea
12. CGCM3.1(T47), Canada
13. CNRM-CM3, France
14. PCM, USA
15. INM-CM3.0, Russia
16. BCCR-BCM2.0, Norway

Additionally, climate projections for the 2050s were generated for a suite of GCMs representing different climate scenarios and compared with the Ensemble projections in Appendix 2.

2.7 Calculating Exposure

Exposure is the extent to which a species will be subjected to changes in temperature and available moisture by the 2050s within its current range.
It is expressed as the percentage of the species range in several categories of temperature and moisture change. The limits of these categories are defined as ±1 and ±2 times the standard deviation of projected changes (Young et al. 2012).

The exposure categories developed by NatureServe for the Canadian version of the CCVI model rely on climate projections for the whole of Canada, including the Far North. Because of the very large changes in temperature predicted to occur in the North, the category limits of the proposed Canadian categories are much broader than those for the U.S. and are unreasonably wide for the magnitude of change expected for Alberta. Accordingly, we calculated exposure category limits based on multiples of the standard deviation of projected temperature and evapotranspiration change from Ensemble data and for Alberta only. The implication is that the exposure categories and vulnerability scores derived from them are valid for comparison only within the Alberta context.

Details of the Alberta exposure calculations are presented as Appendix 2. Figure 5 depicts projected temperature and evapotranspiration anomalies for Alberta in the 2050s based on the Ensemble data, classified into the change categories described above. It predicts increasing temperature primarily from west to east with the most drying in the southeast and the least drying in the Rocky Mountains and Foothills. Temperature and evapotranspiration changes for the 5 GCMs are shown in Figure 30 (Appendix 3).

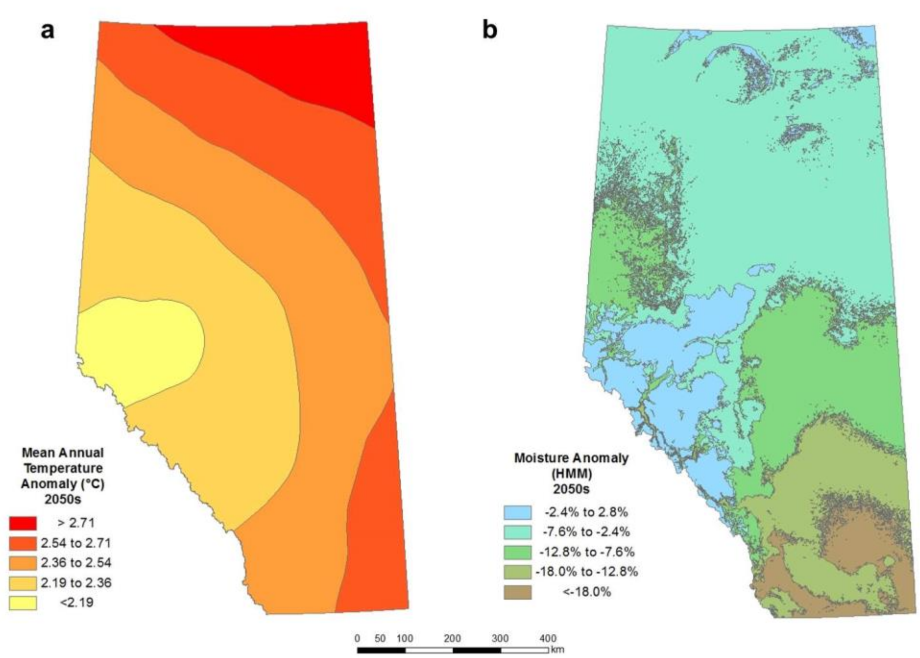

Figure 5. Anomalies between the historical climate data (1971 – 2000) and projected climate for the 2050s (Ensemble): a) the projected change in mean annual temperature categorized into intervals used in the CCVI analysis and b) the projected change in the Hamon moisture metric categorized in CCVI categories.

2.8 Assessing Sensitivity Factors

The CCVI assesses sensitivity to climate change by scoring 24 factors in three categories through literature review, examination of the species climate niche breadth, and species distribution modeling. Each of the 24 factors is provided a score ranging from “Greatly Increase Vulnerability” to “Decrease Vulnerability”, although individual factors may lack extreme values as an option. More than one score can be provided when there is uncertainty or conflicting information. Detailed assessment instructions are provided by Young et al. (2011). Interpretations used in this analysis are provided as Appendix 4.

Appendix 5 provides an abbreviated explanation of how each sensitivity factor contributes to climate change vulnerability. The three sensitivity factors below (2.8.1 to 2.8.3) require more detailed explanation.

2.8.1 Factor B2b--Distribution relative to Anthropogenic Barriers.

The extent to which current anthropogenic barriers can be expected to limit dispersal was assessed by reference to four human footprint maps (Figure 6) developed from the “wall-to-wall” human footprint data set developed by ABMI (Alberta Biodiversity Monitoring Institute 2012). We summarized four categories of human footprint, representing ten specific land uses, as the proportional aerial extent of a township (ca. 93.2 km^2):

1. “Urban”
    a. Residential urban (usually >1 building per ha)
    b. Residential rural dominated by buildings (usually >1 building per ha)
2. “Industry”
    a. Commercial industry (high human density including airports, industrial parks, factories, refineries, hydro generating stations, pulp and paper mills, pump stations, malls, parking lots, etc.)
    b. Industry (low human density entailing ground cleared for coal and mineral surface mines, oil and gas well pads, wind mills, communication towers, gravel pits, heavy oil sand development, spoil piles, etc.)
3. “Roads”
    a. Linear roads, railways and industrial features > 20 m wide
    b. Linear roads, railways and industrial features 10 - 20 m wide
4. “Agriculture”
    a. Annual cereal crops
    b. Irrigated land
    c. Other agriculture
    d. Bare ground created by agricultural activities.

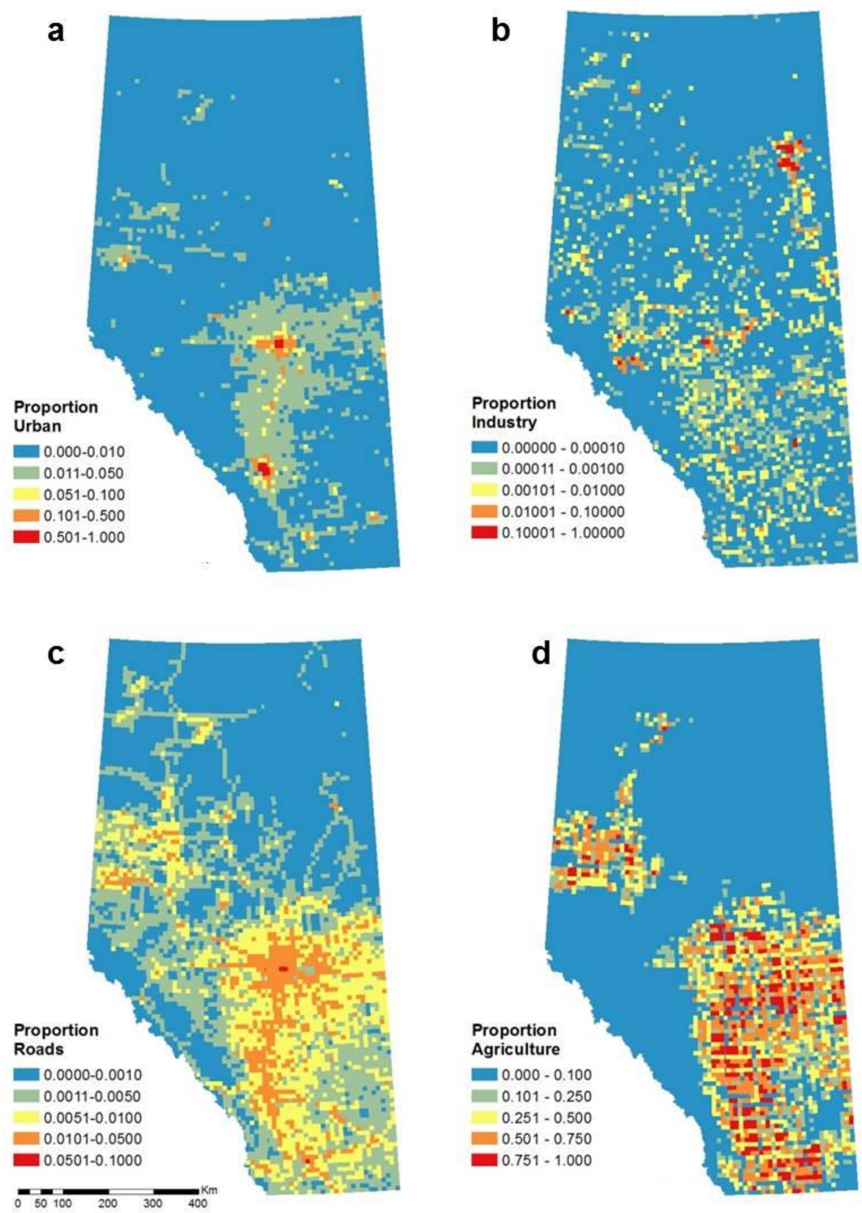

Figure 6. Anthropogenic footprint in Alberta defined by the proportion of a township (ca 93.2 km^2) covered by each disturbance: a) urban, b) industry, c) roads, and d) agriculture. Note the difference in scales among footprint types.

2.8.2 Factor C2ai--Historical Thermal Niche

A proxy for the breadth of a species' evolved thermal niche is provided by the difference between the historical (1971-2000) mean minimum winter and maximum summer temperatures. The NatureServe guidelines (Young et al. 2011, p. 57) are somewhat uncertain as to how to score this factor; we scored it as the category with the largest temperature difference in which ≥10% of the range occurs.

The widest range of annual temperature variation occurs in northern Alberta suggesting that northern species have a broader thermal niche and should be less vulnerable to long-term temperature change. The smallest range in annual temperature, and therefore the highest thermal niche vulnerability, occurs in the northern Rocky Mountains (Figure 5).

2.8.3 Section D--Species Distribution Modeling

Species distribution model factors (Section D) are optional in the CCVI analysis. Data were available for 30 of the 173 species assessed.

Species distribution modeling for boreal passerines was undertaken by Diana Stralberg as part of her PhD research at the University of Alberta. Bird location data were from point-count surveys summarized by the Boreal Avian Monitoring (BAM) project (Cumming et al. 2010) for the period 1992 – 2010 and converted to density based on detection distance. A set of seven bioclimatic variables was used to model bird density by boosted regression tree analysis (Watling et al. 2012). Density was converted to probability of occurrence using a Poisson distribution and an Alberta-specific threshold for core habitat was calculated as the mean probability of occurrence for each species (D. Stralberg, pers. comm., November 2013).

Species distribution modeling for Alberta butterflies and orchids was undertaken by Jessica Stolar and Scott Nielsen as part of Stolar's larger PhD research for the Alberta Species Conservation Atlas[5] at the University of Alberta (J. Stolar, pers. comm. October, 2013). They used the maximum entropy (Maxent) approach (Watling et al. 2012) with species location data provided by the Alberta Conservation Information Management System (ACIMS) and supplementary orchid data from the University of Alberta's vascular plant herbarium[6]. Species-specific probability thresholds (balancing model sensitivity and specificity (see Manel et al. 2001)) were used to generate binary predictions of presence and absence in both the current and 2050s time periods.

2.9 Vulnerability Scores and Categories

The standard CCVI output is a categorical variable ranging from "Extremely Vulnerable" to "Increase Likely", with the categories based on the predefined limits to the calculated vulnerability scores. We suggest that the limits delineating these categories are essentially arbitrary and a continuous, comparative output is more intuitive.

Accordingly, we present the results of our CCVI analysis using vulnerability scores as a continuous variable. To aid in comparisons, we divided the vulnerability scores for the species assessed into quartiles (Table 2). The most vulnerable 25% of Alberta species assessed are labeled "Higher Vulnerability" while the least vulnerable 25% are considered "Lower Vulnerability". The middle 50% are termed "Medial Vulnerability". A corollary of this approach is that the categories are relative within the suite of species assessed. It is not appropriate to

[5] http://www.ace-lab.org/asca.htm
[6] http://vascularplant.museums.ualberta.ca/index.aspx

directly compare the categorical results of this analysis with those from other approaches or assessment areas.

CCVI vulnerability scores potentially can range from -14 to +20. For the Alberta species assessed, the lowest and highest vulnerability scores were -8.77 (Chestnut-collared Longspur) and 14.03 (western spiderwort) respectively. The median vulnerability score was -0.50.

Table 2. Vulnerability scores separating Higher Vulnerability species (highest 25% of vulnerability scores), Medial Vulnerability species (middle 50% of vulnerability scores) and Lower Vulnerability species (lowest 25% of vulnerability scores).

Vulnerability Score	Description	Category Name
<-3.36	Lowest 25% of assessments	Lower Vulnerability
-3.36 to 2.86	Middle 50% of assessments	Medial Vulnerability
>2.76	Highest 25% of assessments	Higher Vulnerability

2.10 Uncertainty

The CCVI model calculates a measure of confidence in species information where uncertainty results from multiple scores for a single sensitivity factor. Confidence is measured by summarizing the results of a Monte Carlo simulation for 1,000 iterations using just one of each of the multiple sensitivity factor scores.

We have chosen not to report the CCVI uncertainty measure because lack of confidence is not measured solely through multiple sensitivity factor scores. For example, detailed species data may provide excellent evidence for two scores for a single sensitivity factor under different conditions. By contrast, when less information is available for a species, the single best assessment of sensitivity is often warranted.

3 Results

3.1 Relative Contribution of Exposure and Sensitivity to Vulnerability Scores

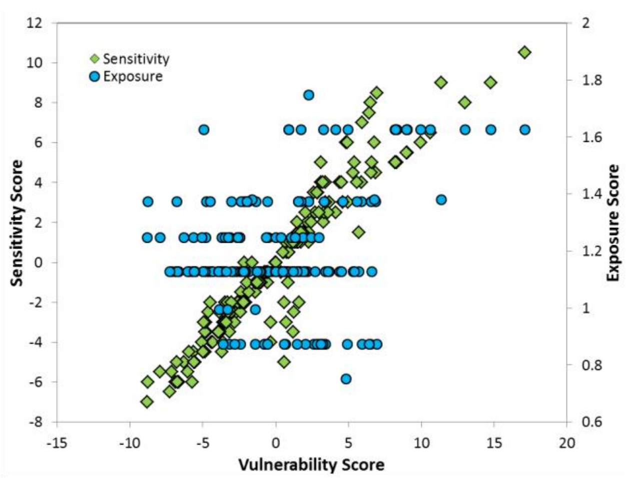

Figure 7. Correlation between sensitivity (green), or exposure (blue) scores, and overall vulnerability for all 173 species assessed.

We examined the contribution of each of the exposure and sensitivity scores to the overall vulnerability score calculated for each species. The CCVI is relatively insensitive to exposure scores; vulnerability scores are determined largely by sensitivity. Vulnerability scores increase linearly with sensitivity (r^2 = 0.90) but are largely unaffected by exposure (r^2 = 0.09) (Figure 7). Young et al. (2009) also noted exposure having a minor effect on vulnerability; they attributed this to small assessment areas resulting in most species experiencing identical exposure, which is not the case for Alberta species.

3.2 Patterns of Vulnerability Across Taxonomic Groups

Taxonomic groups have evolved different adaptations to their environment and can be expected to respond uniquely to climate change. The outcomes from the CCVI analysis indicate the most vulnerable groups in Alberta are reptiles and amphibians while birds are the least vulnerable (Figure 8). However, a more detailed analysis suggests the vulnerability of reptiles may be overestimated and they may, in fact, be no more vulnerable than insects and vascular plants (see Section 3.4).

See the Alberta CCVI website (http://www.biodiversityandclimate.abmi.ca/vulnerability-assessments/) for more details on species and their assessment.

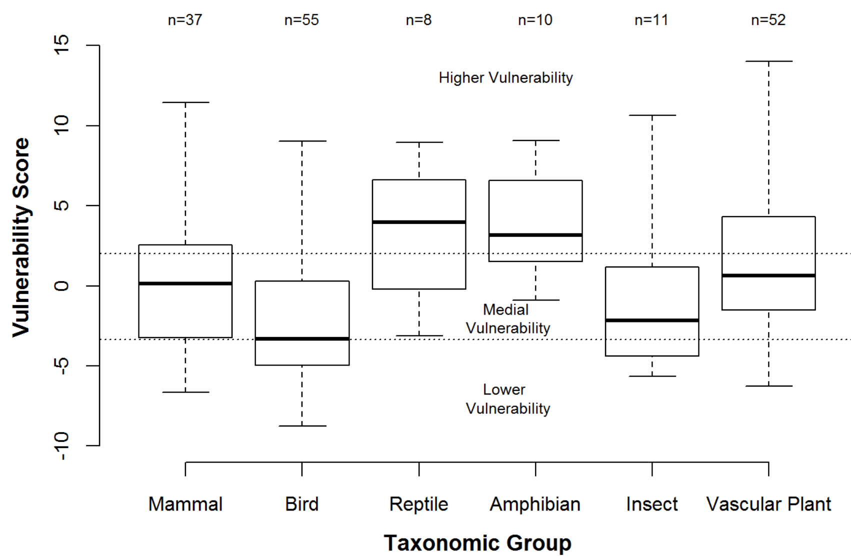

Figure 8. Vulnerability scores by taxonomic group. Whiskers represent extreme values. Higher Vulnerability refers to the highest 25% of scores for all Alberta species assessed and Lower Vulnerability represents the bottom 25%. Medial Vulnerability refers the middle 50% of scores.

Of the 37 species of mammals assessed, eight (22%) species were of Higher Vulnerability and nine (24%) were of Lower Vulnerability (Figure 9). Ord's kangaroo rat is the most vulnerable mammal species as a result of its limited range, significant dispersal barriers and high exposure to climate change. It is followed by the American pika, which is vulnerable largely because of dispersal barriers and its narrow historical and physiological thermal niche. Several mountain and northern species were also assessed as quite vulnerable as a result of dispersal barriers, intolerance of heat, and dependence on snow. Ubiquitous species like mule deer and coyote are the least vulnerable.

Only five (9%) of the 55 species of birds assessed fall into the Higher Vulnerability category while 27 (49%) fall into the Less Vulnerability category (Figure 10). The two most vulnerable species are the Greater Sage Grouse and Whooping Crane both of which have small ranges in Alberta and are at-risk. The Chestnut-collared Longspur was assessed as the least vulnerable species largely as a result of its adaptation to warm, dry habitats. Most birds have excellent dispersal capability, which reduces their vulnerability scores (Section 3.6).

Five of the eight species of Alberta reptiles fall into the Higher Vulnerability category and none in the Lower Vulnerability category (Figure 11). The most vulnerable species are the short-horned lizard and the plains hog-nosed snake both of which have narrow historical thermal and hydrological niches, barriers to dispersal and specific geological requirements. As discussed in Section 3.4, the vulnerability of some reptile species may be overestimated as a result of their small Alberta ranges.

Six of the 10 Alberta amphibian species have vulnerabilities in the top 25% (Higher Vulnerability) for all Alberta species (Figure 12). No species are in the Lower Vulnerability category. All species are sensitive to the physiological hydrological niche (factor C2bii). The most vulnerable species (Great Plains toad, northern leopard frog and the plains spadefoot toad)

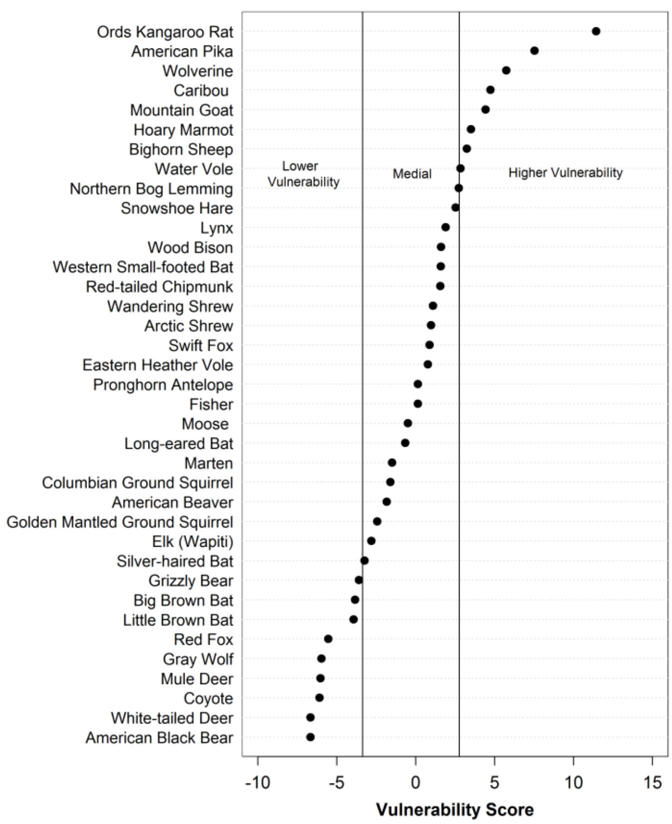

Figure 9. Vulnerability scores for 37 species of Alberta mammals. Higher Vulnerability refers to the highest 25% of scores for all Alberta species assessed and Lower Vulnerability represents the bottom 25%. Medial Vulnerability refers the middle 50% of scores.

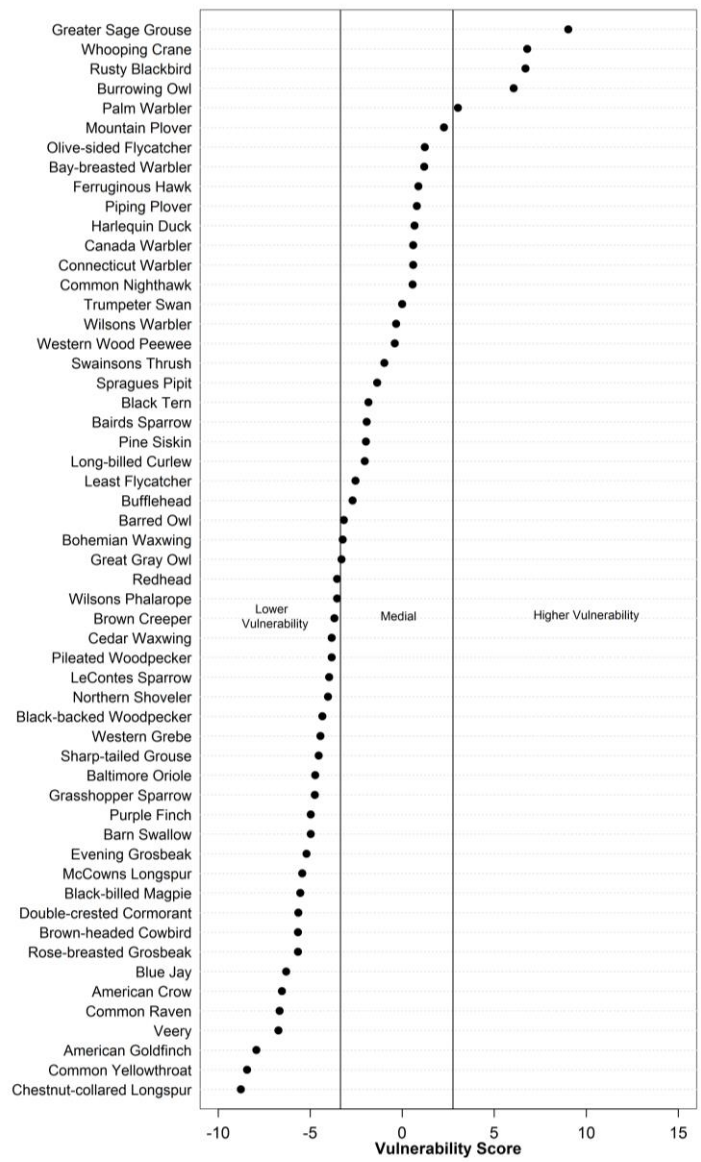

Figure 10. Vulnerability scores for 55 Alberta birds. Higher Vulnerability refers to the highest 25% of scores for all Alberta species assessed and Lower Vulnerability represents the bottom 25%. Medial Vulnerability refers the middle 50% of scores.

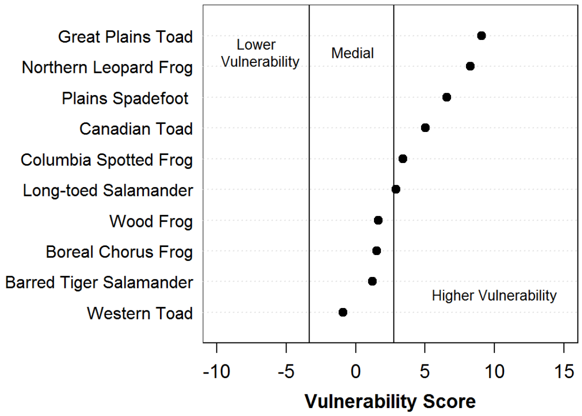

Figure 12. Vulnerability scores for all 10 Alberta amphibians. Higher Vulnerability refers to the highest 25% of scores for all Alberta species assessed and Lower Vulnerability represents the bottom 25%. Medial Vulnerability refers the middle 50% of scores.

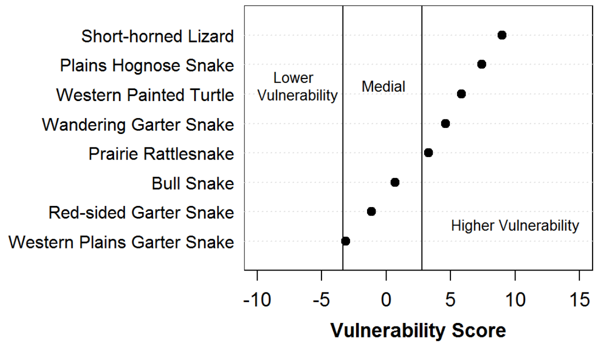

Figure 11. Vulnerability scores for all 8 Alberta reptiles. Higher Vulnerability refers to the highest 25% of scores for all Alberta species assessed and Lower Vulnerability represents the bottom 25%. Medial Vulnerability refers the middle 50% of scores.

are also sensitive to a combination of anthropogenic barriers and a narrow historical thermal niche resulting largely from restricted range. The Medial Vulnerability species (wood frog, boreal chorus frog, barred tiger salamander, western toad) tend to have fewer anthropogenic barriers and broader historical hydrological niches as a result of larger ranges in moister habitats.

Due to data limitations, only 11 species of insects were assessed (Figure 13). The sample size is too small to generalize about the vulnerability to climate change of such a diverse group, but does suggest that the CCVI can address invertebrates satisfactorily. The Yucca moth is the most vulnerable insect assessed as a result of its small range, poor dispersal abilities and complete dependence on the small soapweed yucca plant.

Of the 52 species of vascular plants assessed, only three (6%) fall into the Lower Vulnerability category and 18 (35%) in the Higher Vulnerability category (Figure 14). Western spiderwort was assessed as having the highest vulnerability score of the 173 species in all taxa as a result of its narrow historical hydrological niche, dependence on spring rainfall and low genetic diversity. The least vulnerable plants are mostly fruit producers with seed dispersal by animals and species with effective wind dispersal.

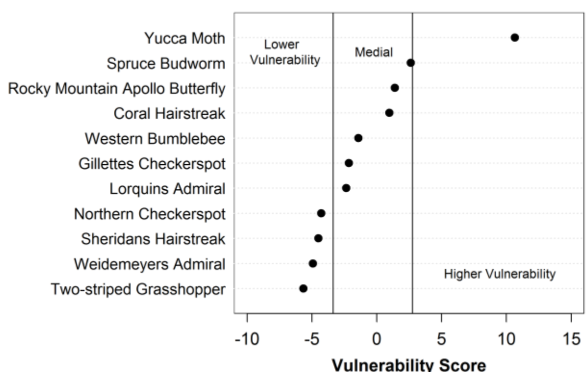

Figure 13. Vulnerability scores for 11 species of Alberta insects. Higher Vulnerability refers to the highest 25% of scores for all Alberta species assessed and Lower Vulnerability represents the bottom 25%. Medial Vulnerability refers the middle 50% of scores.

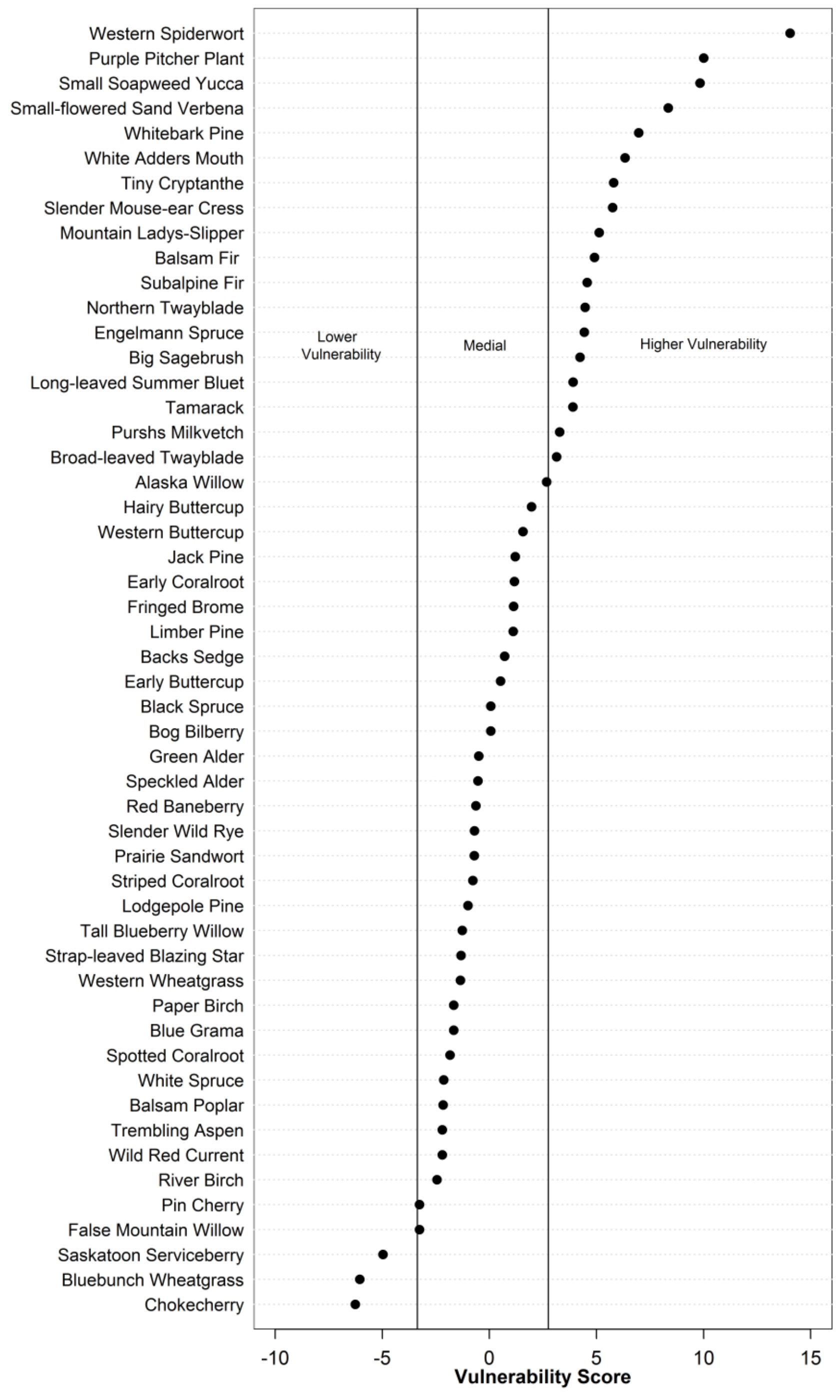

Figure 14. Vulnerability scores for 52 Alberta vascular plants. Higher Vulnerability refers to the highest 25% of scores for all Alberta species assessed and Lower Vulnerability represents the bottom 25%. Medial Vulnerability refers the middle 50% of scores.

3.2.1 Relative Contribution of Sensitivity Factors to Taxon Vulnerability

Sensitivity factors are the primary determinants of the vulnerability score (Section 3.1) and taxonomic groups differ in their mean sensitivity to various CCVI factors. Figure 15 indicates which sensitivity factors have the most influence on vulnerability scores for each taxonomic group. Positive values indicate increased sensitivity to climate change whereas negative values indicate that climate change will tend to have a positive or neutral effect.
Every species is unique in its sensitivity to climate change, but some generalizations can be drawn for taxonomic groups:

- Amphibian vulnerability scores are most sensitive to anthropogenic barriers (B2b), narrow thermal niche (C2ai), and especially the hydrological regime (C2bii).
- Reptile vulnerability scores are most sensitive to anthropogenic barriers (B2b) and narrow thermal (C2ai) and hydrological niches (C2bi), but benefits greatly from physiological adaptation to thermal stress (C2aii).
- Mammal vulnerability scores are most sensitive to narrow thermal niche (C2ai) and adaptation to warming temperatures (C2aii). They benefit mostly from good dispersal ability.
- Bird vulnerability scores are generally not highly sensitive to any CCVI factor, but benefit greatly from excellent dispersal abilities (C1).
- Insect vulnerability scores are sensitive to the thermal niche (C2ai) and are the only group in which narrow diet (C4b) confers increased sensitivity.
- Vascular plant vulnerability scores are most sensitive to the thermal niche (C2ai) and to hydrological adaptations (C2bii) and are the only group for which limited dispersal ability (C1) results in increased sensitivity.

As discussed in Section 3.4, the sensitivity scores for the historical thermal and hydrological niche(factors C2ai and C2bi) for each species are also influenced by Natural Region and by range size.

Sensitivity scoring for individual species may be found in the online assessment sheets (http://www.biodiversityandclimate.abmi.ca/vulnerability-assessments/).

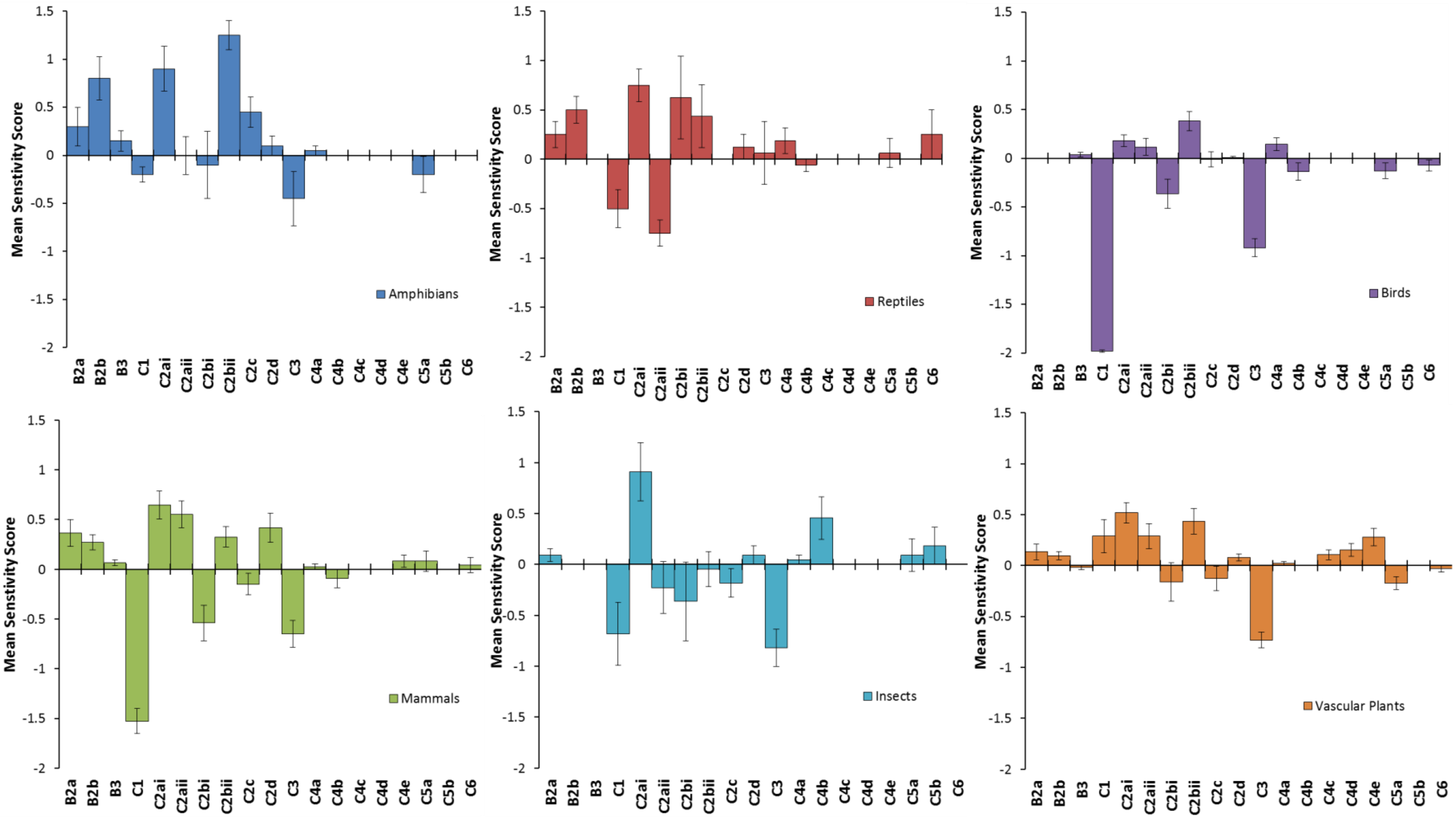

Figure 15. Mean scores (±SE) for each sensitivity factor and taxonomic group. B2a= Distribution relative to natural barriers; B2b= Distribution relative to anthropogenic barriers; B3 = Impact of land use changes related to human response to climate change; C1 = Dispersal and movement ability; C2ai = Predicted sensitivity to changes in temperature; C2aii= Physiological thermal niche; C2bi = Predicted sensitivity to changes in hydrology, precipitation or moisture; C2bii = Physiological hydrological niche; C2c = Dependence on disturbance regimes likely to be impacted by climate change; C2d = Dependence on ice, ice-edge or snow cover; C3 = Restriction to uncommon geological features or derivatives; C4a = Dependence on other species to generate habitat; C4b = Dietary versatility; C4c = Pollinator versatility; C4d = Dependence on other species for propogule dispersal; C4e = Other interspecific dependence; C5a = Genetic variation; C5b = Population bottlenecks; C6 = Phenological response.

3.3 Vulnerability of Species in Alberta's Natural Regions

Species occupying Alberta's six Natural Regions have adapted to local habitats and climatic conditions and groups of species occupying different regions of the province might be expected to have differing vulnerabilities to climate change. However, median vulnerability scores differ very little between Natural Regions (Figure 16a) largely because Regions share many species thereby reducing the variability among Regions. The most noticeable difference is that the Grassland Natural Region has the most variability in vulnerability scores resulting in a greater proportion of Higher Vulnerability species (Figure 16b). As discussed below (Section 3.4), we believe that this may be at least partially an artifact of the manner in which the historical thermal and hydrological niche (factors C2ai and C2bi) are calculated.

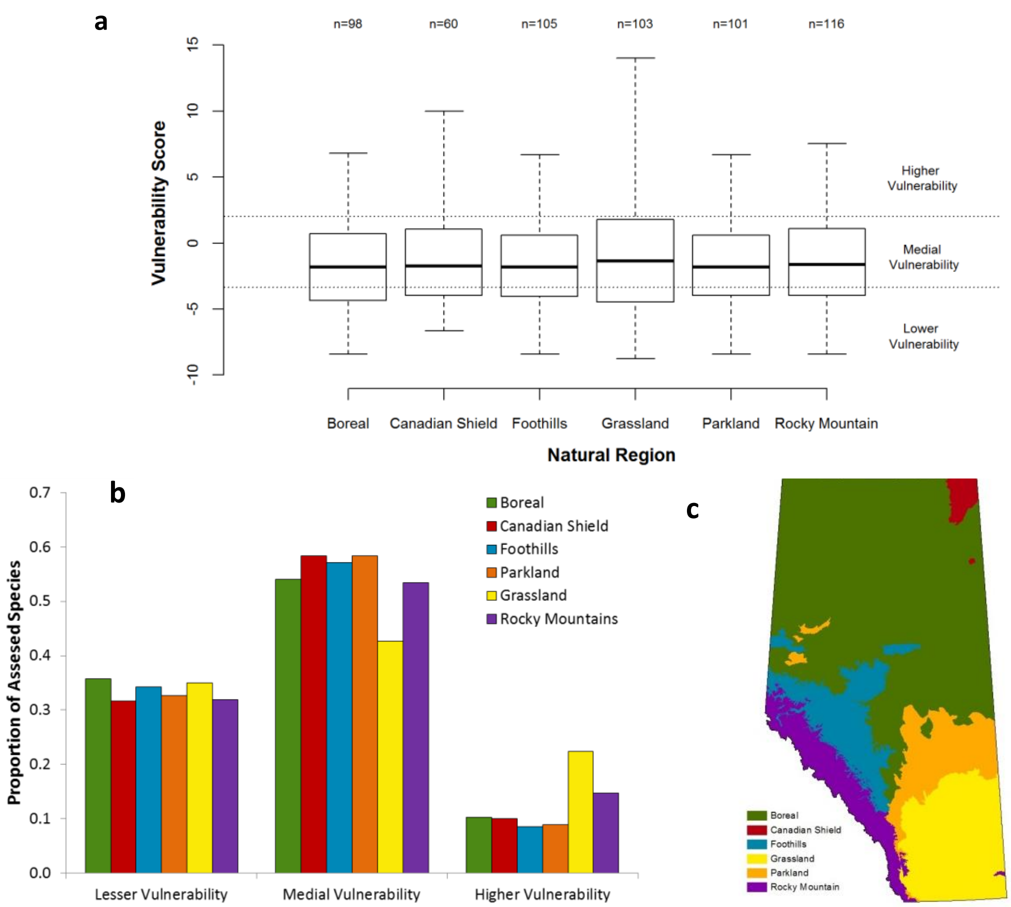

Figure 16. Climate change vulnerability among Alberta's Natural Regions: a) vulnerability scores for species in each Natural Region Whiskers represent extreme values, b) the proportion of species assessed as Lower, Medial or Higher Vulnerability in each Natural Region, and c) the distribution of Alberta's Natural Regions.

Ten of the 98 assessed species (10%) occurring in the Boreal Natural Region have vulnerabilities in the top 25% of all species assessed while 35 (36%) are in the Lower Vulnerability category (Figure 17). Among the most vulnerable Boreal species are the Rusty Blackbird, balsam fir, and caribou. The high vulnerability of the Rusty Blackbird results largely from the species distribution model projection indicating a significant contraction in the area of suitable climate space for this species by the 2050s. Balsam fir is assessed as being quite vulnerable as a result of its narrow hydrological niche in Alberta, its dependence on wet-mesic sites, its susceptibility to increased fire frequency and its low genetic diversity relative to other conifers. The sensitivity factors conferring the most vulnerability on caribou are dependence on snow and the continuing expansion of white-tailed deer with consequential increases in competition and predation.

The vulnerability ranks of several boreal species (wolverine, marten, lynx, snowshoe hare, wood bison, Olive-sided Flycatcher) are much different when exposure is calculated using the 5 individual GCMs rather than using the Ensemble dataset, as presented here. Choice of GCM may have a significant influence on the vulnerability scores in the Boreal Natural Region. This effect is not apparent for other Natural Regions (Appendix 3).

Six of the 60 (10%) Canadian Shield species are Higher Vulnerability while 19 (32%) are Lower Vulnerability (Figure 18). By far the most vulnerable species assessed for the Canadian Shield is the purple pitcher plant. The species' high vulnerability score arises largely from its poor dispersal ability. The median dispersal distance for seeds is only 5 cm exemplifying "Reid's Paradox"; i.e., the observation that a species' dispersal distances is too limited to account for recolonization following glacial recession (Ellison and Parker 2002). The re-colonization of purple pitcher plant in previously glaciated areas suggests dispersal limitation may contribute less to climate change vulnerability than this analysis indicates.

Nine of the 105 (10%) of the Foothills species assessed are Higher Vulnerability while 37 (36%) are Lower Vulnerability (Figure 19). The species represented and their relative vulnerabilities are very similar to the Boreal Natural Region. The northern twayblade is a rare, but widely distributed orchid which is assessed as Highly Vulnerable primarily because it is found in moist, streamside moss carpets occurring in cold air drainages. Wolverine is a cold adapted species that dens only in snowbanks that last late into the spring (Copeland et al. 2010).

Nine of the 101 (9%) of the Parkland species assessed are Higher Vulnerability while 33 (33%) are Lower Vulnerability (Figure 20). The Burrowing Owl is not currently found the Parkland Natural Region, but the historical 1970s range (Alberta Sustainable Resource Development 2005) includes about 17% of the Parkland. The wandering garter snake is vulnerable to climate change largely as a result of its narrow historical thermal and hydrological niches, association with streams and dependence on very specific geological conditions for hibernacula.

Twenty-three of the 103 (22%) Grassland species assessed are Higher Vulnerability while 36 (35%) are ranked as Lower Vulnerability (Figure 21). Small soapweed yucca and the yucca moth are assessed as being very vulnerable to climate change as a result of their mutual dependence, limited dispersal abilities, and the narrow range in historical precipitation within their Alberta range.

Seventeen of the 116 (15%) of Rocky Mountain species assessed are Higher Vulnerability while 37 (32%) are Lower Vulnerability (Figure 22). Dispersal barriers posed by elevation and suitable mountain habitat, increasing threats from mountain pine beetle and blister rust, and dependence on Clark's Nutcrackers for seed dispersal all contribute to the high climate change vulnerability of whitebark pine. Engelmann spruce is vulnerable as a result of the lack of suitable high elevation areas north of its current range in Alberta, its dependence on cool, moist conditions, its slow re-establishment after fire, and the likely increase in spruce beetle outbreaks in the future.

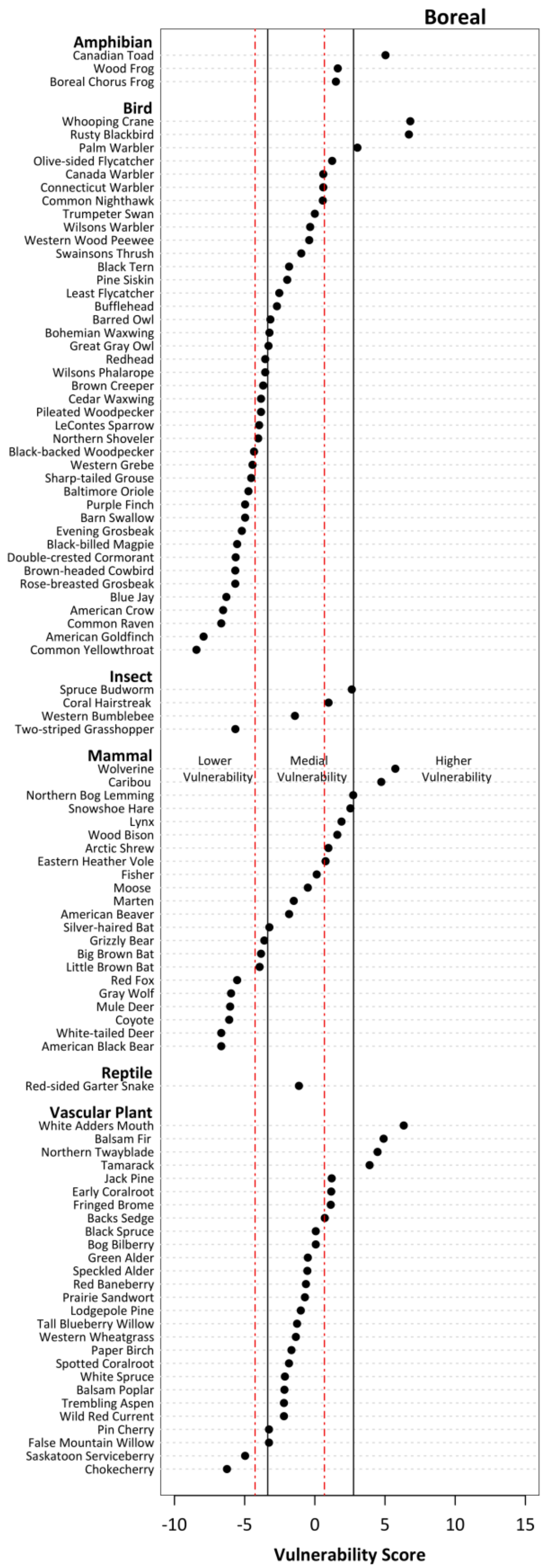

Figure 18. Vulnerability scores for 98 species with a range covering more than 10% of the Boreal Natural Region. Vertical solid lines indicate first and third quartiles for all Alberta species. Vertical dashed lines indicate first and third quartiles for Boreal species only.

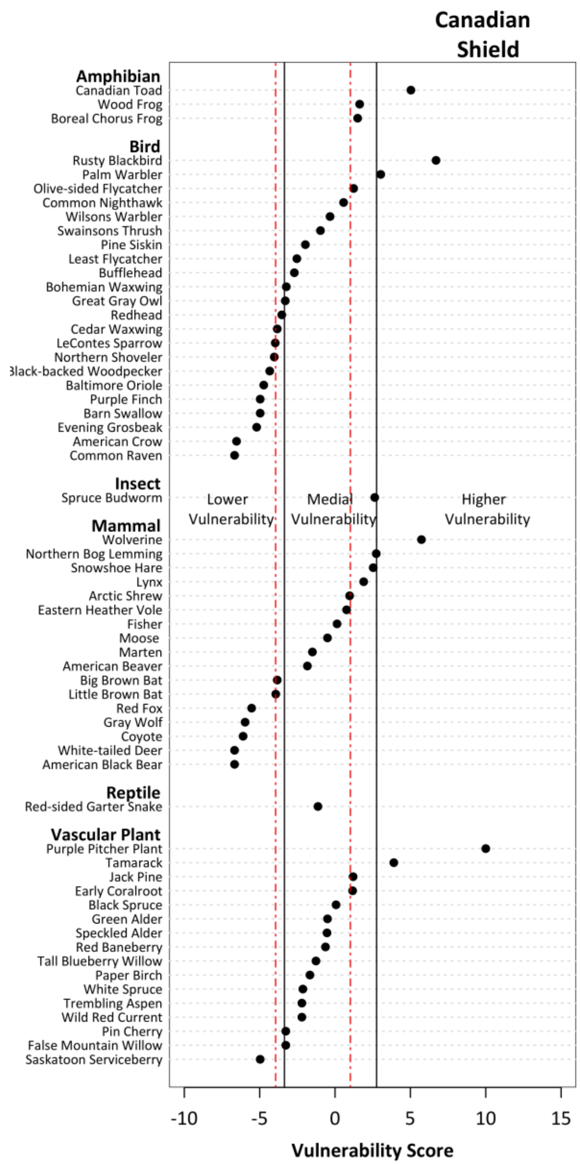

Figure 17. Vulnerability scores for 60 species with a range covering more than 10% of the Canadian Shield Natural Region. Vertical solid lines indicate first and third quartiles for all Alberta species. Vertical dashed lines indicate first and third quartiles for Canadian Shield species.

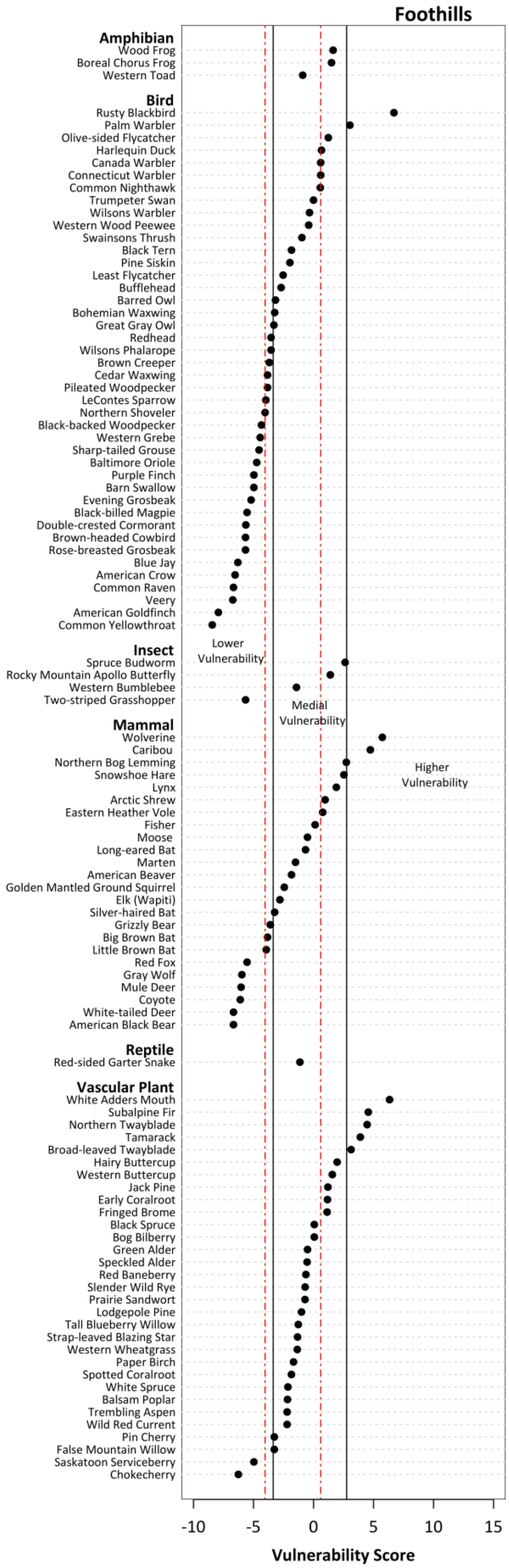

Figure 19. Vulnerability scores for 105 species with a range covering more than 10% of the Foothills Natural Region. Vertical solid lines indicate first and third quartiles for all Alberta species. Vertical dashed lines indicate first and third quartiles for Foothills species.

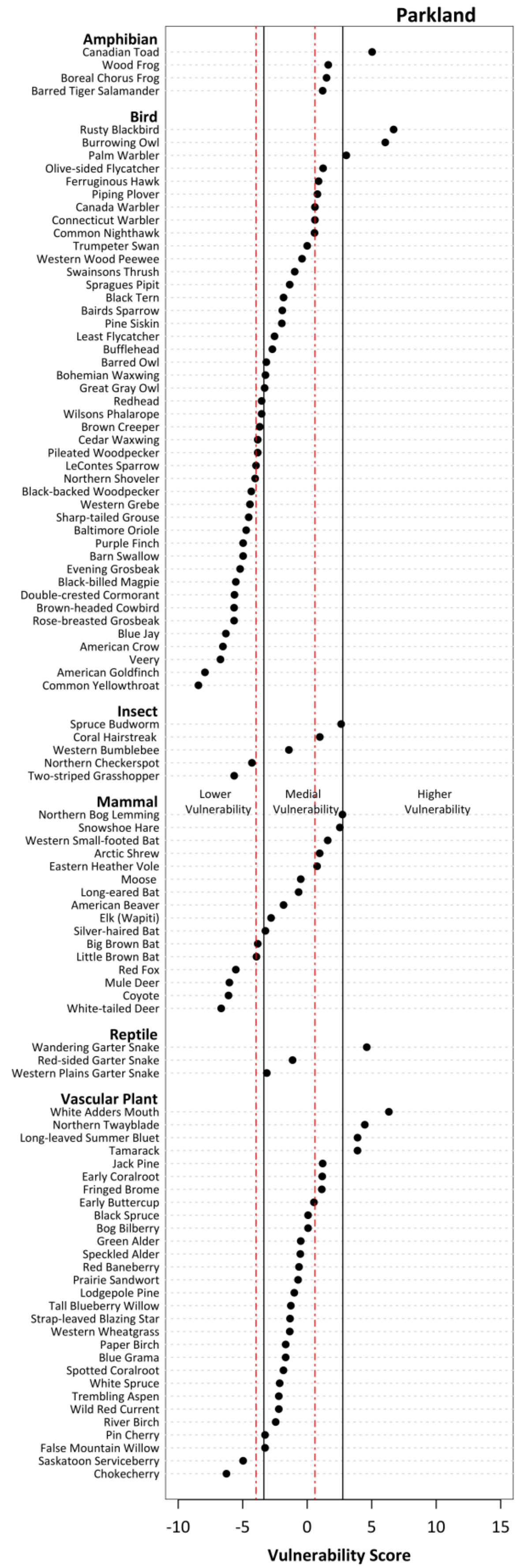

Figure 20. Vulnerability scores for 101 species with a range covering more than 10% of the Parkland Natural Region. Vertical solid lines indicate first and third quartiles for all Alberta species. Vertical dashed lines indicate first and third quartiles for Parkland species.

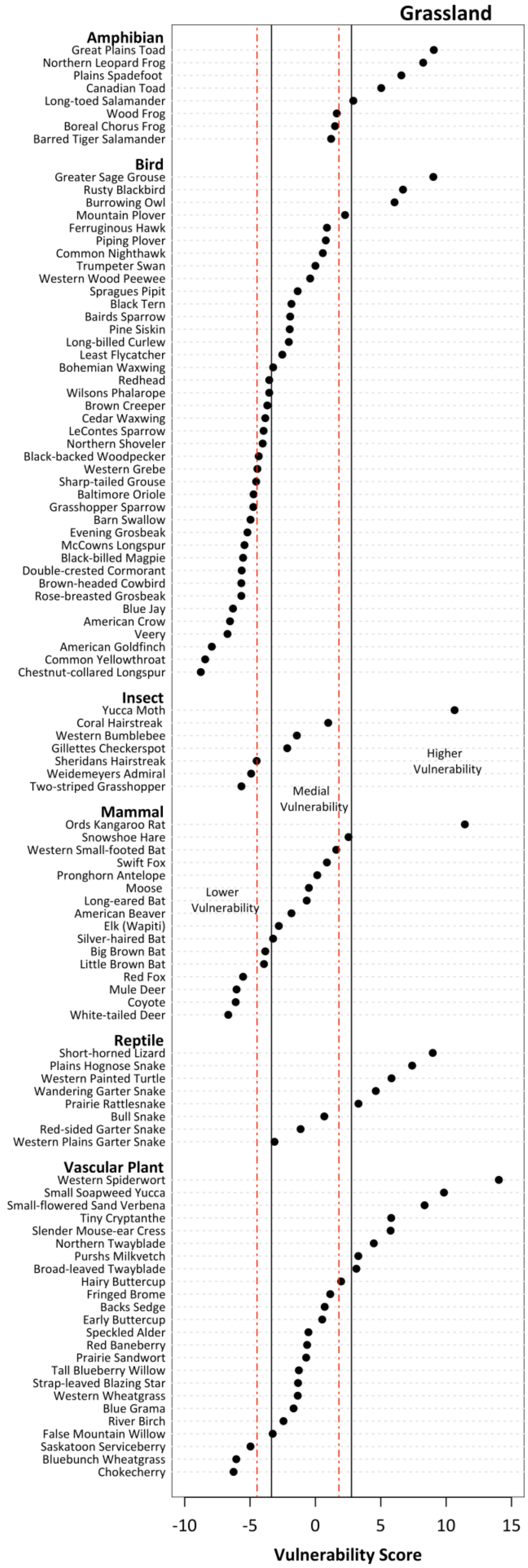

Figure 22. Vulnerability scores for 103 species with a range covering more than 10% of the Grasslands Natural Region. Vertical solid lines indicate first and third quartiles for all Alberta species. Vertical dashed lines indicate first and third quartiles for Grassland species.

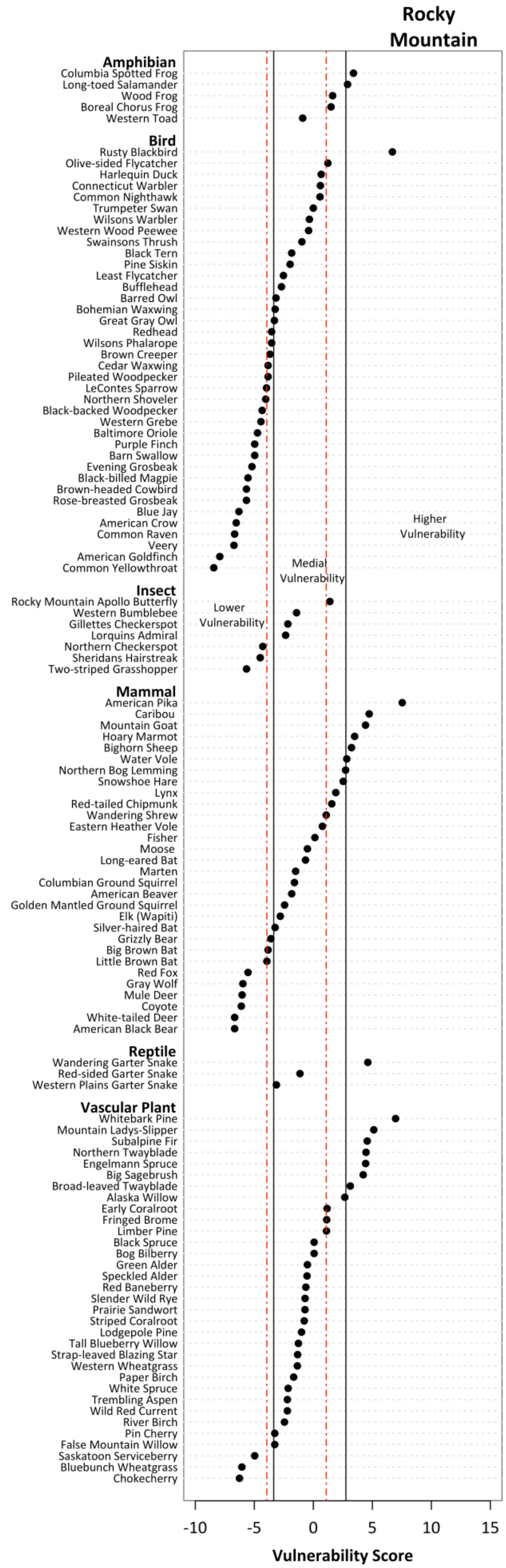

Figure 21. Vulnerability scores for 116 species with a range covering more than 10% of the Rocky Mountain Natural Region. Vertical solid lines indicate first and third quartiles for all Alberta species. Vertical dashed lines indicate first and third quartiles for Rocky Mountain species.

3.4 Climatic Niche, Natural Regions and Range Size

Sensitivity factors C2ai and C2bi are intended as proxies for the evolved thermal and hydrological niches of a species based on the range of environmental extremes experienced in the recent past. They are major determinants of vulnerability scores (Figure 15). However, the values of these sensitivity factors are heavily influenced by climatic differences between Natural Region and by species range size. Natural Region and range size therefore influence vulnerability scores.

3.4.1 Effect of Natural Region on Climatic Niche

C2ai, the thermal niche, is a function of the largest difference between the historical extreme winter and summer temperature in which ≥10% of the Alberta range of a species occurs (Section 2.8.2). Because the Boreal and Canadian Shield Natural Regions experience very wide seasonal temperature variation whereas the Grassland and Rocky Mountain Natural Regions show much smaller differences (Figure 4a), Boreal and Canadian Shield species score lower (less sensitive) for factor C2ai than Grassland and Rocky Mountain species (Figure 23). The higher C2ai sensitivity scores for Grassland species suggest that expected increases in temperature will adversely affect Grassland species more so than Boreal species, thereby inflating the vulnerability of Grassland species relative to Boreal species.

This is a counterintuitive result. Alberta Grassland species are, by and large, warm-adapted species currently at the northern edge of their continental range and can be expected to benefit from future warmer temperatures. By contrast, boreal species are cold-adapted and might be expected to react adversely to warmer temperatures.

Species occurring in drier Natural Regions will show smaller differences between the highest and lowest precipitation (sensitivity factor C2bi) than species with ranges in Natural Areas that receive more precipitation. The Grassland Natural Region has the lowest mean annual precipitation (Figure 5b), so there is little difference between the highest and lowest precipitation within Grassland species' ranges. Again, this calculation results in Grassland species being scored as more sensitive for this factor than species from other Natural Regions (Figure 23), with consequences for the relative vulnerabilities among Natural Regions.

This again is a counterintuitive result because Grassland species are, by and large, arid-adapted species likely to be affected less by declining available moisture than species adapted to more moisture.

The effect of Natural Region on factors C2ai and C2bi suggests comparison of vulnerability scores for species from different Natural Regions (i.e., Figures 9 - 14) should be done with caution.

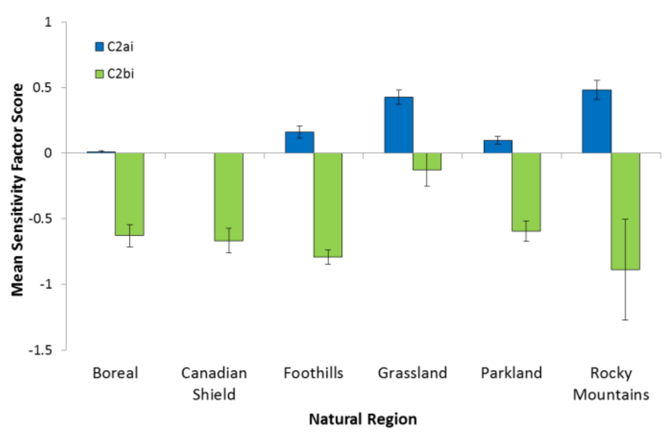

Figure 23. Mean sensitivity scores (±SE) for factors C2ai (historical thermal niche) and C2bi (historical moisture niche) for species in each Natural Region

3.4.2 Effect of Range Size on Climatic Niche

Species with larger range sizes are likely to experience a broader range of seasonal temperature differences (Figure 5a) resulting in lower sensitivity scores for factor C2ai (historical thermal niche; $r = -0.69$, $p < 0.001$, df = 171). Species with larger range sizes also tend to have larger differences between the greatest and least annual precipitation amounts within their ranges (Figure 5b; $r = -0.45$, p = < 0.001, df = 171), which also results in lower sensitivity scores for factor C2bi (historical moisture niche) for those species.

The size of a species' range size in Alberta therefore exerts a strong influence on vulnerability score through these two factors related to the historical niche. Assessed species with smaller Alberta ranges tend to have higher vulnerability scores (Figure 24; $r = -0.51$, p = 1.76e-12, n = 173). Higher Vulnerability species have a mean Alberta range size of 96,445 km^2, while the mean range size of Lower Vulnerability species is 4.5 times larger (430,522 km^2).

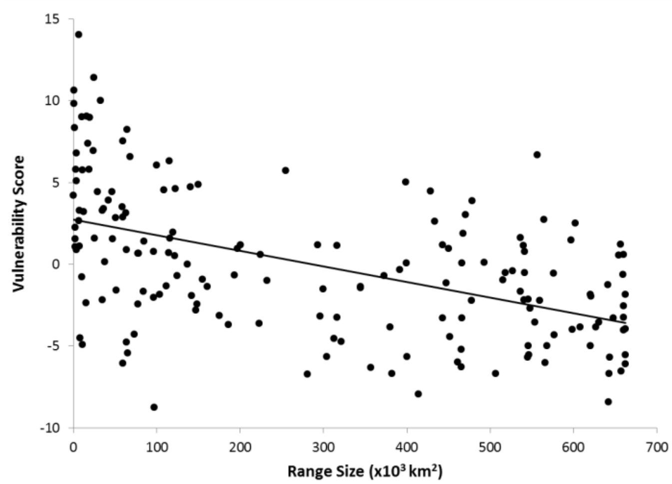

Figure 24. Relationship between vulnerability score and range size in Alberta.

The correlations between all sensitivity factors (except C2aii and C2bii, the physiological niches) and Alberta range size are negative (Figure 25) suggesting that smaller distribution is associated with greater sensitivity. By far the largest negative correlations are between range size and sensitivity factors C2ai and C2bi, the historical temperature and hydrological niches of the species. Removing C2ai and C2bi from the calculation of vulnerability reduces the correlation coefficient from 0.51 to 0.29 ($p<0.001$, df = 171). C2ai is a function of the difference in mean annual temperature in the species' Alberta range. C2bi is determined as the difference between the highest and lowest mean annual precipitation experienced by a species in Alberta. Logically, both should yield higher sensitivity scores with smaller home ranges resulting in a negative correlation between range size and vulnerability score. There is no biological reason for the evolved thermal and hydrological niches to be influenced by range size and this would seem to be an artifact of the analysis.

3.4.3 Removing the Effect of C2ai and C2bi

Sensitivity factors C2ai and C2bi have a powerful effect on vulnerability scores through their interaction with the differing climates of Alberta's Natural Regions and with species range size. Removing these two sensitivity factors from the analysis dramatically reduces the differences between the proportion of Higher Vulnerability species among some taxonomic groups and Natural Regions (Figure 26). Amphibians become the taxonomic group with the largest proportion of Higher Vulnerability species while the proportion of Higher Vulnerability reptile species is brought roughly in accord with mammals and vascular plants. As well, the proportion of Higher Vulnerability species in the Grassland is no longer greater than that of other Natural Regions.

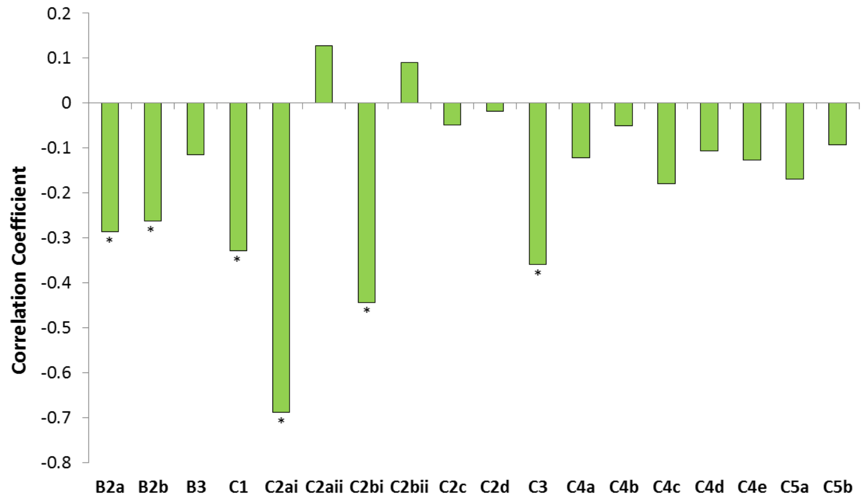

Figure 25. Pearson's correlation coefficient for Alberta range size and factor sensitivity scores for all 173 species. The asterisks (*) indicate statistical significance (α=0.05). B2a= Distribution relative to natural barriers; B2b= Distribution relative to anthropogenic barriers; B3 = Impact of land use changes related to human response to climate change; C1 = Dispersal and movement ability; C2ai = Predicted sensitivity to changes in temperature; C2aii= Physiological thermal niche; C2bi = Predicted sensitivity to changes in hydrology, precipitation or moisture; C2bii = Physiological hydrological niche; C2c = Dependence on disturbance regimes likely to be impacted by climate change; C2d = Dependence on ice, ice-edge or snow cover; C3 = Restriction to uncommon geological features or derivatives; C4a = Dependence on other species to generate habitat; C4b = Dietary versatility; C4c = Pollinator versatility; C4d = Dependence on other species for propagule dispersal; C4e = Other interspecific dependence; C5a = Genetic variation; C5b = Population bottlenecks.

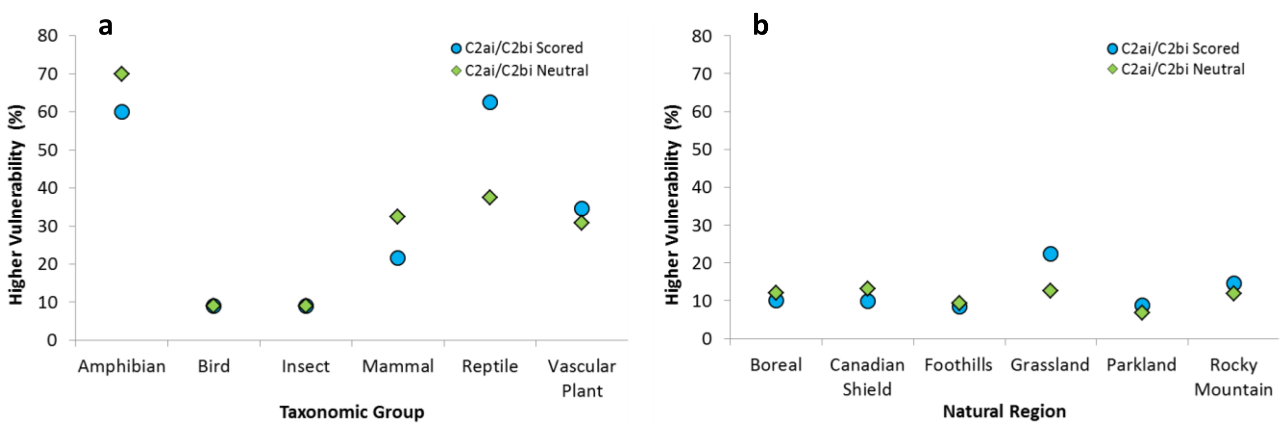

Figure 26. Percentage of Higher Vulnerability species before and after removal of sensitivity factors C2ai and C2bi from the calculation of vulnerability for a) taxonomic groups and b) Natural Regions.

Information about a species' thermal and hydrological niches is an important component of the CCVI. Removing these factors, as in Figure 26, reduces the ability of the CCVI to inform about climate change vulnerability; improved methods to quantify these two factors should be explored. One method might be to determine species niche breadths based on the entire continental range of the species rather than only the assessment area. This would remove the effect of range size and local conditions on the evolved climatic niche. Following the lead of Liebezeit et al. (2013), further efforts also should be undertaken to assess climatic conditions on the wintering range of migratory species.

3.5 Effect of At-Risk Status on Vulnerability

Species at higher risk of extinction, as assessed by Alberta S-Rank, tend to have higher median vulnerability scores (Figure 27a). Alberta S-Ranks are evaluated by the Alberta Conservation Management and Information System (ACIMS[7]) based on methodology developed by NatureServe[8]. Analysis using General Status of Alberta Wild Species 2010[9] categories also shows species at risk generally having higher climate change vulnerability scores. The CCVI does not explicitly incorporate species-at-risk status or its correlates in the calculation of vulnerability. However, detailed information is often more available for highly-studied species at risk leading to more informed assessments.

Another factor that may explain high vulnerability of species-at-risk is their small Alberta range sizes. S-Rank is correlated with Alberta range size ($r = 0.69$, $p < 0.001$, $df = 167$) resulting in species with lower S-Ranks (i.e., more at-risk) having higher scores for the historical thermal($r = -0.45$, $p < 0.001$, $df = 167$) and hydrological niche ($r = -0.51$, $p < 0.001$, $df=167$) sensitivity factors (C2ai and C2bi respectively).

Of the species assessed, the Grassland Natural Region has the largest proportion (44%) of species-at-risk (i.e., S-Rank 1, 2 or 3) and the Canadian Shield the least (7%) (Figure 27b); this may also contribute to the greater number of Higher Vulnerability species in the Grassland Natural Region (Figure 16b).

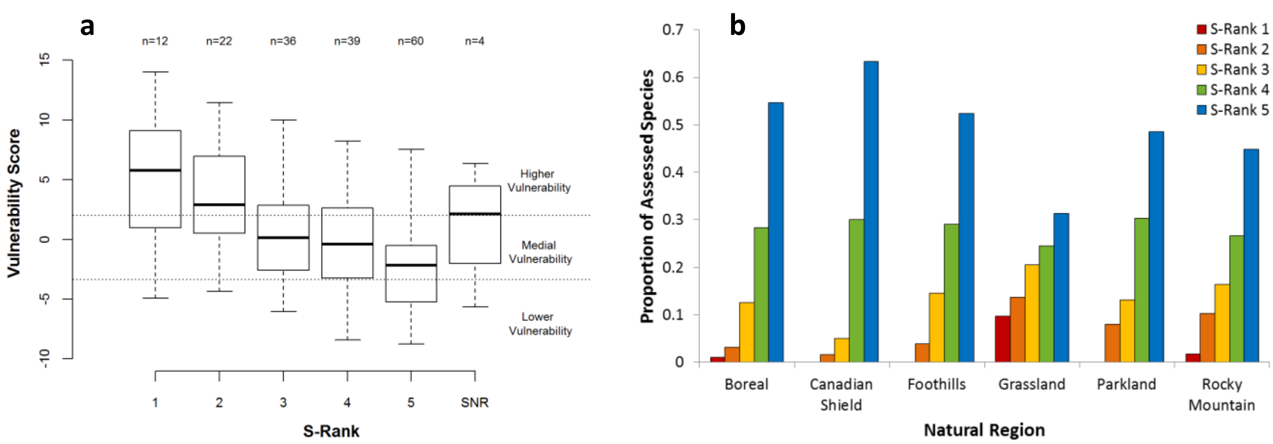

Figure 27. Climate change vulnerability and at-risk status. a) The relationship between vulnerability score and S-Rank. Whiskers indicate total data range. Four species (spruce budworm, two-striped grasshopper, bison and white adder's mouth) have not been ranked by ACIMS and are labeled as SNR. b) The distribution of S-ranks of the species assessed in each Natural Region.

3.6 Species Potentially Shifting their Ranges

Predicting whether a species might shift its range in response to climate change is an important result from the CCVI. The CCVI calculations provide a secondary output indicating whether a species is likely to expand its range in the assessment area or disperse out of it. The determination depends upon extreme or near extreme climate change, the existence of barriers, dispersal ability,

[7] http://www.albertaparks.ca/albertaparksca/management-land-use/alberta-conservation-information-management-system-(acims).aspx
[8] http://explorer.natureserve.org/ranking.htm
[9] http://esrd.alberta.ca/fish-wildlife/species-at-risk/wild-species-status-search.aspx

and the species' range in the assessment area relative to it continental range. We found assessing the last factor (relation of species' range to Alberta) to be particularly subjective and difficult to determine, leading to some indefensible results.

We provide a simpler approach to determining the likelihood of range shifts. We assume that every species will be subject to significant climate change and would benefit from expanding or shifting its range in response, if possible. Using numerical scores, we simply sum the scores for factors B2a (natural barriers), B2b (anthropogenic barriers), B3 (climate mitigation barriers) and C1 (dispersal ability). If the summed value is less than or equal to 0, indicating that dispersal ability is likely to overcome barriers, then we consider it likely that the species will be capable of responding to climate change by changing its range.

Of the 173 species assessed, this simple criterion suggests that 132 species will likely be able to respond to changing climate by shifting their ranges, if suitable habitat is available.

Among the species we assessed that are expected to have limited or very limited range shifts (41 of 173 species, Appendix 6), amphibian species may experience the greatest challenges, mainly because of dispersal barriers surrounding their current ranges (Table 3). Anthropogenic dispersal barriers can also expected to limit reptile range shifts. Mammals expected to have some difficulties in adaptive range shifts are largely from the Rocky Mountain Natural Region, where there are significant natural barriers to dispersal. Range shifts for vascular plants will mostly be limited by their dispersal abilities. The Grassland is the Natural Region with the largest percentage (26%) of species that might be expected to experience some difficulty shifting ranges mainly from the presence of anthropogenic barriers to dispersal.

Table 3. Percentage of species in taxonomic groups and Natural Regions likely to shift range in response to climate change. "Very Limited" = sum of four sensitivity factor ≥1.5, "Limited" = sum of four sensitivity factor 1.5 – 1, "Likely = sum of four sensitivity factors <1.

	Expected Range Shifts		
	Likely	Limited	Very Limited
Mammals	84%	11%	5%
Birds	100%	0%	0%
Reptiles	75%	13%	13%
Amphibians	40%	30%	30%
Insects	91%	9%	0%
Vascular Plants	50%	29%	21%
Boreal	89%	10%	1%
Canadian Shield	87%	11%	2%
Foothills	87%	9%	4%
Grassland	76%	13%	11%
Parkland	84%	11%	5%
Rocky Mountains	83%	11%	5%

4 Discussion

This report is intended to be a starting point for those considering adapting species management practices to include consideration of climate change. The on-line information in the individual species assessments provides more information that can be used to initiate detailed species climate change assessments.

The results of the CCVI analysis confirm expectations and broad patterns noted in other climate change vulnerability assessments. Many species currently at risk are also more vulnerable to climate change, an effect in part exacerbated by their small provincial ranges. Similar to other studies, amphibians were found to be highly vulnerable and birds the least vulnerable (Byers and Norris 2011, Furedi et al. 2011, Schlesinger et al. 2011). A majority of species can be expected to shift or expand their ranges, given the opportunity. The ranked lists of relative vulnerabilities provide an initial alert as to which species in certain taxonomic groups and Natural Regions are likely to be most vulnerable to climate change.

4.1 Limitations to the CCVI Approach

In conducting this analysis, we have become aware of several limitations to the CCVI approach to vulnerability assessment discussed below. However, the CCVI is intended to be a rapid means of achieving a general vulnerability assessment for many species rather than providing detailed analyses of vulnerability for any single species.

4.1.1 Presentation of Vulnerability Scores

As noted in Section 2.9, we contend that categorizing the CCVI vulnerability outputs into classes with labels such as "Extremely Vulnerable" or "Increase Likely" suggests an unsupported level of certainty in the implications of the model outputs. We have opted to provide the actual vulnerability scores without interpretation beyond reference to vulnerability quartiles and have presented results as relative values and ranks. The major shortcoming of our approach is that the results are informative only for the suite of species assessed.

4.1.2 Future Habitat

The CCVI does not take into account the availability of suitable habitat in the future. On the one hand, the CCVI may return a high vulnerability score even when suitable species habitat is expected to expand. For example, many Grassland species, such as the prairie rattlesnake, are assessed as being Higher Vulnerability despite the expectation that grassland habitat is expected to increase in future (Schneider 2013). On the other hand, vulnerability scores are reduced for a species with good dispersal ability regardless of whether suitable future conditions are likely to exist or not. For example, the Bay-breasted Warbler possesses excellent dispersal abilities, but is dependent upon northern forests that are projected to change dramatically in tree species composition over the coming decades (Schneider 2013). Capturing this process will require much more detailed analysis entailing species distribution modeling and estimating rates of habitat change based on complex ecological processes such as dispersal, competition and disturbance.

4.1.3 Accuracy of Range Maps

The range maps used for this assessment provide only a general representation of most species' ranges and are of varying accuracy. As well, the maps do not address small-scale variability in temperature and moisture, particularly with elevation change in the mountains. But, in fact, the CCVI model is relatively unaffected by small inaccuracies in the range maps because of the model's general insensitivity to exposure (Figure 7) for the species we assessed.

4.1.4 Historical Thermal and Hydrological Niche Breadth

The climatic niche of a species is calculated as a function of historical temperature and precipitation patterns through sensitivity factors C2ai and C2bi. These factors are correlated with climatic differences between Natural Regions and by species range size. Removing these sensitivity factors from the analysis results in the assessed species of all Natural Regions, including the Grassland, having similar mean vulnerability scores and a reduction in the vulnerability of reptiles.

The historical thermal niche for each species is determined by difference between mean winter and summer temperatures. Migratory species spend winters outside of Alberta and the breadth of temperatures such species can tolerate is therefore not accurately reflected by this approach (Liebezeit et al. 2013, Small-Lorenz et al. 2013). The CCVI Guidelines argue that migratory species are nevertheless affected by the influence of annual temperature variation on food supply and habitat. The consequence of neglecting the full range for migratory species is that the historical thermal niche (C2ai) is scored as contributing to increased sensitivity more than is reasonable. But, in fact, birds show a low average sensitivity score for this factor (Figure 15) suggesting it has little consequence for the final outcome.

Future CCVI analyses should explore the possibility of using entire species ranges to assess factors C2ai and C2bi.

4.1.5 Insensitivity to Exposure

As noted in Section 3.1, calculation of the vulnerability scores is not particularly sensitive to exposure. Despite large differences in exposure between the GCMs (Appendix 3, Figure 29), changes in vulnerability scores were only apparent for the extremely warm and dry conditions projected by the UKMO-HADGEM1 GCM (Appendix 3, Figure 30).

4.2 Considerations for Species Management in Alberta

A number of management considerations arise out of the results presented above.

4.2.1 Anticipate the Potential Effects of Climate Change on Alberta Species

This analysis has highlighted a number of species assessed as vulnerable to climate change but that are currently not considered to be at risk (e.g., American pika, balsam fir, Engelmann spruce, tamarack). If further research confirms these conclusions, monitoring programs could be considered to establish baselines and trends in populations and distributions.

4.2.2 Concentrate on Species-at-Risk

The CCVI analysis suggests that Alberta species-at-risk tend to have greater vulnerability to climate change than secure species. Therefore, including detailed, species-specific climate risk assessments and mitigation strategies into recovery and management planning will effectively address much of the climate change risk to Alberta's biodiversity at the species level.

4.2.3 Enhance opportunities for dispersal

Most animal species can be expected to expand or shift their ranges in response to climate change, if habitat is available and dispersal is possible. Reptiles and amphibians are especially sensitive to anthropogenic barriers and many plants have limited dispersal capabilities. This emphasizes the need for creative approaches to landscape connectivity and development of an evidence-based policy on assisted migration. Examples include geographically-specific suggestions for maintaining connectivity provided in *Advice to the Government of Alberta for the South Saskatchewan Regional Plan* (South Saskatchewan Regional Advisory Council 2011) and research on the effectiveness of assisted migration to mitigate the effects of climate change for range restricted plants by the Alberta Conservation Ecology lab[10].

4.2.4 Undertake more detailed studies

The CCVI provides a very preliminary picture of a species future in the face of climate change. It does not address the effect of change in climate or land use on future habitat or the size or location of the future climate envelope. A combination of species distribution modeling and detailed ecological, disturbance and land use modeling would be required to predict the future presence of species habitats. Development of methods to address this level of detail remains in its infancy (Flaxman 2011, Fordham et al. 2013).

[10] http://www.ace-lab.org/projects.htm#jennine

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Appendix 1. List of Species Assessed.

AMPHIBIANS	
Ambystoma macrodactylum	Long-toed Salamander
Ambystoma mavortium	Barred Tiger Salamander
Anaxyrus boreas	Western Toad
Anaxyrus cognatus	Great Plains Toad
Anaxyrus hemiophrys	Canadian Toad
Lithobates pipiens	Northern Leopard Frog
Lithobates sylvaticus	Wood Frog
Pseudacris maculata	Boreal Chorus Frog
Rana lutiventris	Columbia Spotted Frog
Spea bombifrons	Plains Spadefoot
BIRDS	
Aechmophorus occidentalis	Western Grebe
Ammodramus bairdii	Baird’s Sparrow
Ammodramus leconteii	LeConte’s Sparrow
Ammodramus savannarum	Grasshopper Sparrow
Anas clypeata	Northern Shoveler
Anthus spragueii	Sprague’s Pipit
Athene cunicularia	Burrowing Owl
Aythya americana	Redhead
Bombycilla cedrorum	Cedar Waxwing
Bombycilla garrulus	Bohemian Waxwing
Bucephala albeola	Bufflehead
Buteo regalis	Ferruginous Hawk
Calcarius ornatus	Chestnut-collared Longspur
Cardellina canadensis	Canada Warbler
Cardellina pusilla	Wilsons Warbler
Catharus fuscescens	Veery
Catharus ustulatus	Swainson’s Thrush
Centrocercus urophasianus	Greater Sage Grouse
Certhia americana	Brown Creeper
Charadrius melodus	Piping Plover
Charadrius montanus	Mountain Plover
Childonias niger	Black Tern
Chordeiles minor	Common Nighthawk
Coccothraustes vespertinus	Evening Grosbeak
Contopus cooperi	Olive-sided Flycatcher
Contopus sordidulus	Western Wood Peewee
Corvus brachyrhynchos	American Crow
Corvus corax	Common Raven
Cyanocitta cristata	Blue Jay
Cygnus buccinator	Trumpeter Swan
Dryocopus pileatus	Pileated Woodpecker
Empidonax minimus	Least Flycatcher
Euphagus carolinus	Rusty Blackbird
Geothlypis trichas	Common Yellowthroat
Grus americana	Whooping Crane
Haemorhous purpureus	Purple Finch
Hirundo rustica	Barn Swallow
Histrionicus histrionicus	Harlequin Duck
Icterus galbula	Baltimore Oriole
Molothrus ater	Brown-headed Cowbird
Numenius americanus	Long-billed Curlew
Oporornis agilis	Connecticut Warbler
Phalacrocorax auritus	Double-crested Cormorant
Phalaropus tricolor	Wilsons Phalarope
Pheucticus ludovicianus	Rose-breasted Grosbeak
Pica hudsonia	Black-billed Magpie
Picoides arcticus	Black-backed Woodpecker
Rhynchophanes mccownii	McCown’s Longspur
Setophaga castanea	Bay-breasted Warbler
Setophaga palmarum	Palm Warbler
Spinus pinus	Pine Siskin
Spinus tristis	American Goldfinch
Strix nebulosa	Great Grey Owl
Strix varia	Barred Owl
Tympanuchus phasianellus	Sharp-tailed Grouse
INSECTS	
Bombus occidentalis	Western Bumblebee
Parnassius smintheus	Rocky Mountain Apollo Butterfly
Tegeticula yuccasella	Yucca Moth
Callophrys sheridaniI	Sheridans Hairstreak
Chlosyne palla	Northern Checkerspot

Euphydryas gillettii	Gillette's Checkerspot
Limenitis lorquini	Lorquin's Admiral
Limenitis weidemeyerii	Weidemeyer's Admiral
Satyrium titus	Coral Hairstreak
Melanophus bivattatus	Two-striped Grasshopper
Choristoneura fumiferana	Spruce Budworm

MAMMALS

Alces americana	Moose
Antilocapra americana	Pronghorn Antelope
Bison bison	Wood Bison
Callospermophilus lateralis	Golden Mantled Ground Squirrel
Canis latrans	Coyote
Canis lupus	Grey Wolf
Castor canadensis	American Beaver
Cervus elaphus	Elk (Wapiti)
Dipodomys ordii	Ords Kangaroo Rat
Eptisicus fuscus	Big Brown Bat
Gulo gulo	Wolverine
Lasionycteris noctovagans	Silver-haired Bat
Lepus americanus	Snowshoe Hare
Lynx canadensis	Lynx
Marmota caligata	Hoary Marmot
Martes americana	Marten
Martes pennanti	Fisher
Microtus richardsoni	Water Vole
Myotis ciliolabrum	Western Small-footed Bat
Myotis evotis	Long-eared Bat
Myotis lucifugus	Little Brown Bat
Neotomias ruficaudus	Red-tailed Chipmunk
Ochotona princeps	American Pika
Odocoileus hemionus	Mule Deer
Odocoileus virginianus	White-tailed Deer
Oreamnos americanus	Mountain Goat
Ovis canadensis	Bighorn Sheep
Phenacomys ungava	Eastern Heather Vole
Rangifer tarandus	Caribou
Sorex arcticus	Arctic Shrew
Sorex vagrans	Wandering Shrew
Synaptomys borealis	Northern Bog Lemming
Urocitellus columbianus	Columbian Ground Squirrel
Ursus americanus	American Black Bear
Ursus arctos	Grizzly Bear
Vulpes velox	Swift Fox
Vulpes vulpes	Red Fox

REPTILES

Chrysemys picta	Western Painted Turtle
Crotalus viridis	Prairie Rattlesnake
Heterodon nasicus	Plains Hognose Snake
Phyrnosoma hernandesi	Short-horned Lizard
Pituophis catenifer	Bull Snake
Thamnophis elegans	Wandering Garter Snake
Thamnophis radix	Western Plains Garter Snake
Thamnophis sirtalis	Red-sided Garter Snake

VASCULAR PLANTS

Abies balsamea	Balsam Fir
Abies bifolia	Subalpine Fir
Actaea rubra	Red Baneberry
Alnus incana	Speckled Alder
Alnus viridis	Green Alder
Amelanchier alnifolia	Saskatoon Serviceberry
Artemisia frigida	Prairie Sandwort
Artemisia tridentata	Big Sagebrush
Astragalus purshii	Pursh's Milkvetch
Betula occidentalis	River Birch
Betula papyrifera	Paper Birch
Bouteloua gracilis	Blue Grama
Bromus ciliatus	Fringed Brome
Carex backii	Back's Sedge
Corallorhiza maculata	Spotted Coralroot
Corallorhiza striata	Striped Coralroot
Crypthantha minima	Tiny Cryptanthe
Cypripedium montanum	Mountain Lady's-Slipper
Elymus trachycaulus	Slender Wild Rye
Halimolobos virgata	Slender Mouse-ear Cress
Houstonia longifolia	Long-leaved Summer Bluet
Larix laricina	Tamarack
Liatris ligulistylis	Strap-leaved Blazing Star
Malaxis monophyllos	White Adder's Mouth
Neottia borealis	Northern Twayblade
Neottia convallaroides	Broad-leaved Twayblade
Pascopyrum smithii	Western Wheatgrass

Picea engelmannii	Engelmann Spruce
Picea glauca	White Spruce
Picea mariana	Black Spruce
Pinus albicaulis	Whitebark Pine
Pinus banksiana	Jack Pine
Pinus contorta	Lodgepole Pine
Pinus flexilis	Limber Pine
Populus balsamifera	Balsam Poplar
Populus tremuloides	Trembling Aspen
Prunus pensylvanica	Pin Cherry
Prunus virginiana	Chokecherry
Pseudoroegneria spicata	Bluebunch Wheatgrass
Ranunculus glaberrimus	Early Buttercup
Ranunculus occidentalis	Western Buttercup
Ranunculus uncinatus	Hairy Buttercup
Ribes triste	Wild Red Current
Salix alaxensis	Alaska Willow
Salix pseudomonticola	False Mountain Willow
Salix pseudomyrinites	Tall Blueberry Willow
Sarracenia purpurea	Purple Pitcher Plant
Tradescantia occidentalis	Western Spiderwort
Tripterocalyx micranthus	Small-flowered Sand Verbena
Vaccinium uliginosum	Bog Bilberry
Yucca glauca	Small Soapweed Yucca

Appendix 2. Details of Exposure Calculations

Calculation of Future Temperature Anomalies

Anomalies between the historic and projected (2050s) mean annual temperature were taken directly from the raw GCM data and then interpolated into rasters at 1° resolution. The interpolated rasters were then reclassified into the categories in Table 4 representing multiples of the standard deviation for projected Alberta temperatures.

Table 4. Categories of projected temperature change to the 2050s based on the mean ± 1 and ± 2 standard deviations.

Category Name	Temperature Change Ranges
High	>2.708
Medium High	2.536 - 2.708
Medium Low	2.364 - 2.536
Low	2.192 - 2.364
Very Low	<2.192

Calculation of Future Evapotranspiration Anomalies

The CCVI model evaluates change in evapotranspiration in terms of Hamon's moisture metric (HMM; Hamon 1961). HMM is the ratio of actual to potential evapotranspiration (AET:PET) where the latter is calculated using total daylight hours and saturated vapor pressure. HMM is equal to 1 when precipitation is equal to or greater than potential evaporation and is 0 when there is no precipitation. HMM was calculated for each point of each downscaled climate projection for the 2050s and for the historic (1971-2000) climate data to determine the change in the moisture metric across this period.

Despite projected small increases in precipitation (Bruce 2011), available moisture will decline throughout most of the province as a result of increased temperature and resulting increases in evapotranspiration. HMM anomaly rasters were reclassified using the following categories (Table 5) calculated from the Ensemble data.

Table 5. Categories of projected Hamon moisture metric changes to the 2050s based on the mean ±1 and ±2 times the standard deviation.

Category Name	HMM Change Ranges
Very High	<-0.180
High	-0.180 to -0.128
Medium High	-0.128 to -0.076
Medium Low	-0.076 to -0.024
Low	-0.024 to +0.028

Appendix 3. Effect of Global Circulation Models on Vulnerability Score and Ranking

For simplicity, and in keeping with NatureServe's suggested approach (Young et al. 2011), we have used the Ensemble climate projections (average for 16 GCMs) for all analyses presented in the main report. Future climate projection data were also generated for 5 individual general circulation models (GCMs), selected based on criteria developed by (Stralberg 2012).

1. INM-CM3.0 (wetter)
2. CGCM3.1(T47) (wetter and less seasonal)
3. GFDL-CM2.1 (drier)
4. UKMO-HadGEM1 (drier and much warmer)
5. ECHAM5/MPI-OM (most representative)

Here we examine how results differ by using any of the other five individual GCMs (Figure 28).

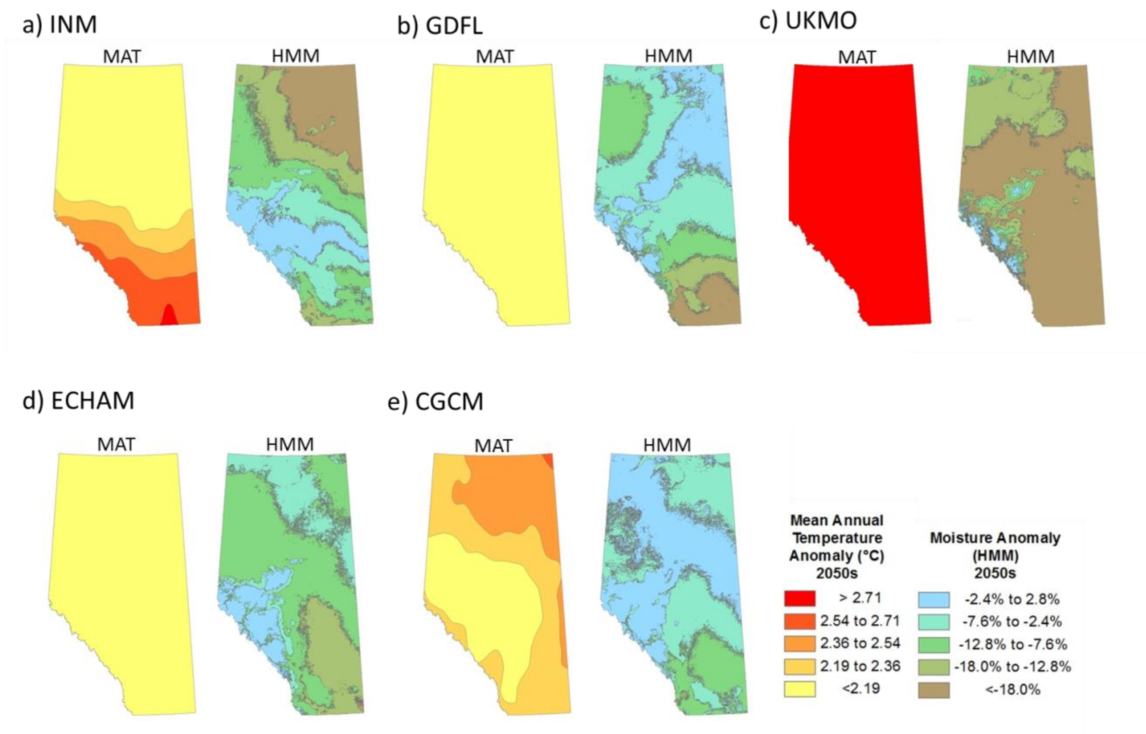

Figure 28. Temperature (MAT) and Hamon moisture metric (HMM) anomalies between the historical period (1971-2000) and the 2050s for five global circulation models. Anomaly maps for the Ensemble dataset are shown as Figure 5 in the main body of the report

The distributions of exposure scores for the five GCMs vary widely (Figure 29). GFDL-CM2.1 and ECHAM5/MPI-OM have greatest proportion of low exposure scores and UKMO-HADGEM1 has by far the largest proportion. The INM-CM3.0 and the Ensemble climate projections have the widest and most central distribution of exposure scores.

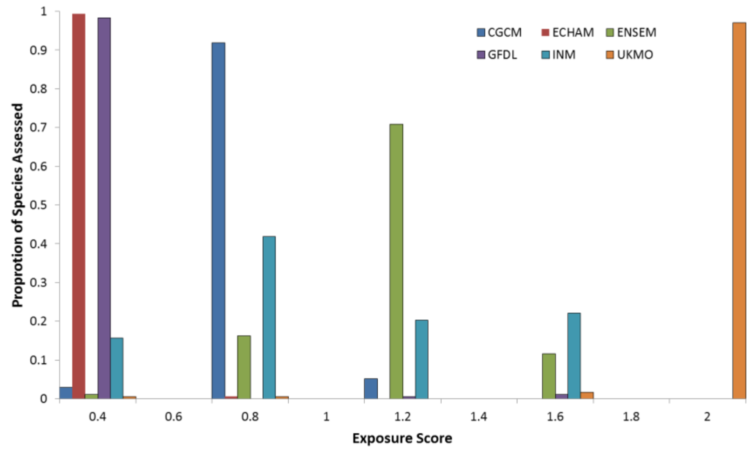

Figure 29. Distribution of exposure scores calculated for 173 species using projections from the 5 GCMs and the Ensemble data. CGCM = CGCM3.1(T47), ECHAM = ECHAM5/MPI-OM, GFDL = GFDL-CM2.1, INM = INM-CM3.0, UKMO = UKMO-HadGEM1.

In contrast to the large differences in the distribution of exposure scores among the GCMs, the vulnerability scores are less variable (Figure 30), reflecting the overall small effect of exposure on vulnerability for the species we assessed (Section 3.1). However, under the more extreme conditions projected by the UKMO-HadGEM-1 model, a larger proportion of species is both more and less vulnerable than predicted by any other GCMs.

The vulnerability rankings for all species based on the five GCMs do not differ greatly from the Ensemble ranking. Kendall's W statistic comparing the ranks calculated for the Ensemble projection to the ranks determined using other GCMs ranges from 0.979 (GFDL-CM2.1) to 0.995 (CGCM3.2(T47)) where 1 equals perfect correspondence. Between 70% (GFDL-CM2.1) and 94% (CGCM3.2(T47)) of species show a rank difference of 10 places or less from the Ensemble rank.

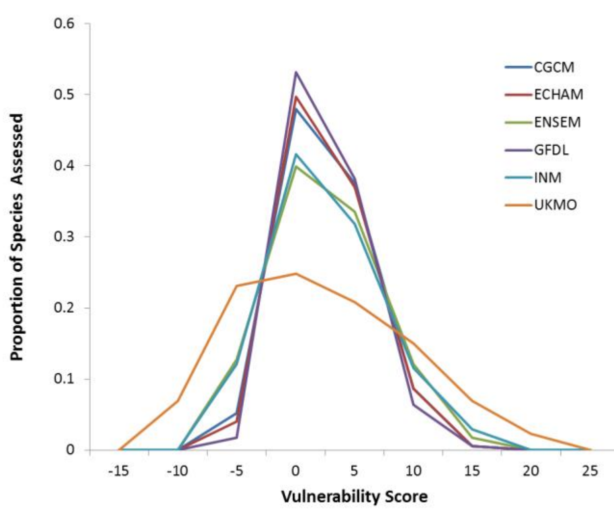

Figure 30. Distribution of vulnerability scores calculated for 173 species using projections from the 5 GCMs and the Ensemble data. CGCM = CGCM3.1(T47), ECHAM = ECHAM5/MPI-OM, GFDL = GFDL-CM2.1, INM = INM-CM3.0, UKMO = UKMO-HadGEM1.

Nevertheless, some species do rank differently depending on the GCM used to model exposure to climate change. Table 6 presents, for each GCM, the 10 species that are ranked higher and lower than the vulnerability ranking obtained from using the Ensemble projection. Many of the species with vulnerability rankings divergent from those obtained using Ensemble data are boreal species. In the boreal, the Ensemble projection shows more spatial variability in temperature change and less extensive drying relative to the five individual GCMs (Figures 5 and 30). Choice of GCM therefore influences vulnerability rankings for boreal species more than species in other natural regions. However, the Ensemble projection provides a reasonable representation of the climate change vulnerability rankings for Alberta species.

Table 6. For each GCM, the ten species diverging most in vulnerability ranking from the Ensemble ranking are presented. For each species, the number of ranks lower or higher than the Ensemble rank is shown.

CGCM		ECHAM		GFDL		INM		UKMO	
Less Vulnerable	**More Vulnerable**	**Less Vulnerable**	**More Vulnerable**	**Less Vulnerable**	**More Vulnerable**	**Less Vulnerable**	**More Vulnerable**	**Less Vulnerable**	**More Vulnerable**
-18 Wolverine	28 Connecticut Warbler	-39 Wolverine	67 Wood Bison	-34 Wolverine	52 Wood Bison	-37 Wolverine	71 Wood Bison	-39 Connecticut Warbler	19 Ground Squirrel
-16 Marten	19 Canada Warbler	-37 Marten	39 Canada Warbler	-31 Snowshoe Hare	39 Canada Warbler	-35 Marten	24 Canada Warbler	-23 Bay-breasted Warbler	19 Sheridan's Hairstreak
-14 Red-tailed Chipmunk	16 Palm Warbler	-35 Snowshoe Hare	32 Baird's Sparrow	-31 Lady's-Slipper	34 Connecticut Warbler	-30 Lynx	16 Hoary Marmot	-20 Palm Warbler	18 Mountain Goat
-13 Lynx	16 Bay-breasted Warbler	-29 Lynx	30 Palm Warbler	-31 Marten	33 Bay-breasted Warbler	-26 Caribou	16 Palm Warbler	-19 Swainson's Thrush	17 Harlequin Duck
-11 Snowshoe Hare	16 Brown Creeper	-27 Limber Pine	26 Redhead	-29 Limber Pine	33 Baird's Sparrow	-20 Snowshoe Hare	15 Hairy Buttercup	-18 Olive-sided Flycatcher	16 Broad-leaved Twayblade
-11 Wandering Shrew	14 Western Wood Peewee	-23 Red-tailed Chipmunk	24 Pronghorn Antelope	-28 Bluebunch Wheatgrass	32 Western Wood Peewee	-19 Mountain Plover	14 Black Tern	-16 Western Wood Peewee	16 Hairy Buttercup
-11 Gillette's Checkerspot	13 Olive-sided Flycatcher	-21 Hoary Marmot	23 Olive-sided Flycatcher	-28 Sheridan's Hairstreak	31 Swift Fox	-17 Grasshopper Sparrow	13 Mountain Goat	-16 Grizzly Bear	16 Weidemeyer's Admiral
-11 Golden Mantled Ground Squirrel	11 Weidemeyer's Admiral	-21 Mountain Lady's-Slipper	23 Black Tern	-27 Red-tailed Chipmunk	29 Palm Warbler	-15 Black Spruce	13 Rocky Mountain Apollo Butterfly	-15 Mountain Plover	15 Subalpine Fir
-11 Elk (Wapiti)	11 Double-crested Cormorant	-20 Blue Grama	22 Ferruginous Hawk	-26 Lynx	29 Olive-sided Flycatcher	-14 Western Wheatgrass	13 Harlequin Duck	-15 Wilson's Warbler	15 Wood Bison
-11 Grizzly Bear	10 American Pika	-20 Wandering Shrew	22 Swift Fox	-23 Hoary Marmot	28 Pronghorn Antelope	-14 Pronghorn Antelope	13 Redhead	-13 Rusty Blackbird	14 Rocky Mountain Apollo Butterfly

Appendix 4. Guidelines for Assessing Sensitivity of Alberta Species to Climate Change

The Climate Change Vulnerability Index (CCVI) is a tool developed by NatureServe to calculate a relative measure of climate change vulnerability based on projected future temperature and moisture and on species sensitivity to these future conditions. Species sensitivity is determined by assessing a series of factors based on information in the scientific literature and assigning each a score according to detailed guidelines described Young et al. (2011). Our experience has shown that these guidelines are sometimes difficult to interpret consistently within the Alberta context. Therefore, we offer the following advice on how to assess climate change sensitivity factors for Alberta species specifically for entry into NatureServe's Climate Change Vulnerability Index (CCVI) software. For more details, refer to Young et al. (2011).

General Principles

- More than one score can be provided in cases of uncertainty.
- Where there is lack of information, sometimes a score of "Neutral" can be inferred. But in most cases, where there is lack of information the scoring should be "Unknown".
- For some factors, firm numbers for percentage of occurrence or specific distances are offered as an assessment criterion. Rarely are such precise data available, so use these percentages as a subjective measure of consequence.
- Reasons for providing a score and references should be provided for each factor, except for those in which the score's rationale is obvious.

Determining Relation of Species Range to Assessment Area

The relationship of a species continental range relative to its range in the assessment area is used by the CCVI to assess whether a species is likely to shift its current range and/or leave the assessment area. Determining this relationship has proven to be a surprisingly difficult decision to make consistently and justifiably. An original version of these guidelines provided advice on how to assess the relationship between a species' Alberta and continental ranges. Subsequently, we developed a simpler algorithm to determine likelihood of range shift that does not require this determination. Consequently, advice on determining the relationship between the Alberta and continental species' ranges has been removed from these guidelines.

B2 Distribution Relative to Barriers

This factor assesses the degree to which natural (e.g., topographic, geographic, ecological) or anthropogenic barriers limit a species' ability to shift its range in response to climate change (Young et al 2011). Barriers are considered landscape features that completely or partially prevent, in the case of Alberta, dispersal to the north or upslope.

Barriers and unsuitable habitat are often difficult to distinguish. Young et al. (2011) state that barriers are considered to be features through or over which a species cannot or will not move while unsuitable habitat is a landscape through which the species can move, but in which it cannot survive and reproduce. Factor C1 addresses unsuitable habitat.

Natural barriers can include mountain ranges for lowland plants, wide valleys for mountain mammals, rivers for many small animals. Anthropogenic barriers include urban areas, cultivated fields, and roads. We are currently developing an anthropogenic disturbance map, which should help in assessing this factor.

Features that limit dispersal but are a long distance from current range cannot be considered as barriers. The CCVI Guidelines state that barriers can be as far from current range as 50 km in flat terrain, 10 km in mountainous terrain and 25 km in intermediate topography. The reasoning is that temperature changes will occur over shorter geographical distances in more mountainous areas.

Natural and anthropogenic barriers are scored by the same criteria. If both natural and anthropogenic barriers exist, factor out the relative contribution of each.

It is not completely clear how to assess this factor for species that are restricted to Alberta's Rocky Mountains (e.g., bighorn sheep, pika, whitebark pine). Because the Rockies trend southeast to northwest and are on the southwestern edge of the province, northern dispersal of species will take them out of Alberta and into British Columbia. There may be no global barriers to dispersal, but dispersal within Alberta will not be possible. However, since the assessment is for Alberta, treat the lack of mountains further north as a barrier.

Greatly Increase Vulnerability-- Barriers completely prevent a range shift north or to higher elevation.
Natural Barrier Example: Pikas are unable to cross valleys and are sometimes found at the highest elevations available.

Anthropogenic Barrier Example: None known for terrestrial species. Probably common for aquatic species blocked by dams and hung culverts.

Increase Vulnerability—Barriers greatly but not completely prevent range shift to the north or upslope.
Natural Barrier Example: Bighorn sheep are prevented from moving north because mountainous terrain does not exist in that direction. Bighorns treat valleys between mountain blocks as barriers, but some dispersers do rarely cross. So, some movement within Alberta is possible.

Anthropogenic Barrier Example: The range of the Plains spadefoot toad is nearly completely surrounded by intensive agriculture and a dense road network.

Somewhat Increase Vulnerability—Barriers that significantly but not greatly prevent range shift to the north or upslope.
Natural Barrier Example: The eastern heather vole is stopped by water bodies >200m wide if frozen and 50m wide if not. Several east-west trending rivers are likely to be barriers.

Anthropogenic Barrier Example: The eastern heather vole is stopped by major highways, particularly those with solid barriers.

Neutral—Significant barriers do not exist.
Example: Most birds and large mammals fall under this category.

B3 Predicted Impact of Land Use Changes Resulting from Human Responses to Climate Change

Strategies designed to mitigate or adapt to climate change have the potential to affect very large areas of land, and the species that depend on these areas… (Young et al. 2011). This factor is not meant to capture general habitat loss but only those related to such climate change mitigation activities as wind-farms, carbon off-set plantations, etc. There are very few of these in Alberta (Cowley Ridge windfarm being one) and we can probably score this as Neutral for almost all Alberta species.

C1 Dispersal and Movements

This factor pertains to known or predicted dispersal or movement capacities and characteristics and ability to shift location in the absence of barriers… (Young et al. 2011). This is interpreted as a species ability to move through habitat that is unsuitable for population persistence and reproduction. As noted earlier, barriers and unsuitable habitat are often difficult to distinguish.

Greatly Increase Vulnerability-- Restricted to species that never disperse more than a few meters.
Example: Plants that spread solely through vegetative shoots.

Increase Vulnerability—Species that rarely disperse more than 10 m.
Example: Plants with heavy seeds that disperse ballistically. This does not include riparian plants that may disperse seed along waterways.

Somewhat Increase Vulnerability—At least 5% of seeds or individuals disperse 10 – 100 m.
Example: Small, slow moving animals like snails, plants dispersed by wind with low efficiency.

Neutral-- At least 5% of seeds or individuals disperse 100 – 1000 m.
Example: Small mammals and plants with efficient wind dispersal.

Somewhat Decrease Vulnerability—Individuals or propagules readily move 1 – 10 km.
Example: Medium sized mammals, plant seeds dispersed by birds or large mammals.

Decrease Vulnerability—Individuals or propagules readily move >10 km. These species tend to occupy all suitable habitat.
Example: Most birds and large mammals, tiny propagules dispersed by upper air currents.

C2aii Physiological Thermal Niche

This factor assesses the degree to which a species is restricted to relatively cool or cold aboveground terrestrial or aquatic environments that are thought to be vulnerable to loss or significant reduction… (Young et al. 2011). This factor is intended to refer to species that depend on cooler microclimates (higher elevations, north-facing slopes, shady ravines, frost pockets, etc) within the general Alberta range. Score higher if species occurs only in northern Alberta or at high altitudes where it is cooler. Do not compare with areas outside Alberta. Dependence on snow is scored separately in Factor C2d.

Greatly Increase Vulnerability-- >90% of occurrences are in cooler areas of Alberta range.
Example: Pikas are temperature sensitive and remain at higher elevations.

Increase Vulnerability—50-90% of occurrences are in cooler areas of Alberta range.
Example: Possibly moose since they, by some accounts, seek out cooler microclimates in summer.

Somewhat Increase Vulnerability—10 – 50% of occurrences are in cooler areas of Alberta range.
Example: Heather voles are largely restricted to alpine and subalpine habitats, although low altitude populations are known.

Neutral—Species distribution within general range is not affected by thermal characteristics.
Example: most species.

Somewhat Decrease Vulnerability—prefers sites warmer than most in its range.
Example: The plains spadefoot toad prefers warmer habitats.

C2bii Physiological Hydrological Niche

This factor pertains to a species' dependence on a narrowly defined precipitation/hydrologic regime, including strongly seasonal precipitation patterns and/or specific aquatic/wetland habitats… that may be highly vulnerable to loss or reduction… (Young et al. 2011)

Deep-water lakes are less likely vulnerable to loss than shallow-water ponds or wetlands. C4 plants should be scored one category less than C3 plants.

Greatly Increase Vulnerability—completely or almost completely (>90% of occurrences) dependent on specific wetland or aquatic habitat that is highly vulnerable to loss.

Increase Vulnerability-- Moderately (50-90% of occurrences) dependent on specific aquatic or wetland habitat or patterns of precipitation that are highly vulnerable to loss or reduction.
Example: Great Plains toad breeds in ditches, ponds and other very temporary water bodies in the prairies where drying is likely to be significant.

Somewhat Increase Vulnerability--Somewhat (10-50% of occurrences) dependent on specific aquatic or wetland habitat or patterns of precipitation that are highly vulnerable to loss or reduction.
Example: Long-toed salamander breeding in temporary ponds or at the edge of streams and lakes.

Neutral—little or no dependence on specific aquatic or wetland habitat or patterns of precipitation.
Example: most birds, mammals and reptiles

Somewhat Decrease Vulnerability—species has very broad moisture tolerances or would benefit from a drying climate.
Example: Chestnut-collared Longspur is found in very dry areas and may benefit from more drying.

C2c Dependence on a specific disturbance regime likely to be impacted by climate change
This factor pertains to a species' response to specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events (Young et al. 2011). It includes direct impacts on the species as well as indirect impacts through habitat changes.

In Alberta, forest and grass fires will almost certainly increase in frequency and intensity as the climate changes. Some species will be benefitted and others harmed. Some pest/pathogen species (bark beetles, brain worm) may increase in incidence.

This factor relies on very subjective criteria of "moderate" vs. "strong" effects, which are not defined. In the end, it depends upon how much certainty and effect magnitude is presented in the literature. Multiple categories may be appropriate.

Increase Vulnerability—the distribution and/or abundance of the species may be strongly reduced by projected disturbance regime.
Example: Whitebark pine is very likely to be decimated by increased blister rust and pine beetle outbreaks.

Somewhat Increase Vulnerability--the distribution and/or abundance of the species may be moderately reduced by projected disturbance regime.
Example: American Crows are vulnerable to West Nile Virus, which is expected to increase with climate change.

Neutral—Little or no response to disturbance regime.
Example: Most species.

Somewhat Decrease Vulnerability-- the distribution and/or abundance of the species may be moderately increased by projected disturbance regime.
Example: Black-backed Woodpeckers are associated with recently burned boreal forest, which is likely to increase in extent. This could also be "Decrease Vulnerability".

Decrease Vulnerability--the distribution and/or abundance of the species may be strongly increased by projected disturbance regime.
Example: Grasshopper Sparrows require bare soil patches, thin litter layers, and few shrubs all of which are maintained by frequent fire. Grass fires increase nestling survival rates. This could also be "Somewhat Decrease Vulnerability".

C2d Dependence on ice, ice-edge, or snow cover habitats

This factor pertains to a species' dependence on habitats associated with ice (e.g., sea ice, glaciers) or snow (long-lasting snow beds, avalanche chutes) throughout the year or seasonally… (Young et al. 2011). In Alberta we should extend this to refer to dependence on permafrost.

The criteria are based on the percentage of subpopulations or range dependent on snow/ice. There are rarely any such data, so the percentages should usually be interpreted as a subjective assessment of how significant snow/ice is on a 0 to 100 scale.

Greatly Increase Vulnerability—Highly dependent (>80% of subpopulations or range) on ice- or snow-dominated habitats or found near snow or ice during at least one stage of the life cycle.
Example: Wolverine depend completely on persistent snow for denning.

Increase Vulnerability--Moderately dependent (50-80% of subpopulations or range) on ice- or snow-dominated habitats or found near snow or ice during at least one stage of the life cycle.
Example: Marten are adapted to snow and are outcompeted by fisher where snow is limited.

Somewhat Increase Vulnerability--Somewhat dependent (10 - 49% of subpopulations or range) on ice- or snow-dominated habitats or found near snow or ice during at least one stage of the life cycle.
Example: Grizzly bears prefer to den in areas with deep snow

Neutral-- Little dependence on snow or ice.
Example: most species.

C3 Restriction to Uncommon Geological Features or Derivatives

This factor pertains to a species' need for a particular soil/substrate, geology, water chemistry or specific physical feature (e.g., caves, cliffs, active sand dunes)… (Young et al. 2011). Assessment is based on a combination of how common the feature is on the landscape and how restricted the species is to the feature. This factor does not refer to biotic features (e.g., snags). Most birds and mammals will not require such features and will be assessed as Somewhat Decrease Vulnerability.

Increase Vulnerability—very highly dependent (i.e., almost always found) associated with a particularly rare geological feature or soil.
Example: Sand verbena limited to rare active sand dunes.

Somewhat Increase Vulnerability—moderately to highly dependent on a particular geological feature or soil. This can be an indicator species found in 65-85% of occurrences on a particularly rare geological feature or derivative OR highly restricted to a feature that is uncommon
Example: Prairie Falcons require cliffs for nesting. Suitable cliffs are not common.

Neutral—having a clear preference (>85% of occurrence found on) for a certain geological feature or derivative that is among the dominant types in the species range.
Example: Plant species requiring a specific pH or soil type if that type is not uncommon in the species range.

Somewhat Decrease Vulnerability—Somewhat flexible but not highly generalized in dependence upon geological features or derivatives. This category applies to most species not strongly tied to any specific geological feature or derivative.
Example: most birds and mammals.

Decrease Vulnerability—Highly generalized with respect to geological features or derivatives and usually described as a generalist.
Example: Young et al. (2011) give examples of common yarrow and the coyote. Probably rarely assessed.

C4a Dependence on Other Species to Generate Habitat
This factor refers to specific biotic habitats or landscape features created by other species. Although nowhere stated, it appears that this factor refers only to positive relationships.

Greatly Increase Vulnerability—refers to required habitat generated primarily by <u>one other species</u> and that species is highly susceptible to climate change.
Example: none known.

Increase Vulnerability--refers to required habitat generated primarily by <u>one other species</u> and that species is moderately vulnerable to climate change. If the susceptibility of the habitat-generating species is unknown, check both Greatly Increase Vulnerability and Increase Vulnerability.
Example: none known.

Somewhat Increase Vulnerability—required habitat generated by <u>one or a few other species</u> with no clear vulnerability to climate change.
Example: Buffleheads depend on excavators such as Northern Flickers to provide nest cavities. However, flickers are not known to be susceptible to climate change.

Neutral—required habitat provided by more than a few species OR does not involve species-specific processes.
Example: Most species.

C4b Dietary Versatility
This factor refers only to animals—for plants assess as Not Applicable (NA), which will be entered into the model as Unknown.

Increase Vulnerability—Completely or almost completely (>90%) dependent on one species for part of the year.
Example: 89% of Ferruginous Hawk diet is Richardson's ground squirrel.

Somewhat Increase Vulnerability-- Completely or almost completely (>90%) dependent for part of the year on a few species from a single guild.
Example: many flycatcher species.

Neutral—diet not dependent on one or a few species.
Example: most species

Somewhat Decrease Vulnerability—Omnivorous.
Example: Grizzly bear.

C4c Pollinator Versatility
This factor refers only to plants—for animals assess as Not Applicable (NA), which will be entered into the model as Unknown. Sometimes this can be inferred from flower shape.

Increase Vulnerability—Completely or almost completely (>90%) dependent on one species for pollination.
Example: some orchids.

Somewhat Increase Vulnerability--Completely or almost completely (>90%) dependent on 2 - 4 species for pollination.
Example: most orchids.

Neutral—Pollination flexible.
Example: most species.

C4d Dependence on other species for propagule dispersal

Increase Vulnerability—Completely or almost completely (ca. 90%) dependent on a single species for propagule dispersal.
Example: Whitebark pine seed is primarily dispersed by Clark's Nutcrackers.

Somewhat Increase Vulnerability-- Completely or almost completely (ca. 90%) dependent on a small number of species for propagule dispersal.
Example: *Trillium ovatum* which is ant-dispersed.

Neutral—disperses on its own or propagules are dispersed by many species.
Example: almost all animals and many plants. More than a few birds and mammals are primarily responsible for dispersal of *Vaccinium* seeds.

C5a Measured Genetic Variation
This factor refers to heterozygosity or number of haplotypes as measured primarily from selectively neutral markers (microsatellites, mtDNA) or quantitative genetic variation. Genetic studies earlier than the mid-90s generally used allozyme variation, which is subject to selective pressures and is about an order of magnitude lower than microsatellite variation. In general, such studies should not be reported, but if the data are good and results are conclusive, it seems wasteful not to use the results. Amount of variation is a subjective judgment relative to other similar species or populations. Numerous measures of genetic variation are reported and it is often difficult for the non-specialist to interpret results.

Increase Vulnerability—Genetic variation reported as very low compared to results from similar techniques in related taxa.
Example: Only 33% of mtDNA variation remains in Whooping Crane populations. Variation is much less than in other cranes.

Somewhat Increase Vulnerability-- Genetic variation reported as low compared to results from similar techniques in related taxa.
Example: mtDNA diversity of northern leopard frogs is reported to decline in Canada from east to west with the Alberta population having lower diversity than the Manitoba population.

Neutral--Genetic variation reported as average compared to results from similar techniques in related taxa.
Example: Western Wood-pewee has average allozymic variation relative to other flycatchers. No mtDNA or microsatellite data were found, so this study was used as a fallback.

Somewhat Decrease Vulnerability--Genetic variation reported as high compared to results from similar techniques in related taxa.
Example: Burrowing Owl is reported to have relatively high genetic variation based on microsatellite analysis.

C5b Occurrence of bottlenecks in recent evolutionary history
This factor is to be used only if C5a is Unknown.

Increase Vulnerability—the population was reduced to <250 mature individuals, to one occurrence, or the occupied area was reduced by >70% at some point in past 500 years.
Example: If there were no genetic data for Whooping Crane, it would be scored as Increase Vulnerability here. A total of 151 swift foxes were introduced into Alberta.

Somewhat Increase Vulnerability—the population was reduced to 251- 1000 mature individuals, to less than 10 occurrences, or the occupied area was reduced by 30 – 70% in the past 500 years.

Neutral—No evidence of bottlenecks in recent evolutionary history. If the species is considered as G4 or G5, it seems safe to infer that there have been no recent population bottlenecks. Otherwise, score as Unknown.
Example: No genetic studies were found for Cedar Waxwings, but they are numerous and there is no reason to believe that they have gone through any recent population bottlenecks.

C6 Phenological Response to Changing Seasonal Temperature or Precipitation Dynamics
Successful adaptation to climate change often entails changing the timing of the life cycle to respond to changing climate. Data are available primarily for timing of bird migration and plant flowering. Comparative interpretations are sometimes difficult. Change should generally only be

reported if it is statistically significant. There are few data causally linking climate change to phenological change, so we should simply assume it exists.

Increase Vulnerability-- Climate has changed but measured species phenology have shown no sign of change.
Example: Least Flycatcher shows no statistically earlier arrival. Risks mis-timing of reproduction and peak of insect prey.

Somewhat Increase Vulnerability—Climate has changed and species phenology has shown some sign of change, but not as much as similar species.
Example: Common nighthawk shows no statistically significant earlier arrival dates. This puts it at potential risk of missing peak of insect-prey abundance.

Neutral--Climate has changed and species phenology has shown about as much change as other similar species.
Example: Northern Shoveler has shown statistically significant earlier arrival that seems to be about the same as other ducks.

Somewhat Decrease Vulnerability—Climate has changed and species phenology has shown more change than in other similar species.
Example: Trembling aspen in Alberta shows statistically significant change in first bloom dates that is greater than in later blooming species.

D1 Documented Response to Recent Climate Change
This factor pertains to changes in population numbers or distribution known to have been caused by climate change. Data should come from peer-reviewed literature and refer to changes greater than 3 generations or 10 years, whichever is longer.

Greatly Increase Vulnerability—Distribution or abundance has undergone a major reduction (>70%) as a result of climate change.
Example: Rusty Blackbird populations have declined 85-95% since 1966. At least one paper attributes this to climate change.

Increase Vulnerability--Distribution or abundance has undergone a moderate reduction (30 - 70%) as a result of climate change.

Somewhat Increase Vulnerability--Distribution or abundance has undergone a small but measureable reduction (10 - 30 %) as a result of climate change.

Neutral—Range size or abundance not known to have changed significantly. Range shifts without major changes are scored as Neutral.
Example: Bay-Breasted Warbler range has shifted northwards slightly, but this is not known to be accompanied by population or range decline.

Somewhat Decrease Vulnerability--Distribution or abundance has undergone a small but measureable increase (10 - 30 %) as a result of climate change.
Example: Evening Grosbeak has increased size of range in Finland.

Decrease Vulnerability-- Distribution or abundance has undergone a moderate increase (30 - 70%) as a result of climate change.

Appendix 5. Description and Brief Explanation of the CCVI Sensitivity Factors

Factor Symbol	Factor Description	Explanation
B1	Exposure to sea level rise.	Not applicable in Alberta.
B2a	Distribution relative to natural barriers.	A species ability to shift range may be limited by natural features preventing movement or dispersal.
B2b	Distribution relative to anthropogenic barriers.	A species ability to shift range may be limited by anthropogenic features preventing movement or dispersal.
B3	Impact of land use changes related to human response to climate change.	Impact on a species from climate change mitigation activities.
C1	Dispersal and movement ability.	Species that have the ability to move long distances are likely to have the capacity to track moving climate envelopes and therefore be less sensitive to climate change.
C2ai	Predicted sensitivity to changes in temperature, based on the historical thermal niche	The thermal niche is represented by the difference between the average historical July and January temperatures.
C2aii	Physiological thermal niche	Species occupying the warmer areas of their Alberta range, or warmer habitats, are likely to be less impacted by higher temperatures.
C2bi	Predicted sensitivity to changes in hydrology, precipitation or moisture based on the historical hydrological niche.	The hydrological niche is represented by the difference between the largest and smallest annual historical precipitation within the species' Alberta range.
C2bii	Physiological hydrological niche.	Species having a high dependence on a specific hydrologic characteristic are likely to be sensitive to changes in precipitation and evapotranspiration.
C2c	Dependence on disturbance regimes likely to be impacted by climate change.	Species responses to disturbances likely to be affected by climate change (e.g., wildfire, disease, etc.).
C2d	Dependence on ice, ice-edge or snow cover.	Species dependence on snow and/or ice.
C3	Restriction to uncommon geological features or derivatives.	Species that depend upon specific abiotic landscape features (e.g., rare soil types, cliffs, caves) may not find suitable habitat within the future climate envelope.
C4a	Dependence on other species to generate habitat.	Species that require other species to provide habitat (e.g., burrows, nesting trees) may be negatively affected by the other species response to climate change.
C4b	Dietary versatility (animals only).	Dietary specialists may be negatively affected by their food species' response climate change.
C4c	Pollinator versatility (plants only).	Plants depending on few species for pollination are may be negatively affected by their obligate pollinator's response to climate change.
C4d	Dependence on other species for propogule dispersal.	Species that depend upon other species for dispersal are more likely to be negatively affected by climate change.
C4e	Other interspecific dependence.	A catchall factor dealing with mutualism, commensalism, parasitism or predator-prey relationships.
C5a	Genetic variation.	Species with less genetic variation are less likely to be able to adapt to climate change.
C5b	Population bottlenecks (if C5a is unknown).	Species that have gone through population bottlenecks are likely to have less genetic variability.
C6	Phenological response	Species that have already shown a change in phenology related to climate change are less likely to be negatively affected.
D1	Documented response to climate change.	Peer-reviewed documentation of population or range response to climate change.
D2	Modeled change in range or population size.	Predicted % change in range or population size in the 2050s from modeling.
D3	Overlap of 2050s range with current range.	% overlap in current and predicted 2050s range.
D4	Overlap of 2050s range with protected areas.	% of future range within protected areas.

Appendix 6. Alberta Species with a Limited Expected Ability to Shift Ranges

For each species listed, the sum of sensitivity factors B2a, B2b (anthropogenic and natural barriers, respectively), B3 (mitigation-related land-use change) and C1(dispersal ability) is greater than ≥1. "Likely Extent of Range Shift" is determined by summing factors B2a, B2b, B3 and C1 and invoking the following criteria: >1.5 = "Very limited", 1.5 to 1.0= "Limited". Anthropogenic and natural barriers are listed in "Limiting Factors" if the scores for these factors are >0. Dispersal abilities are categorized according to C1 values as follows: 3 = "Extremely limited", 2.5 to 1.5 = "Very Limited", 1 to 0.5 = "Limited", -0.5 to 0.5 = "Moderate", -0.5 to -1 = "Good", <-1 = "Excellent".

Taxonomic Group	Scientific Name	Common Name	Likely Extent of Range Shift	Limiting Factors
Amphibian	*Ambystoma macrodactylum*	Long-toed Salamander	Very limited	Anthropogenic and natural barriers, moderate dispersal ability
Amphibian	*Ambystoma mavortium*	Barred Tiger Salamander	Very limited	Anthropogenic barriers, moderate dispersal ability
Amphibian	*Anaxyrus cognatus*	Great Plains Toad	Limited	Anthropogenic barriers, moderate dispersal ability
Amphibian	*Anaxyrus hemiophrys*	Canadian Toad	Limited	Anthropogenic barriers, moderate dispersal ability
Amphibian	*Lithobates pipiens*	Northern Leopard Frog	Limited	Anthropogenic barriers, moderate dispersal ability
Amphibian	*Rana lutiventris*	Columbia Spotted Frog	Limited	Anthropogenic and natural barriers, moderate dispersal ability
Amphibian	*Spea bombifrons*	Plains Spadefoot	Very limited	Anthropogenic barriers, moderate dispersal ability
Insect	*Satyrium titus*	Coral Hairstreak	Limited	Moderate dispersal ability
Insect	*Tegeticula yuccasella*	Yucca Moth	Limited	Limited dispersal ability
Mammal	*Dipodomys ordii*	Ord’s Kangaroo Rat	Very limited	Anthropogenic and natural barriers, moderate dispersal ability
Mammal	*Microtus richardsoni*	Water Vole	Limited	Natural and anthropogenic barriers, good dispersal ability
Mammal	*Ochotona princeps*	American Pika	Very limited	Natural barriers, good dispersal ability
Mammal	*Oreamnos americanus*	Mountain Goat	Limited	Natural barriers, excellent dispersal ability
Mammal	*Ovis canadensis*	Bighorn Sheep	Limited	Natural and anthropogenic barriers, good dispersal ability
Mammal	*Phenacomys ungava*	Eastern Heather Vole	Limited	Anthropogenic and natural barriers, moderate dispersal ability
Mammal	*Synaptomys borealis*	Northern Bog Lemming	Limited	Anthropogenic barriers, moderate dispersal ability
Reptile	*Chrysemys picta*	Western Painted Turtle	Limited	Anthropogenic barriers, moderate dispersal ability
Reptile	*Heterodon nasicus*	Plains Hognose Snake	Limited	Anthropogenic barriers, moderate dispersal ability

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Taxonomic Group	Scientific Name	Common Name	Likely Extent of Range Shift	Limiting Factors
Reptile	*Phrynosoma hernandesi*	Short-horned Lizard	Very limited	Anthropogenic and natural barriers, moderate dispersal ability
Vascular Plant	*Abies balsamea*	Balsam Fir	Limited	Moderate dispersal ability
Vascular Plant	*Abies bifolia*	Subalpine Fir	Limited	Moderate dispersal ability
Vascular Plant	*Alnus incana*	Speckled Alder	Limited	Poor dispersal ability
Vascular Plant	*Artemisia frigida*	Prairie Sandwort	Very limited	Very poor dispersal ability
Vascular Plant	*Artemisia tridentata*	Big Sagebrush	Very limited	Anthropogenic barriers, poor dispersal ability
Vascular Plant	*Astragalus purshii*	Pursh's Milkvetch	Limited	Poor dispersal ability
Vascular Plant	*Betula papyrifera*	Paper Birch	Limited	Poor dispersal ability
Vascular Plant	*Bouteloua gracilis*	Blue Grama	Limited	Poor dispersal ability
Vascular Plant	*Bromus ciliatus*	Fringed Brome	Limited	Poor dispersal ability
Vascular Plant	*Cryptantha minima*	Tiny Cryptanthe	Limited	Anthropogenic barrier, moderate dispersal ability
Vascular Plant	*Halimolobos virgata*	Slender Mouse-ear Cress	Very limited	Anthropogenic barriers, very poor dispersal ability
Vascular Plant	*Houstonia longifolia*	Long-leaved Summer Bluet	Very limited	Very poor dispersal ability
Vascular Plant	*Larix laricina*	Tamarack	Limited	Poor dispersal ability
Vascular Plant	*Liatris ligulistylis*	Strap-leaved Blazing Star	Very limited	Very poor dispersal ability
Vascular Plant	*Pascopyrum smithii*	Western Wheatgrass	Limited	Poor dispersal ability
Vascular Plant	*Picea engelmannii*	Engelmann Spruce	Very limited	Natural barriers, moderate dispersal ability
Vascular Plant	*Picea mariana*	Black Spruce	Limited	Poor dispersal ability
Vascular Plant	*Pinus albicaulis*	Whitebark Pine	Limited	Natural barriers, good dispersal ability
Vascular Plant	*Pinus banksiana*	Jack Pine	Limited	Poor dispersal ability
Vascular Plant	*Pinus contorta*	Lodgepole Pine	Limited	Poor dispersal ability
Vascular Plant	*Pinus flexilis*	Limber Pine	Limited	Natural barriers, excellent dispersal ability
Vascular Plant	*Pseudoroegneria spicata*	Bluebunch Wheatgrass	Limited	Poor dispersal ability
Vascular Plant	*Ranunculus glaberrimus*	Early Buttercup	Very limited	Very poor dispersal ability
Vascular Plant	*Ranunculus occidentalis*	Western Buttercup	Very limited	Very poor dispersal ability
Vascular Plant	*Ranunculus uncinatus*	Hairy Buttercup	Very limited	Very poor dispersal ability
Vascular Plant	*Sarracenia purpurea*	Purple Pitcher Plant	Very limited	Extremely poor dispersal ability
Vascular Plant	*Tradescantia occidentalis*	Western Spiderwort	Very limited	Anthropogenic barriers, poor dispersal ability
Vascular Plant	*Tripterocalyx micranthus*	Small-flowered Sand Verbena	Limited	Anthropogenic barriers, moderate dispersal ability
Vascular Plant	*Yucca glauca*	Small Soapweed Yucca	Limited	Poor dispersal ability