# CLIMATE CHANGE VULNERABILITY OF TERRESTRIAL WILDLIFE:

# AN IDAHO CASE STUDY

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**Authorization to Submit Final Thesis**

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## ABSTRACT

Climate change threatens the persistence and function of species, populations, communities, and ecosystems around the world. Projections for future climate indicate that increases in carbon dioxide and its associated effects to global climate will continue and even accelerate. The world has never faced such a rapid change in climatic conditions and has not experienced similar greenhouse gas concentrations for 3.6 million years. Understanding the potential affects that these changes have on natural systems and their components is vital in informing management focused on conserving and protecting biodiversity and natural ecosystem functions.

Increasing demand for tools for identifying species at-risk to climate change led to the development of a wide variety of climate change vulnerability assessments and tools. These tools, while based on the same general definition of vulnerability, represent a multitude of methods for evaluating the vulnerability of species to climate change. Although these assessments and tools are used to inform management actions, the similarity of their outputs has never been determined. Chapter 2 is dedicated to comparing the outputs of 3 widely available and commonly used tools. Results were poorly correlated between pairs of assessments. This indicates a lack of agreement in how vulnerability is ultimately calculated and a strong need for a more unifying and precise definition of vulnerability.

Chapter 3 addresses climate change vulnerability assessment shortcomings identified by Small-Lorenz and colleagues. The chapter outlines a format for incorporating spatial and seasonal variation of climate projections and species natural history. This model uses an ensemble mean of statistically downscaled region climate projections for the end of the century. The magnitude of change for 12 climate characteristics is weighted by 5 species sensitivity traits. A second model of species adaptive capacity assigns a permeability score to land cover vegetation macrogroups and is combined with trait-based adaptations. These models together constitute the vulnerability evaluation. An example using wolverine (*Gulo gulo*) provides the reader with context for how the framework can be applied. This framework is intended as a first-step towards the integration of more complicated characteristics of species and climate to produce more complete and accurate relative measures of vulnerability.

Vulnerability assessments, and development of tools and methodologies, are still novel when compared to understanding of other wildlife related threats. Future assessments need to focus on performing under a unified and more precise definition of vulnerability. Identification of reliable and critical data inputs will be vital to improving the predictive quality of future assessments. A cooperative effort towards evaluating relative vulnerability of wildlife and their habitats and ecological interactions, and integrating greater complexity through spatial and seasonal models is needed to bridge the gap between theoretical models and on-the-ground management actions.

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# CHAPTER 1

## INTRODUCTION

Global climate change is one of the greatest challenges faced by species and natural systems, and has become one of the most central topics of conservation and management today. Life on Earth has experienced climatic fluctuations for millions of years. However, the rate of increase in carbon dioxide and associated temperature is occurring over a significantly shorter time interval (Trenberth et al. 2007), and the effects of these rapid changes on communities and their component species are apparent around the world (e.g. Parmesan et al. 1999, Parmesan and Yohe 2003, Root et al. 2003, Perry et al. 2005, Parmesan 2006). As environmental changes continue to occur, it is critically important to understand how rapid climate change affects species to appropriately manage for species' persistence and biodiversity.

The primary concern over anthropogenic climate change is not necessarily the magnitude of change, but rather the elevated rate of current anthropogenic climate change relative to the rate of paleoclimatic change (Parmesan and Yohe 2003, Dobrowski et al. 2013). The mid-Pliocene, 3.6 million years ago, was the most recent period in which carbon dioxide concentrations were similar to current levels (Jansen et al. 2007). Temperatures during this time were 2 °C to 3 °C warmer than today. It is very clear that global and regional temperatures are highly sensitive to carbon dioxide concentrations, with greatest sensitivities at high latitudes (Haywood et al. 2000, Jiang et al. 2005, Jansen et al. 2007). A drop in global atmospheric carbon dioxide concentrations took place around 2.7 to 2.2 million years ago when levels decreased to those found in the Pleistocene glacial period (Bartoli et al. 2011). This is believed to result from stratification of deep-ocean and tectonic activity causing mountain uplifting which ultimately led to increased carbon sequestration (Bartoli et al. 2011). From the Pleistocene onward carbon dioxide levels have fluctuated between approximately 180 ppm (glacial) to 270 ppm (interglacial) (Jansen et al. 2007, Bartoli et al. 2011). Warming between glacial and interglacial typically took thousands of years, with subsequent cooling taking even longer (Jansen et al. 2007).

Current concentrations of carbon dioxide are nearing 400 ppm, which is higher than any measured concentration found in ice core records for the past 650,000 years (Jansen et al. 2007, Bartoli et al. 2011). Preindustrial (mid 1700's) carbon dioxide concentration levels are estimated at 280 ppm (Jansen et al. 2007). It has taken around 250 years to increase carbon dioxide concentrations by roughly by 150 ppm. In contrast the difference between glacial and interglacial was approximately 100 ppm. Historically, the transition between the low carbon dioxide concentration of glacial periods and high concentrations during interglacial took several thousand years (Jansen et al. 2007). Effects of this rapid change in climate are becoming more and more apparent, but it is still unclear how species will be affected in the future as carbon dioxide and its associated impacts continue to increase.

Both the direct and indirect effects of climate change on the natural systems are increasingly apparent. Increasing temperatures and fluctuation of moisture regimes and cycles constitute direct changes in climate. Indirect effects range from latitudinal and elevational range shift (Parmesan et al. 1999, Parmesan and Yohe 2003, Root 2003, Perry et al. 2005, Sekercioglu et al. 2008, Chen et al. 2011), phenological mismatch (Shafer et al. 2001, Walther et al. 2002, Parmesan and Yohe 2003, Menzel et al. 2006, Sekercioglu et al. 2008, Both et al. 2009, Yang and Rudolf 2010), and increased risk of extinction (Thomas et al. 2004, Fischlin et al. 2007, Maclean and Wilson 2011, Bellard et al. 2012). These changes do not occur at the same rate for all species, and are predicted to continue into the future (Warren et al. 2001, Perry et al. 2005, Lawler et al. 2009, Bellard et al. 2012, Dobrowski et al. 2013). These climate related observations prompted the scientific community to identify key components of climate and species' natural history that lead to a species being adversely or beneficially affected by changes in local climate.

Climate change vulnerability assessments are a method of evaluating species and climate characteristics to identify species most at-risk to the effects of climate change. Although there are a number of different assessments available, there is as yet no standard for how to design a vulnerability assessment. Similarly, these assessments produce a wide variety of outputs, which have not been assessed for similarity, or consistency. Finally, comparison of data inputs has indicated several shortcomings not only of individual assessments and tools, but also of assessments in general (Small-Lorenz et al. 2013). My objective is therefore to address the major shortcomings of current assessments and provide managers and scientists with a platform from which to strengthen the quality and precision of vulnerability tools and assessments in the future.

Chapter 2 compares the outputs of prominent climate change vulnerability and sensitivity tools. The increased demand for tools to evaluate the vulnerability of species to climate change resulted in an explosion of methodologies that make use of the variety of climate data and species' natural history knowledge. The similarity between results of these methodologies has not previously been evaluated. I compared the similarity of outputs for the species evaluated in common for 3 pairs of assessments.

Small-Lorenz et al. (2013) indicate the shortcomings of modern climate change vulnerability assessments for wildlife. Chapter 3 is a response to these shortcomings in the form of a new methodology for a spatially and temporally explicit climate change vulnerability assessment for terrestrial wildlife. The model focuses on the layered direct and indirect effects of a changing climate on individual species using statistically downscaled projections for 5 CMIP3 climate models. The model also makes use of seasonal variables to allow for the seasonal sensitivities and needs of species to be addressed.

Natural systems in today's world face many challenges rooted in anthropogenic causes. The effects of habitat loss, introduction of exotic and invasive species, destruction of functional food webs and species' interactions will all be compounded by rapid anthropogenic climate change. It is critical that scientists and managers incorporate climate change effects into their planning and management of species, particularly those at risk of extinction. The field of climate change vulnerability assessments for wildlife is still quite young and has immense potential for developing into an analytical tool for wildlife management. Future assessments will need to be flexible and able to incorporate a variety of new data. However, it is first critical that the scientific community understands and addresses the shortcomings of today's models in order to build a strong platform on which to build future species and biodiversity management plans.

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# CHAPTER 2

## COMPARISON OF CLIMATE CHANGE VULNERABILITY ASSESSMENTS FOR WILDLIFE


### Abstract

The need for wildlife climate change vulnerability and sensitivity assessments has increased over the past decade. Use by wildlife and land managers has increased over concerned about the potential effects of climate change on species and landscapes. Although many approaches exist for assessing sensitivity and vulnerability to climate change, little is known about the similarity of results among methods. I compared outputs of three widely available assessments for the Western United States: the NatureServe Climate Change Vulnerability Index, the US Forest Service System for Assessing the Vulnerability of Species, and the Climate Change Sensitivity Database. I performed a broad categorical comparison and examined correlations across rankings to compare assessment outputs. There was found little agreement in species' rankings between pairs of assessments. There is no apparent pattern within, or between, taxa or habitat associations that could explain this poor correlation. Disparities likely result from differences in question format, choice of data input, or how vulnerability, or sensitivity, is calculated. Consideration of vulnerability quantification is needed, particularly regarding species' sensitivity and adaptive capacity, due to limited understanding of species and community responses to climate exposure. Results indicate it is extremely important to be aware of the specific goal and the quality, quantity, and variety of data used in each individual assessment in order to adequately use these assessments as tools for

management planning. With the increasing need to include climate change scenarios in management actions and decisions, cooperation among assessment developers is strongly suggested and could greatly aid in eliminating this discrepancy.

## Introduction

Vulnerability assessments are becoming an important tool for the development of wildlife management strategies under projected climate change. However, the degree of similarity between vulnerability assessments is unclear. Comparison of various assessment outputs could allow a greater understanding of how best to apply each assessment either alone or in tandem with complimentary indices, as well as provide information on how to improve already existing assessments.

The Intergovernmental Panel on Climate Change (IPCC) (Schneider et al. 2007) defines vulnerability as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate extremes." Climate change vulnerability is recognized as a function of exposure to changes in climate, the sensitivity of species, or systems, and the adaptive capacity of species, or systems, to address those changes (Turner et al. 2003, Schneider et al. 2007, Williams et al. 2008, Lawler 2009, Glick et al. 2011). Exposure and sensitivity together represent the potential impact of climate change on a particular species, or system. Sensitivity and adaptive capacity are arguably very similar and often consider closely related variables. Sensitivity represents a measure of the innate characteristics that place a species, or system, at risk to change. Conversely, adaptive capacity measures the degree to which a species, or system, is able to ameliorate that change via behavioral adaptation, or genetic evolution.

Vulnerability assessments quantitatively, or qualitatively, combine measures of exposure, sensitivity, and adaptive capacity to evaluate climate change impacts on species and systems. These assessments are designed to compile large volumes of data about climate exposure and species' sensitivity and adaptive capacity, making them a useful repository of different sources of knowledge for individual species and systems. These diverse data form the foundation from which vulnerability is evaluated. Data that inform the degree of climate exposure for an individual species include projected change in temperature or hydrologic regime, change in disturbance regime, or change in habitats or habitat features (Glick et al. 2011). These factors typically involve changes beyond the species' control. Depending upon the structure of the assessment, species' sensitivity traits range from physiological, behavioral, or ecological traits of the species such as tolerance to temperature or hydrological regimes, dependence upon certain habitats or habitat characteristics, degree of specialization, reproductive ability, or phenological dependencies (Glick et al. 2011). These may be used to amplify or depress the exposure component. Finally, measures of behavioral or genetic adaptive capacity such as behavioral or genetic plasticity, dispersal ability within the landscape, or evolutionary potential are included to represent the potential for an individual species to counteract the potential impacts of climate change (Glick et al. 2011). Both species and system-based assessments use a variety of techniques to combine these measures to identify conservation and management targets (Panjabi et al. 2005, Bagne et al. 2011, Lin and Morefield 2011, Swanston et al. 2011, Young et al. 2011, CCSD 2012, Gardalli et al. 2012).

While sensitivity assessments are similar to, and related to, vulnerability assessments, they represent only one portion of data under consideration in a vulnerability assessment. Sensitivity is one of the 3 major components for a vulnerability analysis. Therefore a sensitivity assessment does not include measures of climate exposure and species' adaptive capacity. However, they can be used to identify species that exhibit traits that may place them at higher risk of becoming threatened or endangered as a result of climate change effects.

Evaluation of exposure, sensitivity, adaptive capacity, and ultimately vulnerability produces important tool for managers at the state level, particularly for revisions of State Wildlife Action Plans (SWAP). Both the US Fish and Wildlife Service (USFWS) and the Association of Fish and Wildlife Agencies (AFWA) strongly encourage state agencies to include climate change in SWAP revisions and to adopt and develop management strategies that consider a future with climate change (USFWS 2010). Climate change vulnerability assessments may allow agencies and their partners to identify species and habitats at high risk of becoming threatened or endangered. This first step of identification would then allow for the development of management actions aimed at reducing climate change vulnerability (Glick et al. 2011). However, there is no current standard assessment, which leaves managers a wide variety of assessments and methodologies from which to choose.

To my knowledge, no systematic comparison of the results of different approaches to assessing vulnerability to climate change has been undertaken. Many agencies and local conservation groups have already incorporated results from these various assessments into climate change management reports and policies within the

Western United States (Young et al. 2009, Bagne and Finch 2010a, Byers and Norris 2011, Dubois et al. 2011, Schlesinger et al. 2011, Brinker and Jones 2012). Given that no two assessment approaches available to date use the same combination of variables, or frame their questions in the same way, it is possible that these approaches produce different results for the same species. Here, I compare the outputs of climate-related vulnerability assessments used in the Western United States. It will be important to understand whether different assessment procedures produce conflicting outputs prior to using these tools to develop new management approaches for species.

We evaluated the general methods and outputs of three commonly used climate change vulnerability and sensitivity assessments for the Western United States: the NatureServe Climate Change Vulnerability Index 2.1 (NSCCVI) (Young et al. 2011), the U.S. Forest Service System for Assessing the Vulnerability of Species (SAVS) (Bagne et al. 2011), and the Climate Change Sensitivity Database (CCSD) (CCSD 2012) (Table 2.1). Here, I (1) briefly summarize the methods and outputs of each assessment; (2) evaluate the similarity of assessment outputs by comparing pairs of assessments that analyze the same species; and (3) discuss the variables that might influence differences among assessment methodologies.

**Methods**

We chose to compare the previously mentioned assessments due to ease of access, applicability to diverse management objectives and groups of species, frequent use by managers and scientists, and broad diversity of species evaluated by each. These three assessments can be compared because they can overlap in the geographic area under consideration. Each assessment approaches the quantification, or categorization, of species' vulnerability (NSCCVI and SAVS), or sensitivity (CCSD), using different methodologies, allowing comparison of different approaches and scoring. I included a sensitivity assessment in this comparison to understand if a full vulnerability assessment is needed, or if the same information can be gathered with less effort. I searched databases and case studies to populate a list of species with available data that were ranked by at least two of the three assessments. This produced three overlapping lists of species, one for each pair of assessments (NSCCVI v. CCSD, NSCCVI v. SAVS, and CCSD v. SAVS).

The intention was not to validate the results of these assessments, but rather to compare the outputs, as they exist currently. Validation of climate change vulnerability assessments that make predictions about the persistence of species in the future will likely require careful monitoring of species to provide feedback on the accuracy of predictions. This feedback could then be used to improve the accuracy of vulnerability predictions.

*NatureServe Climate Change Vulnerability Index*

The NatureServe Climate Change Vulnerability Index (NSCCVI) was developed to provide scientists and managers with a relatively rapid method for grouping species by drivers of vulnerability to climate change. It also aims to increase the efficiency of identifying management concerns and planning for at-risk species (Young et al. 2011). The index is designed for use across North America north of Mexico and is most effective at the scale of national parks and wildlife refuges, or states.

This assessment evaluates vulnerability via the sum of numerical values given to traits of exposure, sensitivity, and adaptive capacity. The Index uses the Climate Wizard (Girvetz et al. 2009) and Hamon AET:PET Moisture Metric (Hamon 1961) to provide users with visuals of downscaled temperature and moisture predictions over the range of target species to address exposure. Specifically, NSCCVI makes use of the Climate Wizard and Hamon projections for the year 2050. Sensitivity is divided between indirect climate change effects and species specific traits that increase vulnerability. There are up to 6 possible responses (Greatly Increase, Increase, Somewhat Increase, Neutral, Somewhat Decrease, Decrease) to each question indicating whether the factor in question increases, or decreases, vulnerability. These measures are used as modifiers of exposure to represent the potential impact of climate change within a predefined geographical area for the target species. Documented responses to climate change, along with results of modeled future species' ranges, are considered measures of adaptive capacity.

Vulnerability is calculated by numerically summing values for exposure, sensitivity, and adaptive capacity and then awarding a categorical score based on threshold values (Young et al. 2011). The index places species into one of six categories ranging from Increase Likely (abundance and/or range expansion within assessed area) to Extremely Vulnerable (abundance and/or range extremely likely to substantially decrease or disappear), or Insufficient Information (inadequate to calculate index score) (Table 2.1; Young et al. 2011). Calculation is performed within a Microsoft Excel spreadsheet, which includes descriptions of all required data and discussion of each question. An additional spreadsheet records the answers to all questions for each species for ease of comparison across species for management consideration. Confidence scores are awarded based on Monte Carlo simulation where multiple answers are indicated for individual questions.

The NSCCVI is capable of incorporating both terrestrial and aquatic species along with cave and groundwater obligate species (Young et al. 2011). It is also possible to evaluate migratory species by separately scoring breeding, non-breeding, and migration ranges. Marine species are not yet addressed by this assessment.

This assessment can be used in conjunction with the NatureServe Conservation Status ranks. For this reason it does not include measures of population or range size, or demographic information, as the Conservation Status addresses these factors.

*US Forest Service System for Assessing the Vulnerability of Species*

The goal of the Forest Service System for Assessing the Vulnerability of Species (SAVS) is to predict the likelihood and magnitude of population level changes for individual species (Bagne et al. 2011). This assessment may be used from the management unit scale up to the entire range of a species, though extents considered should have either homogenous climate projections, or should be entirely encompassed by a single climate model. (Bagne et al. 2011). The temporal scale over which the assessment is performed is defined by the user.

The assessment is made of 22 questions designed to represent the intersection between predicted climate change and the predicted response of the species while ultimately addressing potential management actions. Questions are divided into four categories according to potential management applications (Habitat, Physiology, Phenology, and Biotic Interactions) rather than by exposure, sensitivity, and adaptive capacity metrics. Habitat questions address the potential impact of climate on breeding and non-breeding areas. This section requires knowledge of climate projections, vegetation types, and predicted impacts to vegetation types. Physiology primarily addresses species' sensitivity traits to changes in climate exposure. Phenology questions consider timing of important life history events and how they relate to changes in climate. Finally, the biotic interactions section addresses changes in interspecific interactions that could result from a changing climate. The user is responsible for defining which climate models and projections are considered, as well as consideration of data for each species. Two to four responses are possible for each question related to whether a particular effect of climate change will result in an overall positive (increased resilience), or negative (increased vulnerability) responses by the species.

The SAVS scores species on a scale from -20 (resilient) to +20 (vulnerable) based on user responses (Table 2.1). Each of the four categories is summed and standardized on a -5 to +5 scale. These categorical scores are summed to obtain the vulnerability score. Scores can subsequently be used to rank species, or groups of species, according to management goals. A basic measure of uncertainty is calculated from user responses to each question on whether there is adequate, or inadequate, information to accurately respond.

*Climate Change Sensitivity Database*

The Climate Change Sensitivity Database (CCSD) evaluates the sensitivity of species and ecological systems to climate change (CCSD 2012). It provides an on-line database for information pertinent to the climate-change sensitivities and potential responses of species and ecosystems. This assessment does not incorporate measures of climate change exposure, but instead focuses on inherent traits of species and systems that increase their sensitivity to changes in climate. While the database focuses primarily on sensitivity, some metrics do reflect aspects of adaptive capacity (Glick et al. 2011).

Numerical and categorical sensitivity scores are assigned to each species based on seven input categories (Generalist/Specialist, Physiology, Life History, Habitat, Dispersal Ability, Disturbance Regimes, Ecology, Non-Climatic factors, Other factors). The Generalist/Specialist category evaluates the specificity of a species' relationship to habitat and other resources. The Phenology category addresses species' physiological sensitivities to changes in temperature, precipitation, pH, and salinity. The Life History category provides a measure of the species' reproductive strategy along the r to K continuum. The section on Sensitive Habitats provides a list of habitats that have been pre-determined to be highly sensitive to climatic changes. Species relying on any of these habitats are determined to be highly sensitive to climate change. Dispersal ability is based on a measure of the maximum annual dispersal distance and the prevalence and effectiveness of barriers to dispersal. Dispersal distance is measured in kilometers and is based on the maximum average likely distance that an individual could move to establish a new population (CCSD 2012). A list of dispersal barriers is provided along with a ranking ranging from "none" to "many". The section on Disturbance Regimes documents the degree to which the species is dependent on the nature of various disturbances, both natural and anthropogenic. The Ecological Relationships category considers the potential sensitivity to climate change of the relationships the species has with its environment including foraging, habitat, competition, abiotic, and other relationships. The Non-climatic Factors category encompasses all non-climatic threats such as habitat loss, pollution, and invasive species among others that may further amplify climate-change sensitivity. Finally, the category for Other Sensitivities allows the user to include any other factors relating to sensitivity that may impact the species and to provide a weight for this measure relative to the other measures of the database (CCSD 2012).

Each section asks the user to rank (1 low to 7 high) whether a particular trait lends itself to lower, or higher, sensitivity. Users are encouraged to answer more detailed questions and provide citations, but these do not factor into the overall scoring. As with the previous two assessments, CCSD provides a measure of uncertainty calculated alongside the final sensitivity score. Uncertainty is defined by the user for each category on a scale of 1 to 5.

*Assessment Comparison*

A total list of 95 species was evaluated jointly by at least two of the assessment approaches. These species covered a wide taxonomic and geographic range (Appendix A). Of these, there were 89 species from NSCCVI, 69 species from CCSD, and 40 species from SAVS. Only 8 species were common to all 3 assessments. NSCCVI and CCSD evaluated 61 species in common, SAVS and the NSCCVI evaluated 34 species in common, and SAVS and CCSD evaluated 14 species in common. Using these 3 overlapping lists of species, I evaluated the similarity of pairs of assessment outputs using 2 methods.

First, outputs were divided into either “low” ranking or “high” ranking. The dividing point between low and high was established based on descriptive information available from each assessment (Table 2.1). Outputs were high if they ranked or scored species as having any vulnerability or sensitivity. Outputs were low if they ranked or scored species as having no or low vulnerability or sensitivity (Table 2.1). "Low" qualified as a negative score in SAVS; a rank of Low in CCSD; or a rank of Increasing, or Presumed Stable in NSCCVI. All other rankings or scores were considered "high". I calculated the percent of species that fell within the low, or high, categories for both assessments in each pair. If assessment results were similar, the percent of species with high or low vulnerability should be, likewise, similar. Differences in either the percent of species with low or high rankings, or the composition of species within those categories could indicate that assessments lack similarity in methodology or scoring technique. Individual species "low" and "high" rankings for each pair of assessments can be found in supplementary material (Appendix B).

Second, I applied Spearman's ranked correlation coefficient to compare outputs of each pair of assessments. Values for $\rho$ and P were calculated in R 2.14.0 using the rcorr() function of the Hmisc (ver. 3.9-3) package. The null hypothesis was that $\rho$ did not differ from 0, indicating a lack of correlation between the ranked results of paired assessments. The alternative hypothesis was that $\rho$ differed significantly from 0 ($\alpha$ = 0.05), indicating correlation between the ranked results of paired assessments. I used the CCSD numerical scores for this analysis to more accurately represent the ranking order.

Although the assessments evaluate many of the same species, the geographical area evaluated by each assessment may not correspond with each other. For this reason, 6 species were evaluated separately using all three approaches within the same geographical context. One researcher performed all of the assessments. Where possible similar questions were answered using the same information to maintain as much similarity in data input as possible between assessments. Microsoft Excel was used to assess the degree of correlation between results.

Correlation between NSCCVI and SAVS was expected to be higher than that between NSCCVI and CCSD or SAVS and CCSD. Both NSCCVI and SAVS calculate overall vulnerability by incorporating measures of climate exposure and species' sensitivity (potential climate change impact) and adaptive capacity. The CCSD only measures how sensitive species are to climate change – it does not incorporate any predictions of climate exposure, and does not explicitly address adaptive capacity. Therefore, the rankings produced by the CCSD should be less similar to those of the other 2 indices than should the rankings of the NSCCVI and the SAVS be to each other.

**Results**

The three assessments were not well correlated with each other and did not have the same distribution of high and low rankings or scorings between pairs of assessments (Figure 2.1). CCSD produced almost 3.5 times more highly vulnerable ranks than NSCCVI (Figure 2.1a). Ninety-six percent of species were ranked as high by either CCSD or NSCCVI, but only 27% were ranked high by both. Similarly, over 5 times as many species scored high in SAVS as ranked high in NSCCVI (Figure 2.1b). Ninety-four percent of species were ranked high by either SAVS or NSCCVI, but only 18% were ranked high by both. Greater similarity existed between CCSD and SAVS, which differed by 14% (Figure 2.1c). Ninety-two percent of species were ranked high by either CCSD or SAVS, and 86% were ranked high by both. Of the 8 species evaluated by all three assessments, only the NSCCVI produced low ranks of vulnerability for any species (Figure 2.1d).

None of the Spearman's ranked correlation coefficients were statistically significant at the $\alpha = 0.05$ level. The correlation between NSCCVI and CCSD was nearly significant with a $\rho$ of 0.25 and $P$ value of 0.0530. This pair also had the greatest number of species evaluated in common and could be said to have very similar scoring structures. Both pairwise comparisons with the SAVS assessment were not significant (SAVS v. CCSD: $\rho = 0.40$, $P = 0.1562$; SAVS v. NSCCVI: $\rho = 0.26$, $P = 0.1449$). The comparison between SAVS and CCSD had the highest Spearman's correlation coefficient, but also the smallest sample size.

Similar results were seen between the 6 Idaho species. Correlation was highest between CCSD and NSCCVI ($r = 0.8712$). Correlation between CCSD and SAVS and NSCCVI and SAVS was significantly lower ($r = 0.2878$ and $r = 0.2218$ respectively). Woodland caribou (*Rangifer tarandus*) ranked most similarly across all three assessments (Table 2.2). In contrast, the American three-toed woodpecker (*Picoides dorsalis*) showed a wide range of rankings (Table 2.2). Assessment inputs for all species can be found in the supplementary material (Appendix C).

## Discussion

Many climate change vulnerability assessments are now being used to identify and inform management actions for species and ecosystems (Panjabi et al. 2005, Young et al. 2009, Bagne and Finch 2010a, Bagne and Finch 2010b, Byers and Norris 2011, Dubois et al. 2011, Lin and Morefield 2011, Schlesinger et al. 2011, Swanston et al.

2011, Bringer and Jones 2012, Coe et al. 2012, Gardali et al. 2012). Lack of a common assessment, or a common evaluation technique or outcome, have led to the development of a variety of methodologies for calculating vulnerability. The lack of similarity in outputs of the vulnerability and sensitivity assessments evaluated here speaks to the diversity possible in the formation and application of assessments. There is, as yet, no formal specific definition of how to form a vulnerability assessment because of the large potential number of variables that could be incorporated. For this reason, examination of individual assessment goals, geographical and temporal scale, and choice of input information is critical in order to use each assessment to its full potential.

The only assessment output pairing that appeared similar at the broad scale analysis was CCSD and SAVS. Results of the Spearman ranked correlation coefficient indicate that the results of CCSD and SAVS are not correlated. Although this pairing did show the highest correlation, it also has the smallest sample size. The majority of species also appeared to be ranked similarly between the two assessment approaches (Appendix A). However, some difference should be expected between these assessments because CCSD measures only species' sensitivity, whereas SAVS also includes elements of climate exposure and species' adaptive capacity. Similarly, analysis of the 6 Idaho species showed poor correlation between results of these two assessments. More data is needed to better assess the degree of correlation between these assessments.

General comparisons of low and high ranks and scores between NSCCVI and SAVS indicate that these two are poorly correlated and do not produce similar results. Far more species are scored high by SAVS than are ranked high by NSCCVI. As with the comparison between CCSD and SAVS, this discrepancy may be a result of the definition for high and low vulnerability ranks or scores for each assessment. However, this lack of correlation is upheld by the results of the Spearman test, which are not statistically significant (Figure 1). Unlike CCSD and SAVS, greater similarly should perhaps be expected between NSCCVI and SAVS due to the fact that they both measure vulnerability, i.e., they both incorporate exposure, sensitivity, and adaptive capacity. While both of theses assessments measure vulnerability, they do so in slightly different ways. The difference in scores and ranks between these assessments indicates the importance of thoroughly understanding the underlying goal of each assessment as well as the quality, quantity, and variety of data used.

The lack of a strong correlation between NSCCVI and CCSD outputs is, to some degree, expected because they are assessing different measures (overall vulnerability and species' sensitivity, respectively). Similar to the previous two pairwise comparisons, the appearance of a greater percentage of species ranked highly by CCSD is likely a result of how low and high rankings were defined. The reason for the lack of correlation between NSCCVI and CCSD may be largely attributed to the inclusion of climate exposure and species' adaptive capacity measures in NSCCVI. This could also be attributed to lack of overlap in geographic regions, as there was higher correlation between these two assessments in the 6 species assessment.

Establishing a common definition for the dividing point between "low" and "high" ranks and scores was difficult across all assessments. Differences in how ranks or scores are awarded make cross comparison between assessments more complicated. More similar distributions may have been possible if the dividing point between low and high was adjusted. I chose to divide the outcomes of each assessment according to where assessment descriptions defined the difference between low and high vulnerability, or sensitivity.

There are many possible reasons for the differences noted among the assessment outputs. Neither CCSD, nor SAVS, require the level of detail concerning species distributions and climate data as seen in NSCCVI (Bagne et al. 2011, CCSD 2012). Similarly, differences in how the overall vulnerability of a species is calculated can change the impact of individual data inputs. For example, NSCCVI uses an equation based on direct climate change and its cascading influence on indirect climate effects, species' sensitivity, and species' adaptive capacity (Young et al. 2011). SAVS approaches vulnerability calculation in a different manner by integrating exposure and either sensitivity or adaptive capacity into each question to include both the predicted climate change as well as the predicted response (Bagne et al. 2011). The final score is the overall sum of the scores from each section of questions. In this way, exposure, sensitivity, and adaptive capacity are incorporated together for each question, rather than broken out into separate sections.

Perhaps one of the greatest difficulties in attempting a comparison of this nature is the diversity of overlap in geographic areas between assessments for the same species. Almost no species have been evaluated by multiple assessments within the same geographic region. The underlying differences between regional and local habitats and climate impacts can therefore confound comparison across vulnerability assessments. However, the results of the comparison of the 6 Idaho species showed that the assessments were again poorly correlated. It is clear that each of these assessments has valuable insight to offer concerning sensitivity and vulnerability of wildlife species.

Features that are generally addressed by one assessment may be may be addressed more completely, or from a different perspective, in additional assessments. For this reason it is strongly recommend that users evaluate species with multiple assessments to create a more complete picture of vulnerability.

How questions about vulnerability and sensitivity are worded for the user, along with their perception of the species in question, or of climate effects in a particular region, will most certainly influence answer choice when completing each of these assessments. For example, all three assessments phrase questions concerning sensitivity of species' physiological thresholds differently. The CCSD asks the user to rank physiological sensitivity (temperature, moisture, carbon dioxide, pH, salinity, etc.) where low sensitivity equates with tolerance to change in a wide range of variables (CCSD 2012). SAVS has six questions pertaining to physiology, but only one question that directly inquires if "limiting physiological conditions [are] expected to change" (Bagne et al. 2011). The possible answers to this question focus on temperature and moisture tolerances and whether they are predicted to exceed upper thresholds, remain within current thresholds, or decrease such that lower thresholds are exceeded. Finally, NSCCVI also focuses on temperature and moisture tolerance, but also enquires about historical conditions (Young et al. 2011). Users are asked to rank the variation in historical temperature and moisture regimes experienced by a given species. Next, the user is asked to rank how restricted a given species is to cool environments, or a specific moisture regime. All three assessments enquire about physiological sensitivity, but use varying numbers of questions and phrase their questions differently.

To date, I am not aware of any similar vulnerability assessment comparisons, and this may be due to the relatively recent development and use of these tools. However, because of the increased demand for climate change assessments, novel comparisons such as this one can greatly assist in the development and growth of future vulnerability assessments. This is particularly important for state and federal agencies, among others, that must review and update their management plans and actions to reflect the potential impacts on sensitive species.

*Opportunities*

Further evaluation of these and other vulnerability assessments with geographic and species overlap comparisons is needed (Davison et al. 2011, Small-Lorenz et al. 2013). Incorporating seasonal variability both in species' distribution and natural history could also greatly improve estimates of vulnerability and pinpoint areas and resources of key concern (Small-Lorenz et al. 2013). Increasing the number of species assessed in common would increase sample sizes and allow for greater diversity of comparisons among taxa and habitat associations.

Additionally, a better understanding of the degree to which exposure, sensitivity, and adaptive capacity contribute to overall species vulnerability will improve vulnerability assessments in the future. While sensitivity is specific to individual species or populations, exposure is contingent upon the geographic area of interest. Therefore, if two species are similarly sensitive, but one exists in a region with greater exposure, vulnerability for that species should be greater. Likewise, inclusion of geographical variation in natural and anthropogenic barriers along with evolutionary potential and dispersal abilities would improve measures of adaptive capacity (Davison et al. 2012). Consideration for community level interactions including trophic interactions, competition, and facilitation would also improve predictions for species persistence at the ecosystem and landscape level. Applying vulnerability analyses to on-the-ground management will require spatially dynamic assessments that allow for the variation in structure and function across a landscape and within communities. Incorporating a measure of spatial plasticity to the greater vulnerability score of any particular species could highlight areas of high concern, or refuges and corridors (Davison et al. 2012). These are likely continuing goals, but will greatly assist in development and use of vulnerability assessments.

It is important to remember that these assessments are estimates of vulnerability to the multiple effects of climate change and should therefore somehow account for the uncertainty of both future climate predictions and gaps in species' life history knowledge (Glick et al. 2011). More cross-evaluations of assessment performance will be needed to more finely tune each assessment and incorporate new information as it becomes available. Additionally, agreement over the definition and combination of variables is key for these approaches to progress. It will be important to foster conversations about the inputs, spatial and temporal scale, and equations of vulnerability to improve future assessments (McCarthy et al. 2010).

Both state and federal land management agencies are now looking to climate change vulnerability assessments to inform management decisions. Although these assessments might provide an opportunity for agencies to prioritize species' vulnerabilities to climate change, these vulnerability assessments are currently limited in their applicability until they are applied to landscapes across different seasons (Small-Lorenz et al. 2013). Incorporating seasonality and temporal variability may help span the gap between assessment results and on-the-ground management actions to address climate related concerns.

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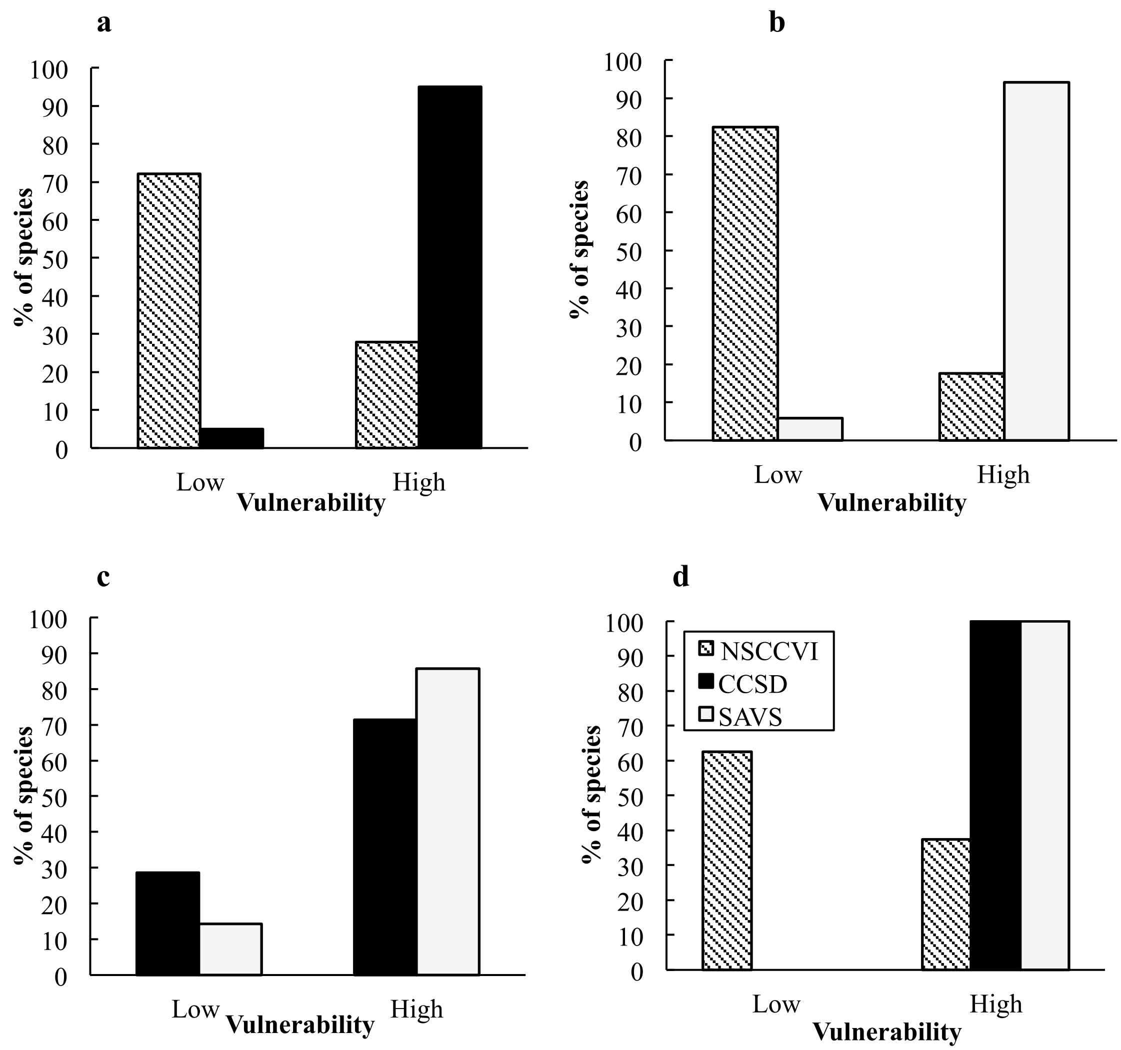
**Table 2.1** Characteristics of vulnerability and sensitivity assessments

| **Assessment Title** | **Major Inputs** | **Output** Low | High | **Uncertainty Score?** | **Geographic areas covered** | **Author** |
|---|---|---|---|---|---|---|
| System for Assessing the Vulnerability of Species (SAVS) | • Habitat<br>• Physiology<br>• Phenology<br>• Biotic Interaction | *-20 to 0* | *0 to +20* | Yes | Southern Arizona and New Mexico | US Forest Service (Bagne et al. 2011) |
| NatureServe Climate Change Vulnerability Index v2.1 (NSCCVI) | • Downscaled change in temperature (Climate Wizard 2050s)<br>• Moisture availability (Hamon AET:PET, Climate Wizard 2050s<br>• Current species distribution<br>• Physiological, phenological species traits<br>• Knowledge of natural and anthropogenic barriers<br>• Documented adaptation | • *Increase Likely*<br>• *Presumed Stable* | • *Moderately Vulnerable*<br>• *Highly Vulnerable*<br>• *Extremely Vulnerable*<br>• *Insufficient Evidence* | No | Nevada and the Great Basin | NatureServe (Young et al. 2011) |
| Climate Change Sensitivity Database (CCSD) | • Generalist/Specialist<br>• Physiology<br>• Life History traits<br>• Habitat sensitivities<br>• Dispersal Ability<br>• Disturbance Regime<br>• Ecological interactions<br>• Non-Climatic, Other | • *Low sensitivity* | • *Medium sensitivity*<br>• *High Sensitivity*<br>• *Extremely High Sensitivity* | Yes | Pacific Northwest US | University of Washington/ The Nature Conservancy (CCSD 2012) |

**Table 2.2** Results for 6 species evaluated across the Climate Change Sensitivity Database (CCSD), NatureServe Climate Vulnerability Index (NSCCVI), and the Forest Service System for Assessing the Vulnerability of Species (SAVS)

| | **Canada Lynx** | **Woodland Caribou** | **Cliff Chipmunk** | **Lesser Goldfinch** | **Juniper Titmouse** | **American Three-toed Woodpecker** |
|---|---|---|---|---|---|---|
| **Climate Change Sensitivity** | 67 - High | 81 - High | 34 - Medium | 22 - Low | 39 - Medium | 57 - Medium |
| **NatureServe Climate Vulnerability Index** | Moderately Vulnerable | Highly Vulnerable | Not Vulnerable Increase Likely | Not Vulnerable Presumed Stable | Not Vulnerable Presumed Stable | Highly Vulnerable |
| **Forest Service System for Assessing the Vulnerability of Species** | 4.55 | 10.00 | 4.55 | 7.27 | 0.00 | 1.82 |

**Figure 2.1** Percentage of species falling under low or high vulnerability/sensitivity in common between (a) NSCCVI (NatureServe Climate Change Vulnerability Index) and CCSD (Climate Change Sensitivity Database), (b) NSCCVI and SAVS (System for Assessing the Vulnerability of Species), (c) CCSD and SAVS, and (d) all three vulnerability assessments as of November 2012 for the Western United States.



# CHAPTER 3

SPATIAL CLIMATE CHANGE VULNERABILITY ASSESSMENT FOR TERRESTRIAL WILDLIFE: AN IDAHO CASE STUDY


## Abstract

Climate change vulnerability assessments are relatively new tools aimed at identifying and quantifying the threat of climate change to species and ecosystems. Recent evaluation indicates that current assessments often overlook seasonality and geographic variation of climate and species' life history traits. I developed a spatial vulnerability assessment for terrestrial wildlife incorporating downscaled climate projections and seasonality. The assessment provides spatial models of the seasonal and annual of climate change exposure, weighted species' sensitivity to change in climate, and an adaptive capacity model incorporating species' traits and dispersal capabilities. These spatial tools were applied in a vulnerability assessment by comparing the effects of climate and species' adaptive capacity to protected lands in Idaho. An example of the application of this method is provided using an ensemble of 5 climate models for the wolverine (*Gulo gulo*) in Idaho. Wolverine showed highest vulnerability across southern Idaho. They are most affected by retention of spring snow and increasing summer temperatures. Low reproductive capacity and K-selected life history decreases the trait based adaptive capacity for wolverine, despite high landscape permeability and extensive dispersal ability. Future needs for vulnerability assessments include identification of validation datasets for current estimates of vulnerability and the more explicit inclusion of species' interactions and trophic cascade effects.

**Introduction**

The rapidity and magnitude of climate change projected for the next century presents a significant threat to wildlife and is a major topic of concern for wildlife and land management professionals at local, regional, and global scales. Evidence of climate related changes are already apparent across multiple taxa. Latitudinal range shifts (Parmesan et al. 1999, Parmesan and Yohe 2003, Root 2003; Perry et al. 2005, Chen et al. 2011), and elevational range shifts (Sekercioglu et al. 2008, Chen et al. 2011) are documented around the globe. These shifts are occurring at varying rates and often in the direction consistent with those predicted by climate change, and are projected to continue in the future (Warren et al. 2001, Perry et al. 2005, Lawler et al. 2009, Bellard et al. 2012). Differential advancement in the timing of phenological events has similarly been observed around the world (Shafer et al. 2001, Walther et al. 2002, Parmesan and Yohe 2003, Menzel et al. 2006, Parmesan 2006, Sekercioglu et al. 2008, Both et al. 2009, Yang and Rudolf 2010). These changes along with associated lag time in adjusting to changes in range and phenology, climate related habitat loss or degradation, expansion of disease or invasive species, and physiological intolerance of climate change among others are predicted to lead to the extinction of 10-70% of extant taxa by the end of the century (Thomas et al. 2004, Fischlin et al. 2007, Maclean and Wilson 2011, Bellard et al. 2012). These observations and predictions prompted the rapid development of climate change vulnerability tools and assessments to identify species most at risk of extinction and to inform active management plans for those species and habitats with the highest vulnerability.

Climate-related vulnerability assessments have become increasingly popular tools, based on quantitative and qualitative information, for informing wildlife management plans at the local and regional level (E.G.: Young et al. 2009, Bagne and Finch 2011, Lin and Morefield 2011, Davison et al. 2012, Gardalli et al. 2012, MCCS and NWF 2012). The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate extremes” (Schneider et al. 2007). A robust vulnerability assessment should include measures of climate exposure, the sensitivity of the species to change in climate, and the adaptive capacity of that species to ameliorate changes (Schneider et al. 2007, Glick et al. 2011). Exposure is a measure of the magnitude, direction, and rate of change in the components of climate. Sensitivity considers the degree to which a species’ innate characteristics and traits make it more or less likely to be affected by climate change. Measures of adaptive capacity encompass the traits and behaviors that a species possesses – including environmental potential- that allow it to ameliorate the impacts of climate change (Glick et al. 2011).

The novelty of, and increased demand for, measuring the vulnerability of species to climate led to an explosion in the variety of methodologies developed. Two major groups grew out of these developments: vulnerability tools and vulnerability assessments. Tools evaluate a variety of species, or systems, by combining measures of exposure, sensitivity and adaptive capacity. (e.g. Young et al. 2009, Bagne et al. 2011). Assessments are how the tools and information pertinent to the region, species, and management goals are applied to inform management actions (e.g. Davison et al. 2012, MCCS and NWF 2012). Because much of climate change vulnerability is still poorly understood, tools attempt to simplify the great complexity into a more manageable evaluation. Drawbacks and shortcomings of these novel tools and assessments have since been identified by Small-Lorenz et al. (2013).

A major challenge still facing managers is the lack of tools and assessments that address geographic and seasonal variability of climate and species' natural history (Small-Lorenz et al. 2013). Given the number of species requiring assessment and the restricted time and resources available to most agencies, incorporation of geographic and seasonal variability is difficult, though not impossible (Davison et al. 2012). Inclusion of temporal and geographic variability could greatly improve the application of tools and assessments to management plans and goals. Incorporating seasonal dynamics could help identify the severity of climate effects on species relative to important life history events (Small-Lorenz et al. 2013). Incorporating geographic variation in climate may identify future limitations of species, land use, or dispersal. Additional shortcomings of individual tools and assessments include the lack of consideration of migratory species and their stopovers (Small-Lorenz et al. 2013).

Here, I developed a set of climate change vulnerability tools for terrestrial wildlife species that addresses the most basic shortcomings of previous vulnerability tools, and can be used as part of the Idaho State Wildlife Action Plan (SWAP) revision. As part of the 2001 appropriation of State Wildlife Grant funds by the U.S. Congress, all states are required to complete a comprehensive wildlife conservation strategy, now known to as SWAPs (IDFG 2005). This major goal of these plans is to identify species of greatest conservation need (SGCN) and implement long-term strategies that promote their conservation (IDFG 2005). Strong emphasis and encouragement by federal agencies to incorporate climate change into the 2015 SWAP revisions (USFWS 2010a) motivated the selection of the species of greatest conservation need (SGCN) for the state of Idaho as the target wildlife species. As such, the climate change vulnerability assessment needed to encompass spatial and seasonal variability of climate change.

The assessment described here follows the definition of vulnerability provided by the IPCC by combining climate exposure, species' sensitivity, and species' adaptive capacity, but expands upon this basic model in several ways. Climate exposure is evaluated using statistically downscaled models of projected climate. The total effect of climate change is calculated by applying seasonal sensitivity weights based on species' life history requirements to the spatially heterogeneous climate exposure. Species' adaptive capacity is calculated using measures of species' dispersal and landscape permeability in concert with trait-based adaptive ranking to measure the species' geographic and temporal plasticity. These comprise the vulnerability tools. A preliminary vulnerability assessment was performed comparing the effects of climate change and species' adaptive capacity on currently protected areas within the target region. An example of the application and interpretation of this methodology is provided for wolverine (*Gulo gulo*), an SGCN in Idaho.

These tools are intended to be first-step towards the inclusion of more complicated aspects of vulnerability, which are currently not, or infrequently, addressed (Small-Lorenz et al. 2013). This model is intended to be developed further to suit the needs of individual users and changing data availability. The goal of the assessment framework is to 1) identify the potential spatial and temporal effects of climate on species, 2) identify where species exhibit high and low adaptive capacity, and 3) identify areas of management focus through a vulnerability assessment.

**Methods**

This assessment framework consists of 8 major steps (Figure 3.1). These steps are presented in a general format so they remain applicable for a variety of data sources and species depending upon availability, and/or accuracy, for different regions. This climate change vulnerability assessment is a dynamic process whereby new data may be added as they become available to keep assessment results relevant and up to date. While this framework has been applied to other species, an example using data on wolverine in Idaho is used in this chapter to demonstrate the application and interpretation of this framework.

*Determine Target Region and Species*

First, target species must be identified in order to initiate an assessment, along with the target region where the assessment will be carried out. The SGCN of Idaho were identified as the target species group and target region. The target region may span several states or provinces, or may be the size of a national park, or management area. Caution should be exercised when choosing smaller geographical regions of interest (e.g. wildlife management areas) relative to the resolution of available climate projections, because of the potential for a mismatch in scale. Smaller target regions that occur over few pixels, or entirely within a pixel, would inadequately capture the geographic variability of climate, which subsequently would affect the variability represented within the vulnerability analysis. Even at the state level, uncertainties in the climate data may be beyond those acceptable depending upon the land area, topography, and scale of climate models.

*Identify Sensitivity Components*

Following the identification of the target species and region, it is necessary to consider the pathways (sensitivities) by which a species can be affected by climate change prior to choosing specific climate projection data. Identifying these sensitivity categories provides a set of criteria with which to begin evaluating available climate data. Species can be both directly and indirectly sensitive to changes in climate characteristics.

The example provided here used sensitivity components previously identified through the Climate Change Sensitivity Database (CCSD). The CCSD is an online database that allows users to input information based on 9 categories of sensitivity (CCSD 2012). Five of these factors (Physiology, Sensitive Habitats, Disturbance Regimes, Ecological Relationships, and Generalist/Specialist) were selected to evaluate sensitivity for this assessment. The remaining categories (Life History, Dispersal Ability, Non-climatic, and Other) were used to inform the model of species' adaptive capacity.

*Identify Climate Projection Data*

Choice of climate projection data should directly relate to the sensitivity components from the previous step. At present, there are a wide variety of climate data to choose from, depending upon the ultimate goal of the assessment. It is important that the data chosen for the assessment adequately address the direct and indirect sensitivities of the target species, as these will affect interpretation of species vulnerability to climate change.

Multiple scenarios may be appropriate to account for uncertainty and stochasticity of climate and climate predictions. The Coupled Model Intercomparison Project phase 3 (CMIP3) Special Report on Emissions Scenarios (SRES) contained 4 major families of socioeconomic scenarios that make predictions about population growth; economic and technological development; emissions of greenhouse gasses; and emphasis on global, regional, or local solutions (A1, B1, A2, B2; IPCC 2000). These were used for the IPCC Third and Forth Assessment Reports (TAR and AR4). The IPCC Fifth Assessment Report (AR5) used the updated CMIP5 Representative Concentration Pathways (RCP). These scenarios focus on the change in radiative forcing based on greenhouse gas concentrations rather than on socioeconomics, ranging from 2.6 $W/m^2$ to 8.5 $W/m^2$ (van Vuuren et al. 2011).

Several global climate models (GCMs) have been run for each climate scenario. While full-scale GCM outputs will work within this model framework, downscaled GCM projections can better capture the heterogeneous nature of climate across a landscape. As mentioned earlier, resolution of the downscaled GCM is essential, as coarser models may average over important landscape-climate interactions that affect species' vulnerability. Downscaled climate projections are the result of the statistical, or mechanistic, increase in resolution from global climate models (GCM). GCM projections are typically around 300km (Meehl et al. 2007). Downscaled models typically have higher resolutions ranging from 50km down to 1km. Downscaled models are also available for multiple time periods (e.g. 2050s, or 2080s). Using multiple models, or an ensemble mean, is strongly recommended where possible, to incorporate model variability and minimize uncertainty.

End-of-the-century (2070-2099) climate projections for 5 climate models for 2 SRES scenarios (A1B and A2) were available for the Northwestern U.S. and Southwestern Canada via the US Geological Survey (USGS) (Shafer 2013). At the time that this project began, downscaled models using CMIP5 RCP scenarios were not available. The 5 downscaled GCMs were available at 30 arc-second resolution (approximately 1km; Table 3.1). The GCMs were run using the SRES A1B and A2 emissions scenarios, then statistically downscaled. SRES A1B assumes slow global population growth, rapid development and sharing of technologies, a high but balanced energy use, and slow land use conversion (IPCC 2000). SRES A2 assumes high global population growth, high-energy use focused on fossil fuels, slow technological development, and a moderate rate of land conversion (IPCC 2000). Annual projections were downscaled for both a historical time period (1961-1990) and the end of the century (2070-2099). The wolverine example detailed in this chapter provides results for the ensemble mean of the 5 climate models (Shafer 2013) under the SRES A2 scenario. An ensemble mean was used to account for the variability in projections of current climate models.

Given the previously determined sensitivity components and available climate projection data, this assessment makes use of 8 basic climate characteristics (mean temperature and total precipitation for each of the 4 seasons), and 4 additional climate characteristics (snow water equivalent, frost free days, and mean temperature of warmest and coldest months) as basic measures of modeled climate most likely to affect wildlife

(Table 3.2; Shafer 2013). These characteristics were chosen in an attempt to minimize uncertainty that inevitably compounds when using models of derived climate characteristics, and also to adequately represent the climate characteristics that most affect terrestrial wildlife species.

*Evaluate Species' Sensitivity*

The climate change sensitivity of a species is the species' susceptibility to change and considers innate characteristics that relate to tolerance of change in climate (Glick et al. 2011). Sensitivity serves to increase or decrease the overall effect of climate change through the inherent characteristics and dependencies of the species (Glick et al. 2011). I developed a tool in Microsoft Excel (Version 14.3.7; Microsoft Corporation 2010) to calculate sensitivity weights for each climate characteristic. This tool also calculates the mean, minimum, and maximum inter-seasonal effect of climate change, and rankings of landscape permeability and adaptive traits, discussed below. The tool is divided between the 5 sensitivity categories mentioned above. Each category asks the user to identify the level of sensitivity (Low, Moderate, High, Very High) to a particular climate characteristic, whether the species is sensitive to an increase or decrease in the characteristic, and any known thresholds. For example, the first question concerning species' physiological sensitivities asks the user to identify the species level of sensitivity to the mean temperature in each season. Each of the 4 available answers corresponds to a specific numeric weight: Low = 0.5, Moderate = 1, High = 2, and Very High = 3. While much of the data necessary for the development of sensitivity weights is available through the CCSD, additional sources may be required to provide adequate material to inform all fields.

Sensitivity weights can be calculated in a number of different ways. Two possible methods were compared for this case study using sensitivity data for 3 Idaho SGCN. First, I calculated the sensitivity weight for each climate characteristic as the product of all of the contributing weights for that characteristic (Equation 3.1).

$$w_i = \Pi(w_{ij}) \qquad \text{Equation 3.1}$$

Where *w* is the sensitivity weight, *i* refers to the individual climate characteristic, and *j* refers to the sensitivity category. The second method for calculating the sensitivity weight for each climate characteristic is the average of all contributing weights (Equation 3.2).

$$w_i = \frac{\Sigma w_{ij}}{5} \qquad \text{Equation 3.2}$$

The results of these two methods were compared using data for 3 Idaho SGCN to illustrate how the two methods may provide similar, or different outputs for species. These species were chosen because they are speculated to represent a range of sensitivities from direct sensitivity to climate characteristics (wolverine), to indirect sensitivity (great gray owl (*Strix nebulosa*)), to low climate sensitivity (bighorn sheep (*Ovis canadensis*)). Model results were divided into 10 equally spaced intervals and ranked from 1 (low) to 10 (high). I then calculated the correlation between the percent land area that fell within each of these 10 intervals for the product and mean methods for each species. I also compared the general shape of the distributions for the rescaled product and mean climate effect models.

*Evaluate Climate Change Exposure*

This evaluation focuses on the magnitude and direction of change between the historical and end-of-century projections for each of the 12 climate characteristics. I used ArcMap 10.0 (ESRI 2010) to convert the original annual NetCDF files to raster format using Multidimensional Tools. The mean and standard deviation were calculated for both the historical (1961-1990) and end-of-century (2070-2099) time intervals using Cell Statistics (Spatial Analyst: Local). Magnitude of deviation between the two time periods was calculated using the following:

$$d = \frac{\bar{x}_h - \bar{x}_p}{\sqrt{\frac{s_h^2}{n} + \frac{s_p^2}{n}}} \qquad \text{Equation 3.3}$$

Where *d* is an index of the deviation in the characteristic from historical to end-of-century, $\bar{x}_h$ and $\bar{x}_p$ are the mean of the historical and projected end-of-century time periods respectively, $s_h$ and $s_p$ are the standard deviation of the historical and projected time periods respectively, and *n* is the number of years in each time period (30 years). This measure of deviation was performed for all 12 climate characteristics independently. Output rasters were masked to the Idaho state boundary.

*Evaluate Effect of Climate Change*

The effect of climate change on an individual species is a function of the climate exposure and the species' sensitivity. Seasonal climate change effects were calculated by weighting spatial models of climate exposure by species' sensitivity. The weighted exposure models were then summed by season and re-scaled from 1 (low) to 10 (high). These maps indicate seasonal hot spots of climate change effects for a given species. Two models of the annual effect of climate change were produced from the seasonal models. First, all 12 sensitivity-weighted climate characteristics were summed and rescaled from 1 (low) to 10 (high). The second annual model involved identifying the maximum seasonal effect across all four seasonal models.

The severity of seasonal effects was calculated using Microsoft Excel. The tool previously described applies the sensitivity weights to the minimum, mean, and maximum deviation value of each climate characteristic. These weighted ranges are displayed seasonally to indicate how the effect of climate change on the species varies by characteristic and seasons.

*Evaluate Species' Adaptive Capacity*

Adaptive capacity was developed as a separate model from that of the effects of climate change and was a combination of spatial dispersal and trait based characteristics. Dispersal ability and barriers, as well as philopatry, reproductive capacity, life history, trophic level and dietary flexibility indicate the adaptive potential of species to counteract climate effects.

A species' dispersal capability was defined as the combined landscape permeability, the species' dispersal distance, and known barriers to dispersal. I used the USGS National Gap Analysis Program (GAP) land cover data at the National Vegetation Classification (NVC) macrogroup level, which provided 25 distinct land cover macrogroups for the state of Idaho (GAP 2011). Each macrogroup was ranked from 0 (not permeable) to 10 (highly permeable) based on information from the CCSD and additional sources. The species' USGS GAP distribution model, as suitable, was reclassified as 10 (highly permeable) (USGS 2013). Additional barriers to dispersal (e.g. roads) were reclassified and ranked according their degree of impermeability. The end result was a model of total landscape permeability for the target species across Idaho. This spatial model of landscape permeability was overlaid on each of the seasonal and annual climate effects models in the final vulnerability assessment.

A ranking of the species' adaptive capacity based on inherent traits was developed in a similar fashion to the sensitivity weights using Philopatry, Life History, and Trophic Flexibility. Philopatry is the propensity of the species to return to its birthplace. Life history is a measure of reproductive capacity along the r – K selection continuum. Trophic flexibility is a measure of the dietary flexibility a species exhibits, and its overall trophic level within the community. Species with greater dietary flexibility exhibit greater adaptive capacity. Similarly, species at lower trophic levels (eg. Herbivores) are indirectly affected to a lesser degree than those species at higher trophic levels (e.g. Carnivores) (Both et al. 2009, Brodie and Post 2011). Higher trophic level species that are not specialist foragers may also be buffered from the effects of climate change because they integrate across trophic levels. All traits were ranked 1(low) to 4(very high) and averaged to obtain an adaptive capacity rank. Species exhibiting low philopatry, high reproductive capacity (r-selection), that are herbivorous or omnivorous with low dietary specialization were awarded a high adaptive capacity weight. Some information on the philopatry and life history were available from the CCSD (CCSD 2012) although additional sources were necessary. This trait based numerical score is used to compare the relative trait based adaptive capacity across species.

*Conduct Vulnerability Assessment*

Vulnerability is the intersection of exposure, sensitivity, and adaptive capacity (Glick et al. 2011). Vulnerability assessment frameworks should reflect the goals and management objectives of the region of interest and therefore can be tailored to individual regions and agencies. They may also incorporate additional measures not previously considered by the tools detailed above such as the species' projected distribution or the projected distribution of critical habitat. This assessment focused on the goals and needs of the Idaho Department of Fish and Game (IDFG) for the 2015 SWAP revision. It is important to point out that the climate vulnerability assessment was only one consideration in the update and revision for the Idaho SWAP.

This assessment overlays the distribution of protected lands, seasonal climate effect and species' adaptive capacity along with the species current modeled distribution to identify areas of future management concern for individual species. An example of the final step in this framework is provided in the discussion using Idaho wolverine.

*Example: Wolverine in Idaho*

An example of the how to apply the framework and associated tools described above was carried out using data on the wolverine in Idaho. Wolverines are a circumboreal species with populations across Europe, Asia, and North America. In Idaho, wolverines are found in the mountainous center of the state, with more limited populations in the northern panhandle and in the south (Figure 3.2). The species was proposed for listing under the United States Endangered Species Act in 1995 (Carlton and Steele 1994) and 2000 (Carlton et al. 2000). Listing was warranted but precluded and wolverines were awarded candidate status (USFWS 2010b). Wolverines are listed as SGCN in Idaho due to limited current population trend data and low population numbers across the state (IDFG 2005). One study suggests that populations have become genetically fragmented in Idaho in part because of low densities and sparse current distribution (Kyle and Strobeck 2001).

Wolverines are a cold adapted species with multiple physiological traits, including thick fur and moderate foot loading, allowing them to tolerate very cold temperatures and traverse soft snow pack (Aubry et al. 2007). In general, wolverines tend to avoid lower elevations in summer and instead migrate to cooler higher elevations (Aubry et al. 2007, Copeland et al. 2010). The species was at one time considered a habitat generalist, but recent studies have raised questions about the wolverines' relationship with snow (Magoun and Copeland 1998, Copeland et al. 2010, Inman 2013). The species may be a snow obligate during denning season and require specific snow structure for insulation of kits and constructing dens (Magoun and Copeland 1998, Aubry et al. 2007). However, firm evidence of this dependence is still lacking. For that reason, the example assessment provides results assuming both an obligate relationship with spring snow and no obligate relationship with spring snow.

Wolverines are capable of dispersing long distances through many habitat types. They typically avoid urbanized, or heavily developed, areas and large roads (Copeland et al. 2007, Inman 2013). Some avoidance of cliff and scree areas has been noted in the literature (Copeland et al. 2007). Limited reproductive capacity and habitat fragmentation resulting from human disturbance make the added effects of climate change a concern for the future persistence and management of this species (IDFG 2005, Brodie and Post 2010, McKelvey et al. 2010, Peacock 2011).

## Results

While the framework above has been applied to other species, the results presented in this chapter are for wolverine in Idaho to emphasize the application and interpretation of the framework presented in the methods.

### *Species' Sensitivity*

The sensitivity of the example species varied depending upon the assumption of an obligate relationship with one or more climate characteristics. When assuming that wolverines have an obligate relationship with spring snow conditions, they exhibit strongest sensitivity for both spring precipitation and snow water equivalent (Table 3.3). Similarly, sensitivity was elevated for proximate characteristics that influence this relationship, such as spring temperature, winter precipitation, and the number of frost-free days (Table 3.3). When not assuming an obligate relationship, but still considering the species cold tolerance, several changes in the sensitivity weights are apparent. Sensitivity to spring and winter climate characteristics decreased significantly (Table 3.4). Individual sensitivity weights to summer and autumn climate characteristics remained unchanged. Under the non-obligate scenario, wolverines exhibit highest sensitivity to summer temperatures and the temperature of the warmest month (Table 3.4).

Both the product method and the mean method of calculating sensitivity weights produce similar distributions when rescaled so that they may be compared (Figure 3.3). However, species that exhibit low sensitivity to climate characteristics (e.g. bighorn sheep) appear to be affected by climate far less when using the product sensitivity weight method than when using the mean sensitivity weight method. Correlation was poor between the product and mean methods of calculating sensitivity weights for the species of low overall sensitivity (-0.0914, bighorn sheep), but very high for both species that exhibited either direct (0.9429, wolverine), or indirect (0.9767, great gray owl) climate sensitivity. This result is reinforced when observing the similarity of the distributions (Figure 3.3). Using the product method of calculating sensitivity produces a right skewed distribution, where as using the mean method produces a left skewed distribution. Calculating sensitivity weights using the mean ranks a greater percentage of the target region as having stronger effects of climate change on species with low sensitivity. Species that exhibit either direct or indirect sensitivity tend to have very similar curves using both methods.

*Climate Exposure*

Mean summer temperatures exhibit the greatest magnitude change from historical to end-of-century for the 5 model ensemble mean under SRES A2 (Table 3.5). Precipitation remains similar to 1961-1990 modeled conditions throughout the year, although some areas are predicted to see a significant loss of precipitation particularly in summer. Snow water equivalent is expected to decrease despite an increase in winter precipitation in some areas. The number of frost-free days is predicted to increase.

*Effect of Climate Change*

Under the assumption that wolverine are spring snow obligates, the projected effect of climate change is strongest across the southern part of the target region (Figure 3.4). Hot spots of the effect of climate change vary seasonally (Figure 3.5). Overall effects of seasonal climate change are highest in spring (Table 3.6). While the magnitude change in spring climate characteristics is not as great as other seasons, the wolverines heightened sensitivity to spring climate characteristics increases the overall effect of climate on wolverine assuming an obligate spring snow relationship.

When assuming that the wolverine does not have any obligate relationship with spring snow, there was very little change to the models of the effect of climate change. Both the annual (Figure 3.6) and the seasonal (Figure 3.7) models of the effect of climate change are very similar to those produced under an assumption of spring snow dependence. Wolverines in the Salmon region in central Idaho are projected to face a marginally stronger annual effect of climate change under the non-obligate assumption (Figure 3.6a). However, the maximum seasonal effect throughout the year decreases slightly across the northern part of the state (Figure 3.6b). The effect of both spring and winter climate change is significantly reduced overall (Table 3.6). Spatially there is little change in the effect of spring and winter climate other than being decreased slightly across the northern part of the state (Figure 3.7)

*Species' Adaptive Capacity*

Wolverines exhibit high landscape permeability throughout much of their current modeled distribution in central Idaho (Figure 3.8). Southern Idaho is less permeable than the central and northern portions of the state with a higher number of urban barriers.

Wolverine received a moderate adaptive capacity ranking (Table 3.7). Wolverines are carnivorous, but highly flexible in their diet. However, slow reproductive output, higher age of sexual maturity, and higher degree of philopatry decreased their overall trait based adaptive capacity despite their trophic flexibility.

## Discussion

Over the next century, anthropogenic climate change threatens to directly and indirectly affect a wide variety of taxa. Understanding how spatial and temporal dynamics of climate change affect species could greatly improve the ability of managers and scientists to alleviate climate stress on biodiversity loss (Bellard et al. 2012). This spatially and temporally dynamic assessment framework is a "first-step" attempt at incorporating aspects of spatial and temporal variability into wildlife climate change vulnerability assessments. The intention of this framework is to provide a basis for the development of more complex assessments in the future.

The method for calculating sensitivity (product vs. mean) did not lead to considerable differences in the output when calculating the effect of climate change upon directly or indirectly sensitive species. The greatest disagreement between the 2 methods occurred when calculating the sensitivity weight for species exhibiting low sensitivity. The difference between the methods may be a result of the range of sensitivity weights when using the product (0.03125 to 243), versus the mean (0.5 to 3) method. The product method appears to allow for an extension of this range both at the upper and lower end. Care should be taken when considering a method for calculating sensitivity and whether that method will exaggerate the output of species exhibiting low or high sensitivity. These methods of determining species' sensitivity to climate characteristics are novel and continued conversation it is strongly encouraged to refine and further develop this component of vulnerability evaluation.

Characterizing a species' dependency on certain climate characteristics can have important implications when informing management decisions. As in the example described above, assuming wolverines exhibit an obligate relationship with spring snow produces a sensitivity and management focus on spring precipitation and temperature, and snow water equivalent. When assuming wolverines do not exhibit this obligate relationship, the focus shifts to summer temperature. Despite this change in sensitivity emphasis, the overall geographic hot spots of management focus remain similar under both the obligate and non-obligate scenarios for this species. This similarity may not hold for all species. Although this change in sensitivity weighting does not produce a change in geographic focus, it does change the seasonal focus of potential management actions, and what aspects of the species' life history are affected. The example suggests that incomplete knowledge of species' sensitivity can result in an overestimation, or underestimation, of the species' sensitivity to climate characteristics, and ultimately to the overall effect of climate change on that species. Therefore, although the areas of management focus may remain unchanged, altering sensitivity weights has important implications in directing management action planning and timing.

Previous assessments have used spatially and/or seasonally homogenous measures of climate exposure. However, these do not adequately address the how seasonal and spatial heterogeneity of climate may differentially affect species. This assessment used heterogeneous measures of climate exposure to address the importance of considering spatial and seasonal effects of projected climate change. The severity of climate effects varies not only across a landscape, but also between seasons. While seasonal and annual hot spots of climate effect represent areas and seasons of high risk for individual species, areas of low seasonal and annual effect may represent climate refugia. Maps that indicate the projected severity of climate effects could assist in future wildlife management planning by indicating areas of least climate change. These areas may provide refuges for those species exhibiting high climate sensitivities, but with minimal capacity for adaptation.

The permeability of the landscape and individual species dispersal ability may greatly contribute to the ability of species to cope with the effects of climate change. The example in this chapter focuses on a highly mobile species with a capacity for moving through many land cover types (Vangen et al. 2001). Other species with more limited dispersal, or those subject to a greater number of barriers may be at increased risk to the local effects of climate change, and loss of genetic connectivity, because of their restricted capacity for movement. The distribution and connectivity of protected lands will be important for species with limited dispersal capabilities, or those subject to dispersal barriers.

Plasticity of behavioral and inherited traits will similarly be important measures of adaptive capacity. There is current little data on the plasticity of behavioral and inherited traits for most species. For this reason, vulnerability assessments use measures of reproductive capacity and foraging or habitat specificity to estimate a species capacity for coping with environmental change. While these may be imperfect measures of trait plasticity, they provide information on the rapidity with which evolution could take place (r vs. K selected species) and propensity of species to adjust to a changing landscape.

In the case of the example species, the majority of lands on which wolverines occur are classified as GAP status 2 or 3 lands. Status 2 lands are permanently protected from land cover conversion, where limited use including the suppression of natural disasters is permissible. Status 3 lands are also permanently protected, but are subject to extractive use. Large proportions of these lands are designated wilderness, or national forest, and experience relatively low levels of land cover conversion, or anthropogenic interference. These protected lands also overlap with land cover types that are highly permeable for the wolverine. However, wolverines in the southeast corner of the state are subject to more fragmented protected lands and a higher number of dispersal barriers than those in the central part of the state. This could inhibit genetic connectivity between the two areas. While wolverines are highly mobile, their slow reproductive turnover and high trophic level are likely to increase the negative consequences of indirect climate effects.

Overall, the findings for the example are in agreement with other studies concerned with the effect of climate change on wolverines. Several studies have identified the strong potential for negative effects of climate change on wolverines under the assumption that they are spring snow obligates. These studies stress the potential consequences of reduced future snow pack and spring snow retention under multiple climate change scenarios (McKelvey et al. 2010, Brodie and Post 2011, Peacock 2011).

Loss of snow has previously been linked to declining populations and decreased breeding success (Magoun and Copeland 1998). Change in prey availability and survival could also change with earlier green-up and decrease snow cover (Persson 2005, Bordie and Post 2011). A decrease in spring snow retention, particularly throughout lower elevations, would push wolverine into more isolated high elevation habitat during the denning season (Brodie and Post 2011). Rain-on-snow events may accelerate melting and compaction of snow at lower elevation where temperatures do not remain adequately cold enough to produce snow. Therefore, higher elevations denning habitat may improve, but lower elevation habitat would decrease in quality (McKelvie et al. 2011, Brodie and Post 2012).

Other studies have identified reason for concern under the assumption that wolverine are not a spring snow obligate species. One previous study correlated wolverine locations with areas that averaged less than 22 °C average maximum August temperature (Copeland et al. 2010). Stress of increasing summer temperatures also could to push wolverine to cooler microhabitats (Peacock 2011). Increasing summer temperatures, particularly temperatures at the warmest part of the summer are predicted to be one of the characteristics experiencing the greatest magnitude of change. This may restrict activity or movement of wolverines due to physiological stress (Peacock 2011). Warmer drier summers also increase the risk of more extensive, frequent, and intense fires throughout wolverine habitat (Flannigan et al. 2000, Dale et al. 2001). Fire, human disturbance, and physiological climate stress could increase the fragmentation of already somewhat fragmented populations in the southeast corner of Idaho.

This assessment may underestimate the adaptive capacity of wolverine in southeast Idaho because of the extent of the target region considered. It is unknown if individuals in the southeast corner of the state are connected to a larger contiguous population in Wyoming or Montana.

For wolverine, the most important climate change and adaptation considerations will likely be in encouraging dispersal to habitats least affected by climate change, promoting genetic connectivity between populations (Schwartz et al. 2009), and identifying and maintaining summer and spring habitats (Magoun and Copeland 1998, McKelvey et al. 2011). Finally, monitoring of wolverine populations as they relate to changes in snow cover and summer temperatures will help to improve this assessment for future management.

**Opportunities and Challenges**

The vulnerability tools and assessment developed here are a first-cut at attempting to incorporate geographic and temporal variability. Vulnerability assessments are one way to identify at-risk species, but there is still significant room for advancement in the development of these assessments. Below are challenges, opportunities and recommendations for the future development of climate change vulnerability assessments.

All climate change vulnerability assessments are inherently susceptible to the uncertainty and/or errors in their supporting and input data. These errors can arise both in the climate projection data and through imperfect knowledge of species sensitivities and capacity for adaptation.

Global climate models are only approximations of actual global climate and therefore carry some uncertainty in their projections of future climate. Although individual climate models may not accurately reflect climate patterns, applying ensemble means and the ensemble minimum and maximum provide more accurate estimations and a confidence interval (Rupp et al. 2013).

The process of statistically downscaling introduces additional uncertainty on top of that already present in GCMs. GCMs provide a single value for a particular climate characteristic over a large area. Statistically downscaling this value so that it reflects individual values of a climate characteristic over many smaller areas involves interpolating the relationship between local environmental characteristics and large-scale climate (Schoof 2013). The statistical relationship used to downscaling the climate projections and the variables considered may, or may not, accurately reflect the true relationship between large-scale climate and local climate. For that reason, downscaled climate projections introduce additional uncertainty.

Finally, the general vulnerability formula offers little specificity as to the method for measuring and combining exposure, sensitivity, and adaptive capacity. There has been limited discussion to further refine the definitions of these three components of vulnerability. Discussion of how best to combine the potentially hundreds of inputs has also been lacking. For this reason components seen in one vulnerability assessment may be incorporated differently, or absent, from other assessments. I feel that the assessment and tools developed here provide users with an adequate framework of spatial and seasonal vulnerability for terrestrial wildlife species. However, users should be aware that because of the complexity involved in developing a vulnerability assessment, cross-comparison between assessments can be difficult due to methodological and input differences (Lankford et al. *in press*).

Despite the drawbacks associated with using climate data and having incomplete knowledge of species, there are also several opportunities that a spatial and seasonally dynamic vulnerability assessment can offer.

Whereas previous assessments provide limited relative prioritization of species (Small-Lorenz et al. 2013), inclusion of spatial and seasonal heterogeneity can provide managers with a more in depth tool for decision making. These tools can prioritize species as well as the areas and seasons in which they will be most strongly affected. This kind of information bridges a gap between prioritization and on-the-ground management that has not previously been addressed.

Incorporation of spatial and temporal variability also opens the potential for using GAP analysis to quantify on-the-ground threat of climate change for lands under various levels of protection. Future assessments that wish to incorporate geographic variability of climate in particular could greatly benefit from using GAP analysis to identify current and future connectedness and the propensity of species to disperse from an protected lands to unprotected lands. Given the inclusion of more in-depth species and habitat interactions, these types of analyses may even allow managers to identify future areas in need of protection based on species' adaptive capacity and the projected effects of climate change.

More effective future assessments will likely include both spatial and seasonal context. Inclusion of migratory species and their diverse habitat needs throughout the year and across both national and international borders could improve development of specific management actions to improve their conservation. Models of the seasonal climate effects on habitats and functional groups could provide more complete information for higher trophic level species vulnerability assessments. Similarly, species' interactions and the potential for cascading climate effects are currently difficult to quantify, but need to be addressed in the future to improve vulnerability predictions. Finally, including habitat and species' range shifts and future natural and anthropogenic landscape alteration would improve application of adaptive capacity models and development of habitat corridors. Other considerations for the development of assessments include careful wording of questions and explicit statement of data inputs and goals.

Many vulnerability assessments exist. However, these assessments do not always agree with one another (Lankford et al. *in press*). Comparison of assessment outputs and of the goals and user inputs is strongly recommended before assigning any single value of vulnerability to any species (Lankford et al. *in press*). Many assessments, including this one, are deductive and based strongly on expert opinion. It is recommended that users of this and other assessments take the time to evaluate species using multiple assessments, understanding the variety of goals and data that each identifies.

Validation of vulnerability assessments is needed if the scientific and management community wishes to use these as management tools. The challenge behind this validation is that the vulnerability assessments make predictions about species' persistence far into the future. Feedback on both the quality and accuracy of the climate projection data as well as the specific sensitivities and life history traits of wildlife species is needed to improve vulnerability tools. Methodology of validation may vary from species to species, depending upon what is currently known about both the species and climate characteristic projections. Monitoring species' distribution, reproductive success, and source and sink dynamics in relation to pertinent climate characteristics could be one method of providing model validation data down the road.

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**Table 3.1** Global climate models (GCM) statistically downscaled and used in the ensemble calculations of climate exposure, effect and vulnerability for Idaho species of greatest conservation need.

| Model Name | Acronym | Year Published | Authors |
|---|---|---|---|
| Community Climate System Model, ver. 3.0 | CCSM3 | 2005 | National Center for Atmospheric Research, USA |
| Coupled Global Climate Model, ver. 3 | CGCM3.1 (T47) | 2005 | Canadian Centre for Climate Modeling and Analysis, Canada |
| Goddard Institute for Space Studies ModelE-R | GISS-ER | 2004 | National Aeronautics and Space Administration/Goddard Institute for Space Studies, USA |
| Model for Interdisciplinary Research on Climate (medium resolution) | MIROC3.2 (medres) | 2004 | Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, Frontier Research Center for Global Change, Japan |
| Hadley Centre Coupled Model, ver. 3 | UKMO-HadCM3 | 1997 | Hadley Centre for Climate Prediction and Research/Met Office, UK |

**Table 3.2** List of 12 climate characteristics provided by USGS and used to estimate spatial climate exposure (Shafer 2013).

| **Type of characteristic** | **Characteristic name** | **Description** |
|---|---|---|
| Temperature | Mean temperature of the warmest month | 30 year mean of the average temperature (°C) for the warmest month of each year |
| | Mean temperature of the coldest month | 30 year mean of the average temperature (°C) for the coldest month of each year |
| | Mean winter temperature | Average temperature (°C) through December, January, and February |
| | Mean spring temperature | Average temperature (°C) through March, Aril, and May |
| | Mean summer temperature | Average temperature (°C) through June, July, and August |
| | Mean autumn temperature | Average temperature (°C) through September, October, and November |
| | Number of frost free days | Number of days above 5° C |
| Precipitation | Total winter precipitation | Total cumulative precipitation (mm) for December, January, and February |
| | Total spring precipitation | Total cumulative precipitation (mm) for March, April, and May |
| | Total summer precipitation | Total cumulative precipitation (mm) for June, July, and August |
| | Total autumn precipitation | Total cumulative precipitation (mm) for September, October, and November |
| | Snow water equivalent | Total liquid water equivalent in snowpack (mm) |

**Table 3.3** Sensitivity values as calculated for Idaho wolverine (*Gulo gulo*) assuming an obligate relationship with spring snow. These values are informed by the Climate Change Sensitivity Database, expert opinion, and literature review. Climate characteristics are awarded a weight for each of 5 sensitivity categories ranging from 0.5 (low sensitivity) to 3 (very high sensitivity). Two methods of calculating climate characteristic sensitivity weights are examined here as the product or the mean of the weights for the 5 individual categories.

| Climate Characteristic | Physiology | Habitat | Disturbance | Ecology | Generalist/ Specialist | Sensitivity Weight (Product) | Sensitivity Weight (Mean) |
|---|---|---|---|---|---|---|---|
| **Spring** | | | | | | | |
| Mean spring temperature | 1 | 1 | 0.5 | 2 | 3 | 3.0 | 1.5 |
| Total spring precipitation | 0.5 | 3 | 0.5 | 2 | 3 | 4.5 | 1.8 |
| Number of frost free days | 0.5 | 1 | 0.5 | 2 | 3 | 1.5 | 1.4 |
| **Summer** | | | | | | | |
| Mean summer temperature | 3 | 1 | 0.5 | 1 | 1 | 1.5 | 1.3 |
| Total summer precipitation | 0.5 | 2 | 0.5 | 1 | 1 | 0.5 | 1.0 |
| Mean temperature warmest month | 3 | 1 | 0.5 | 1 | 1 | 1.5 | 1.3 |
| **Autumn** | | | | | | | |
| Mean autumn temperature | 1 | 1 | 0.5 | 1 | 1 | 0.5 | 0.9 |
| Total autumn precipitation | 0.5 | 2 | 0.5 | 2 | 1 | 1.0 | 1.2 |
| **Winter** | | | | | | | |
| Mean winter temperature | 1 | 1 | 0.5 | 1 | 2 | 1.0 | 1.1 |
| Total winter precipitation | 0.5 | 2 | 0.5 | 2 | 3 | 3.0 | 1.6 |
| Mean temperature coldest month | 1 | 1 | 0.5 | 2 | 2 | 2.0 | 1.3 |
| Snow water equivalent | 0.5 | 3 | 0.5 | 2 | 3 | 4.5 | 1.8 |

**Table 3.4** Sensitivity values as calculated for Idaho wolverine (*Gulo gulo*) with no assumption of an obligate relationship with spring snow. These values are informed by the Climate Change Sensitivity Database, expert opinion, and literature review. Climate characteristics are awarded a weight for each of 5 sensitivity categories ranging from 0.5 (low sensitivity) to 3 (very high sensitivity). Two methods of calculating climate characteristic sensitivity weights are examined here as the product or the mean of the weights for the 5 individual categories. Italicized numbers indicate change in sensitivity value from Table 3.3.

| Climate Characteristic | Physiology | Habitat | Disturbance | Ecology | Generalist/ Specialist | Sensitivity Weight (Product) | Sensitivity Weight (Mean) |
|---|---|---|---|---|---|---|---|
| **Spring** | | | | | | | |
| Mean spring temperature | 1 | 1 | 0.5 | *1* | *1* | *0.5* | *0.9* |
| Total spring precipitation | 0.5 | *1* | 0.5 | *1* | *1* | *0.25* | *0.8* |
| Number of frost free days | 0.5 | 1 | 0.5 | *0.5* | *0.5* | *0.0625* | *0.6* |
| **Summer** | | | | | | | |
| Mean summer temperature | 3 | 1 | 0.5 | 1 | 1 | 1.5 | 1.3 |
| Total summer precipitation | 0.5 | 2 | 0.5 | 1 | 1 | 0.5 | 1.0 |
| Mean temperature warmest month | 3 | 1 | 0.5 | 1 | 1 | 1.5 | 1.3 |
| **Autumn** | | | | | | | |
| Mean autumn temperature | 1 | 1 | 0.5 | 1 | 1 | 0.5 | 0.9 |
| Total autumn precipitation | 0.5 | 2 | 0.5 | 2 | 1 | 1.0 | 1.2 |
| **Winter** | | | | | | | |
| Mean winter temperature | 1 | 1 | 0.5 | 1 | *0.5* | *0.25* | *0.8* |
| Total winter precipitation | 0.5 | *1* | 0.5 | *1* | *1* | *0.25* | *0.8* |
| Mean temperature coldest month | 1 | 1 | 0.5 | *1* | *1* | *0.5* | *0.9* |
| Snow water equivalent | 0.5 | *1* | 0.5 | *1* | *1* | *0.25* | *0.8* |

**Table 3.5** The average magnitude and direction for the ensemble minimum, mean, and maximum of 5 statistically downscaled climate models for 12 climate characteristics. Negative values refer to a loss, or decrease in the climate characteristic, while positive values refer to a gain, or increase. All values are unitless and refer to the relative index of change from 1961-1990 to 2070-2099.

| | **Magnitude Deviation Index** | | |
|---|---|---|---|
| **Climate Characteristic** | **Ensemble Minimum** | **Ensemble Mean** | **Ensemble Maximum** |
| Mean Spring Temperature | 5.20 | 13.31 | 23.78 |
| Mean Summer Temperature | 18.35 | 22.74 | 27.53 |
| Mean Fall Temperature | 9.52 | 14.43 | 19.10 |
| Mean Winter Temperature | 3.47 | 8.44 | 12.63 |
| Total Spring Precipitation | -0.42 | 1.18 | 3.40 |
| Total Summer Precipitation | -4.50 | -2.15 | 0.84 |
| Total Fall Precipitation | -0.39 | 1.72 | 4.06 |
| Total Winter Precipitation | -0.04 | 1.75 | 3.39 |
| Mean Temperature Warmest Month | 1.71 | 13.00 | 24.69 |
| Mean Temperature Coldest Month | 4.41 | 7.63 | 12.02 |
| Snow Water Equivalent | -8.05 | -5.13 | -1.22 |
| Number of Frost Free Days | 4.93 | 10.52 | 14.58 |

**Table 3.6** Index of the seasonal effect of climate change on wolverine in Idaho. Index is calculated as the sensitivity weighted minimum, mean, and maximum exposure (magnitude of change in each climate characteristic) within the state of Idaho. The direction of the index (positive or negative) indicates the direct of change in the climate characteristic (gain or loss). This table shows the range for the effects of climate change for all 12 climate characteristics for both the spring snow obligate and non-obligate assumptions.

| | **Climate Effect** Spring Snow Obligate | | | **Climate Effect** Non-Obligate | | |
|---|---|---|---|---|---|---|
| **Climate Characteristic** | Min | Mean | Max | Min | Mean | Max |
| **Spring** | | | | | | |
| Mean spring temperature | 7.80 | 19.97 | 34.67 | 4.68 | 11.98 | 21.40 |
| Total spring precipitation | -0.76 | 2.12 | 6.12 | -0.34 | 0.94 | 8.75 |
| Number of frost free days | 6.09 | 14.73 | 20.41 | 2.96 | 6.31 | 8.75 |
| **Summer** | | | | | | |
| Mean summer temperature | 23.86 | 29.56 | 35.79 | 23.86 | 29.56 | 35.79 |
| Total summer precipitation | -4.50 | -2.25 | 0.84 | -4.50 | -2.25 | 0.84 |
| Mean temperature warmest month | 2.22 | 16.90 | 32.10 | 2.22 | 16.90 | 32.10 |
| **Autumn** | | | | | | |
| Mean autumn temperature | 8.57 | 12.99 | 17.19 | 8.57 | 12.99 | 17.19 |
| Total autumn precipitation | -0.47 | 2.06 | 4.87 | -0.47 | 2.06 | 4.87 |
| **Winter** | | | | | | |
| Mean winter temperature | 3.82 | 9.28 | 13.89 | 2.78 | 6.75 | 10.10 |
| Total winter precipitation | -0.06 | 2.80 | 5.42 | -0.3 | 1.40 | 2.71 |
| Mean temperature coldest month | 5.73 | 9.92 | 15.63 | 3.97 | 6.87 | 10.82 |
| Snow water equivalent | -14.49 | -9.23 | -2.20 | -6.44 | -4.10 | -0.98 |

**Table 3.7** Adaptive capacity ranking for wolverine (*Gulo gulo*) in Idaho: Traits scores (1 to 4) are averaged together to produce the trait based adaptive capacity ranking (ranging 1 to 4) that is paired with the dispersal capability spatial model.

| Adaptive Trait | Input Choice | Rank for Wolverine (*Gulo gulo)* |
|---:|:---:|:---:|
| Philopatry | 1 (Low) – 4 (High) | High (2) |
| Life History | 1 – 4 | Low – K selected (1) |
| Trophic Level | Herbivore, Omnivore, Insectivore, Carnivore | Carnivore – low specialization (3) |
| Specialization | 1 (low ) – 4 (high) | |
| **Adaptive Capacity Ranking** | | **2.00** |

**Figure 3.1** Flowchart indicating data inputs for developing climate change vulnerability tools and how tools can be combined to conduct a vulnerability assessment.

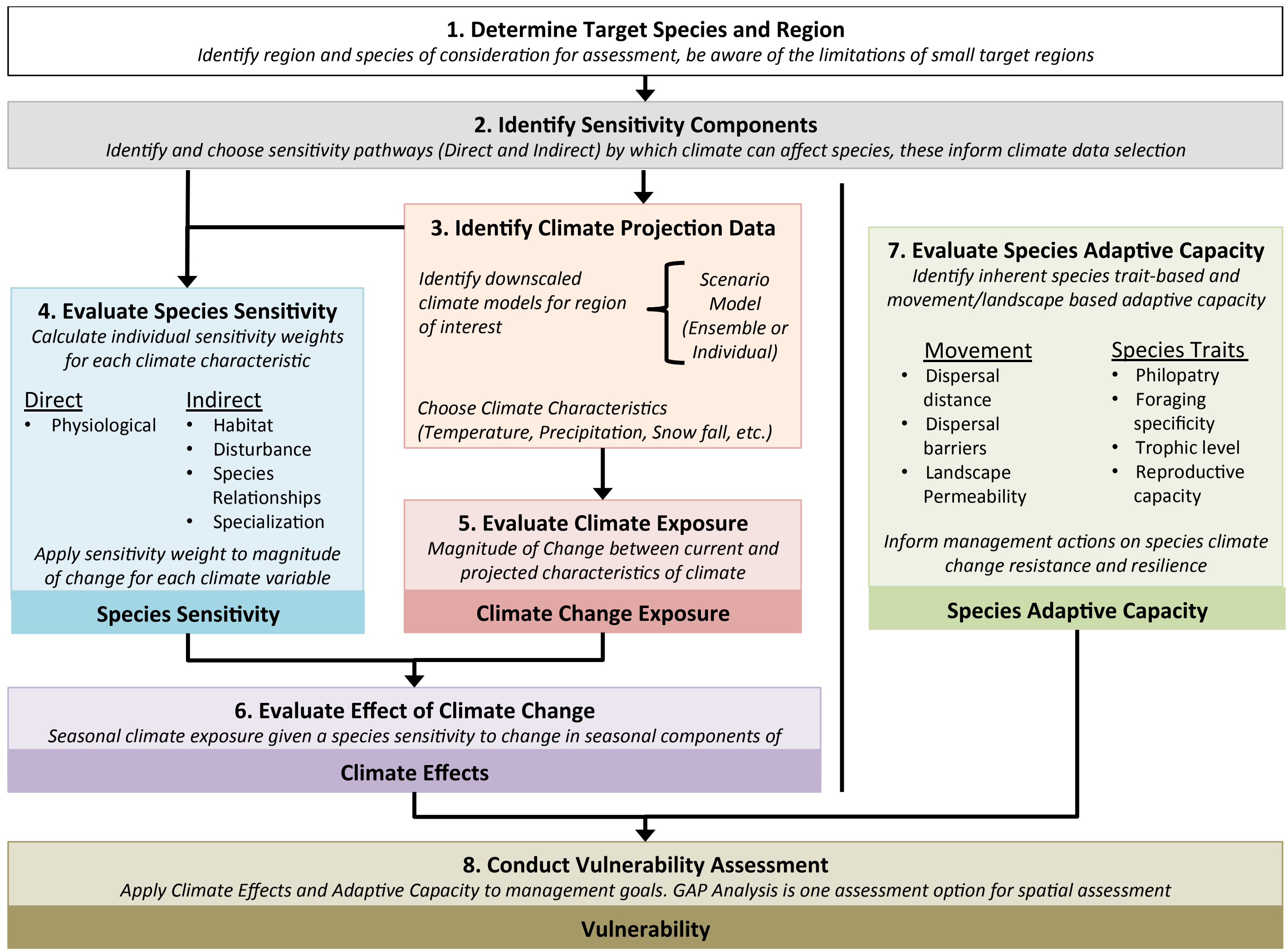


**Figure 3.2** The distribution of wolverine (*Gulo gulo*) in Idaho based on Northwest Regional Gap Analysis Program (NW Re-GAP) occurrence data (USGS 2013).

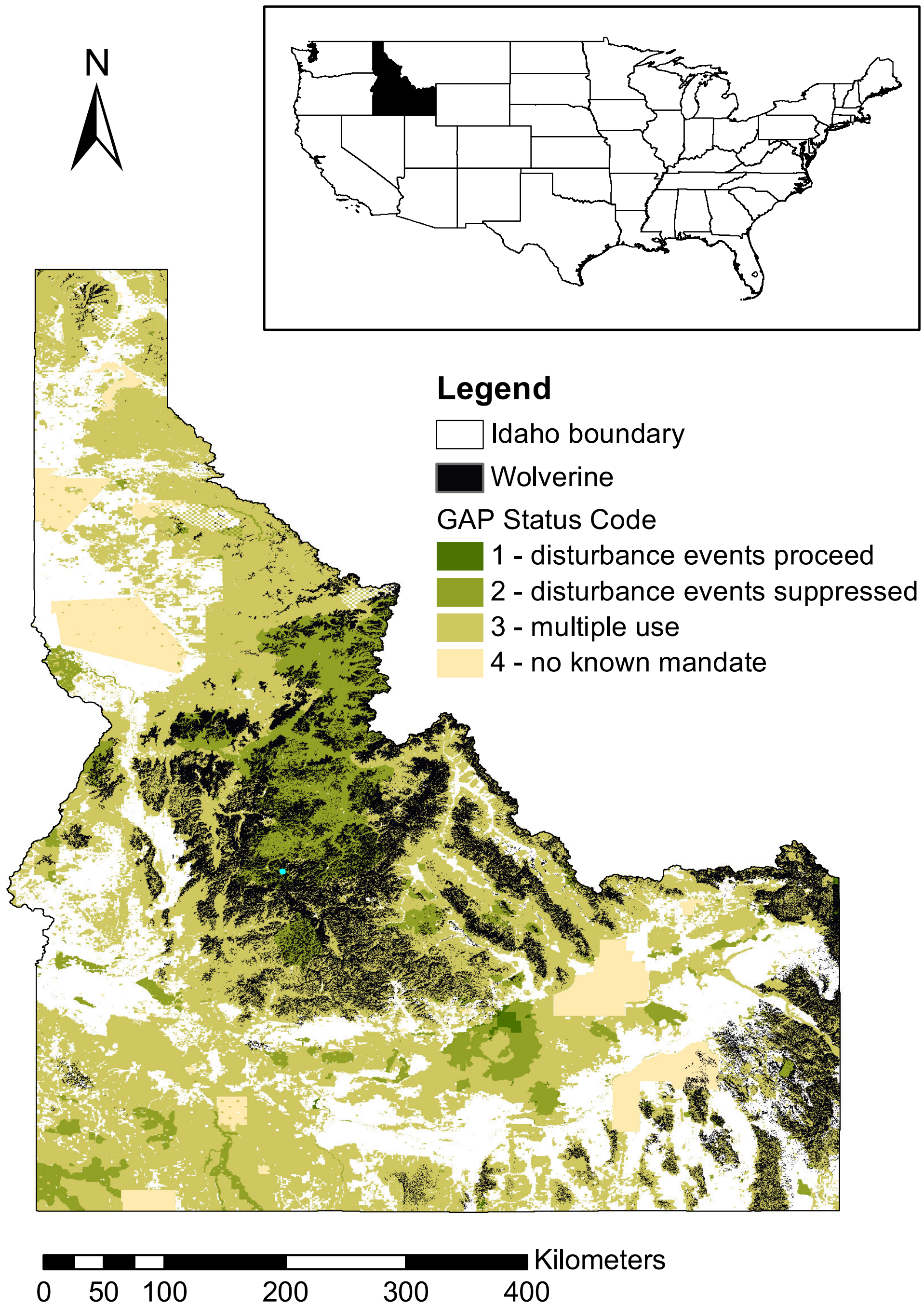


**Figure 3.3** Product vs. mean graphs for a) bighorn sheep (*Ovis canadensis*), b) great gray owl (*Strix nebulosa*), and c) wolverine (*Gulo gulo*).

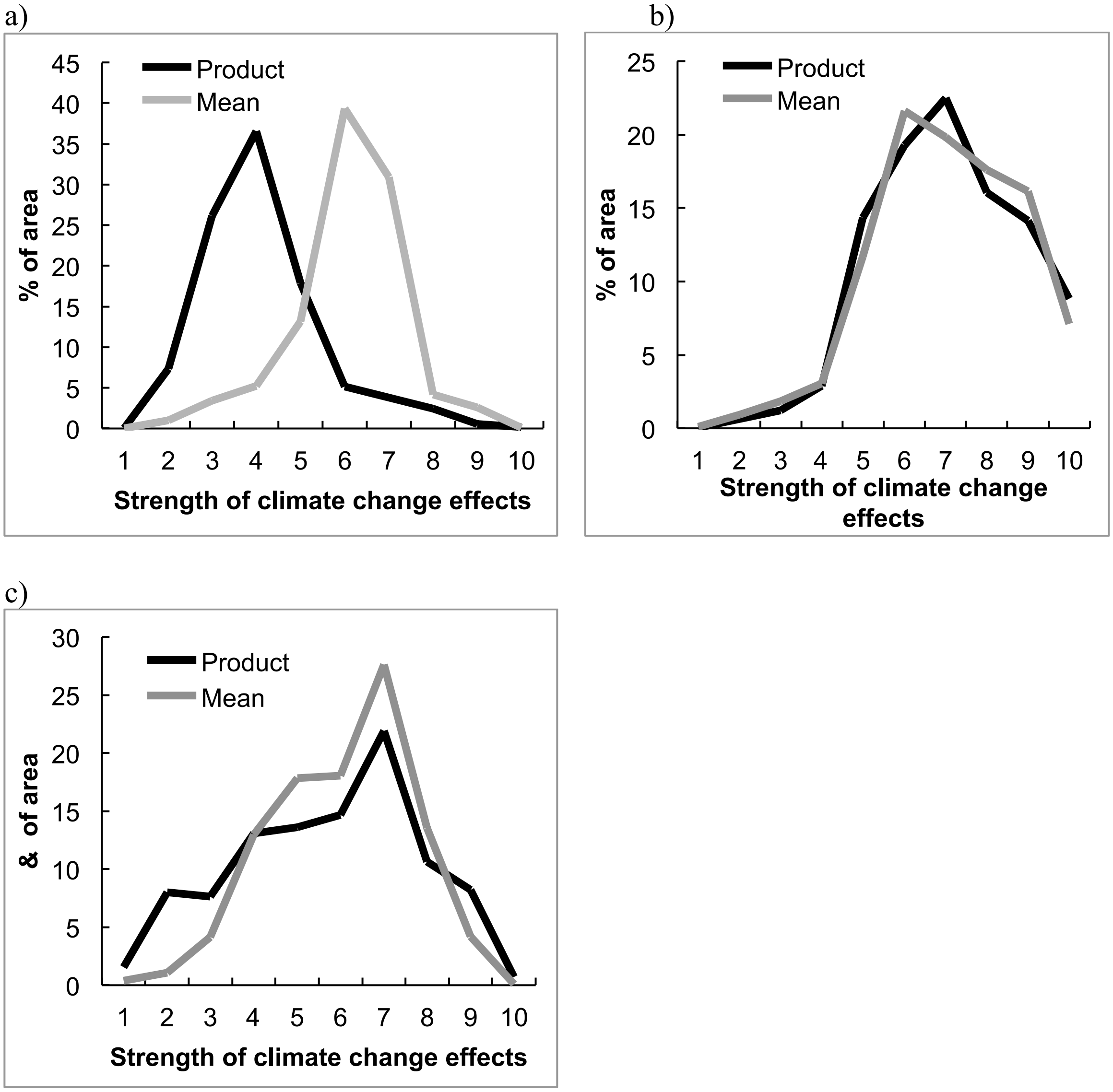


**Figure 3.4** Ranked annual effect of climate change (sensitivity weighted climate exposure) for the ensemble mean Special Report on Emission Scenarios (SRES) A2 end-of-century projections for Idaho wolverine (*Gulo gulo*) assuming obligate relationship with spring snow. Annual effect is a) calculated as the sum of the effect of all 12 individual climate characteristics and reclassified on a 1 (low climate effect) to 10 (high climate effect) scale, and b) the maximum values across all 4 seasonal climate effect models.

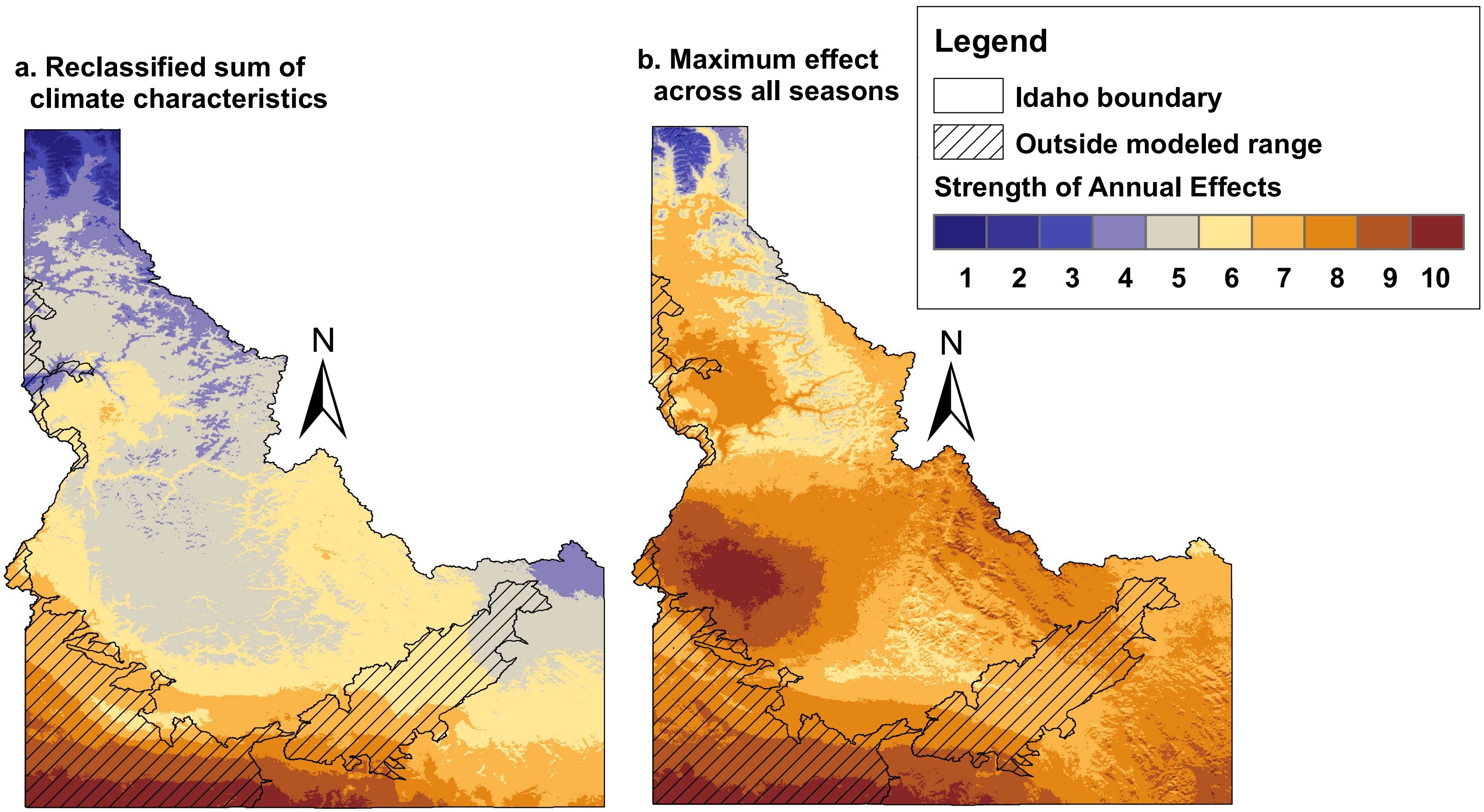


**Figure 3.5** Seasonal effect of climate change (sensitivity weighted climate exposure) for the ensemble mean Special Report on Emission Scenarios (SRES) A2 end-of-century projections for Idaho wolverine (*Gulo gulo*) assuming an obligate relationship with spring snow in a) Spring (March, April, May), b) Summer (June, July, August), C) Autumn (September, October, November), and d) Winter (December, January, February). Each seasonal effect is calculate as the sum of the effect of all individual seasonal climate characteristics (Table 3.2) and reclassified on a 1 (low climate effect) to 10 (high climate effect) scale.

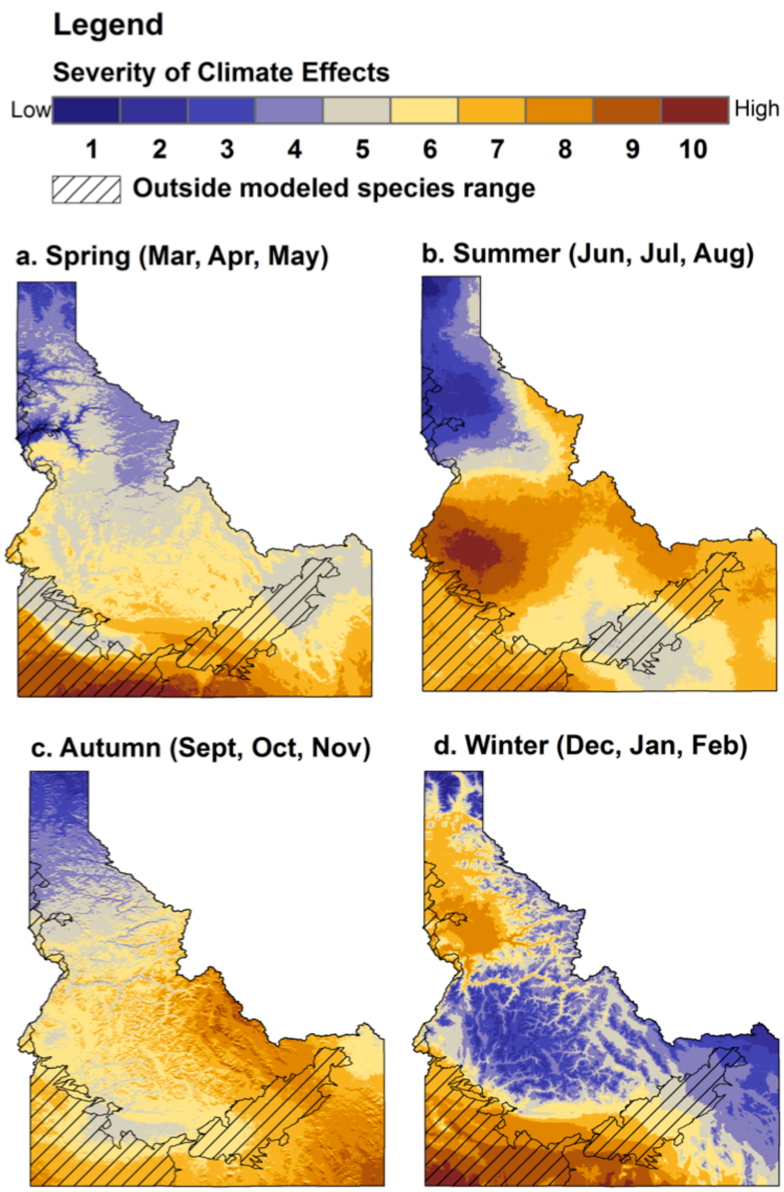


**Figure 3.6** Ranked annual effect of climate change (sensitivity weighted climate exposure) for the ensemble mean Special Report on Emission Scenarios (SRES) A2 end-of-century projections for Idaho wolverine (*Gulo gulo*). These models assume that there is no obligate relationship with spring snow. Annual effect is calculate as the sum of the effect of all 12 individual climate characteristics and reclassified on a 1 (low climate effect) to 10 (high climate effect) scale.

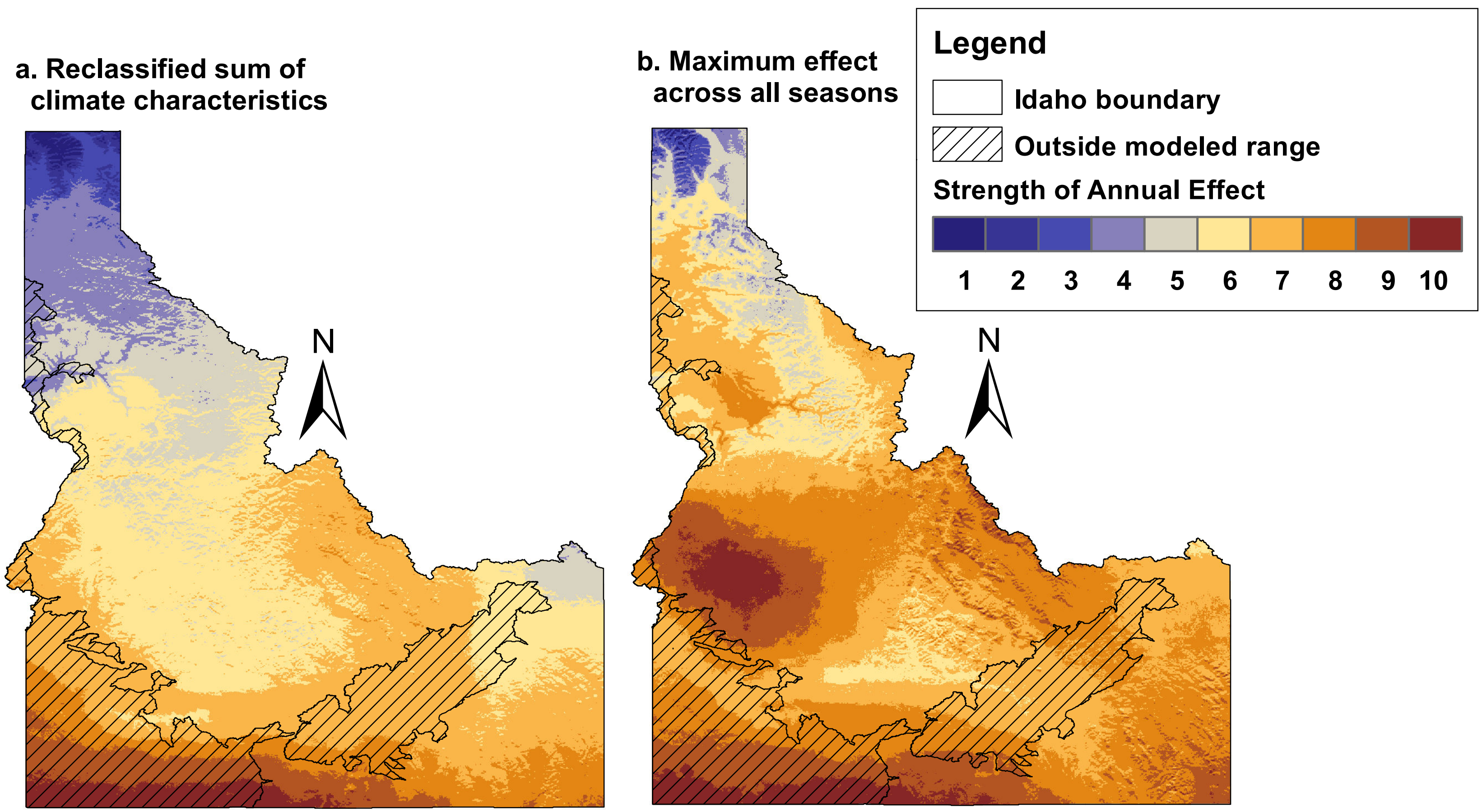


**Figure 3.7** Seasonal effect of climate change (sensitivity weighted climate exposure) for the ensemble mean Special Report on Emission Scenarios (SRES) A2 end-of-century projections for Idaho wolverine (*Gulo gulo*) in a) Spring (March, April, May), b) Summer (June, July, August), C) Autumn (September, October, November), and d) Winter (December, January, February). These models assume that there is no obligate relationship with spring snow. Each seasonal effect is calculate as the sum of the effect of all individual seasonal climate characteristics (Table 3.2) and reclassified on a 1 (low climate effect) to 10 (high climate effect) scale.

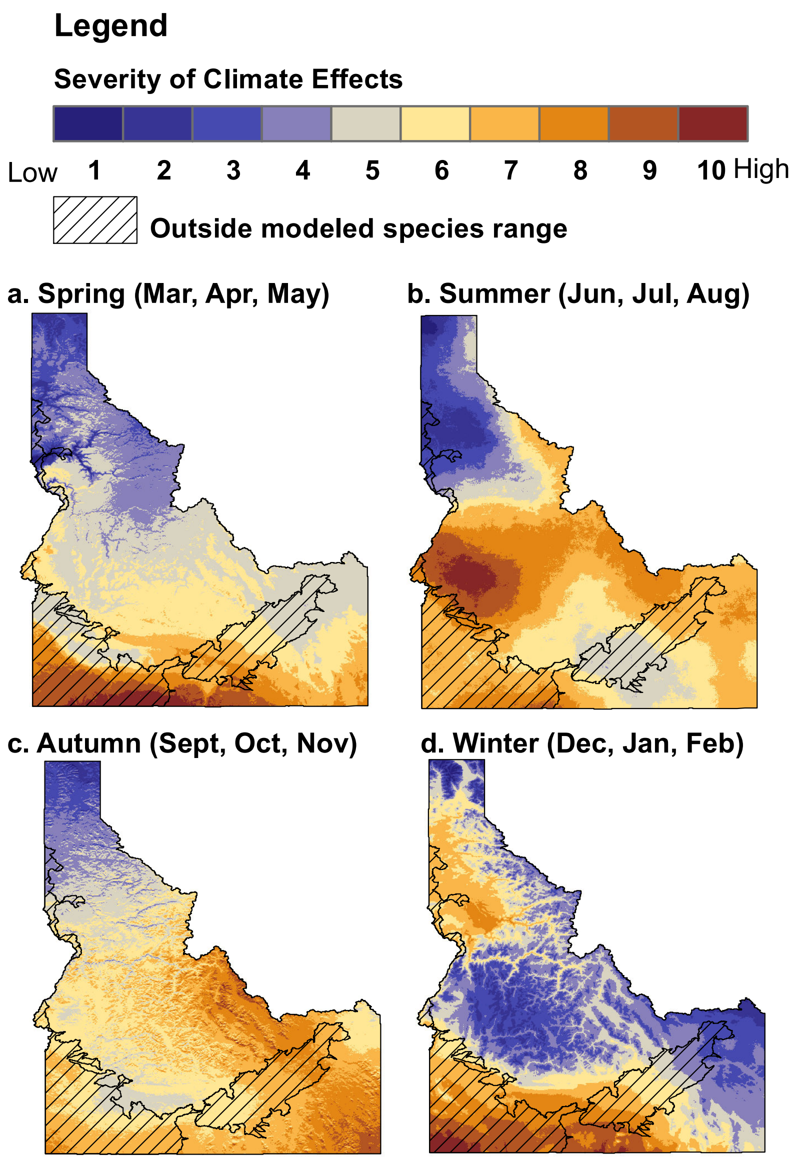
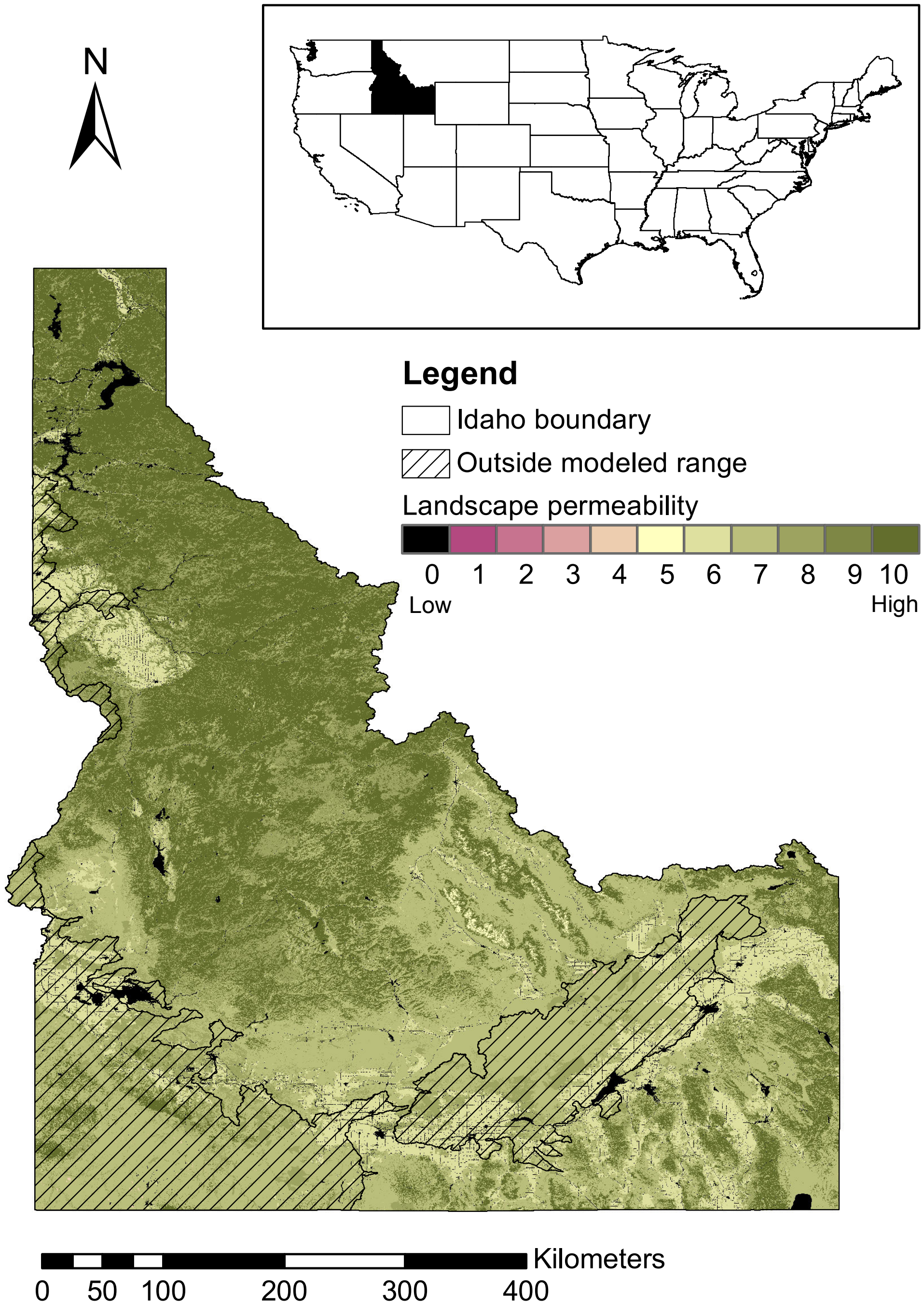


**Figure 3.8** Adaptive capability for wolverine displaying dispersal and landscape permeability from 0 (impermeable) to 10 (highly permeable).



# CHAPTER 4

## CONCLUSIONS

Global anthropogenic climate change is a threat to biodiversity, species and ecosystem persistence and function, and human wellbeing. A better understanding of species' reactions and resilience to changing climate is needed to inform conservation and management efforts that seek to avoid loss of biodiversity and ecosystem function (Williams et al. 2008).

Climate change vulnerability tools and assessments are useful, but contradictory in their estimation of species' vulnerability (Lankford et al. *in press*). Although developed from the same general equation of vulnerability, current assessments show little similarity in their outputs, as discussed in Chapter 2. This conflict of outputs strongly indicates a need for a more precise definition of vulnerability and its inputs. The method of calculating and measuring vulnerability needs to be revisited (Williams et al. 2008). A unified framework will need to provide set definitions and structure, but will also need to be flexible as new data are available concerning species' natural and life history, and climate projects, and as understanding of vulnerability increases in complexity.

Although these tools provide a relative ranking for prioritization, they exhibit several key shortcomings that limit their on-the-ground applicability (Small-Lorenz et al. 2013). As a whole, vulnerability tools and assessments do not explicitly incorporate the seasonal and geographic variability of climate and species' natural history (Small-Lorenz et al. 2013). Chapter 3 presents a framework and set of tools that account for spatially and seasonally dynamic climate projections, as well as seasonal change in use and life history requirements of species. The assessment attempts to view the effects of climate change through a more ecologically minded lens. It also leaves room for incorporation of new and updated information. However, this is a first-step and should be explored further, particularly where species' and community interactions are concerned.

The future of vulnerability assessments rests in the complexity and validation of predictions. Climate affects species and systems through an enormous variety of indirect pathways (Glick et al. 2011). Future iterations of assessments wishing to integrate spatial and temporal characteristics should allow for a wide variety of climate characteristics beyond the typical temperature and precipitation metrics. Key considerations for future research are identifying species' thresholds to direct climate change, understanding the functional relationships between a species and its community and ecosystem, and identifying species that are critical to the persistence of current communities. Validation of results from tools and assessments will be critical (Araujo et al. 2005). Validation efforts have been made for climate models, but have not yet been extended to models of the cascading affects on ecosystems and species. Vulnerability predictions and the climate projections that inform them are typically made for the middle or end of the century making identifying validation data sets difficult. Species related measures may include data on reproductive rates, population density, sink and source population fluctuations, availability of critical resources, and presence-absence data. Just like the development of new vulnerability assessments, validation will need to be flexible and based on the data inputs, the species of consideration, and the goal of the assessment.

Understanding the effects of climate change on wildlife species has important implications for people as well. We do not yet understand how climate change may impact the availability, distribution, and/or consistency of critical ecosystem services such as water filtration, pollination, pest control, nutrient cycling, or the provisioning of resources (Costanza et al. 1997). May ecosystem services are closely tied to climate cycles (Constanza et al. 1997). Shifts in the range of diseases have the potential not only to expand the distribution of human diseases, but also the range of pests and diseases for resources such as forests and domestic animals. Increased intensity and frequency of drought will be harmful to agriculture particularly in areas that rely on rain rather than stored water or irrigation.

While climate change is not the only threat to species, it is likely to be one of the major threats over the next century (Wilcove et al. 1998, Sala et al. 2000, Thomas et al. 2004, Jetz et al. 2007). Changes in land use and land cover will likely have the largest affect on species persistence (Sala et al. 2000), these will also be compounded by the direct and indirect effects of climate change. The effects of global anthropogenic climate change are already apparent around the globe and projected to accelerate (Thomas et al. 2004, Parmesan 2006, Meehl et al. 2007). Both changes in land use and the effects of climate change are likely to result in novel climates and species' assemblages, potentially high extinction rates, and continued shifts in species' ranges and phenological events (Thomas et al. 2004, Sekerciglu et al. 2008, Maclean and Wilson 2011, Bellard et al. 2012). These threats and the shortcomings of current assessments indicate the definitive need for a unified effort to improve vulnerability evaluation and prioritization of species management actions. Working collaboratively toward a unified concept of climate change vulnerability evaluation will be critical for informing management actions across species, communities, landscapes, and ecosystems. Building a better understanding of the relationship between the natural world and climate could dramatically impact our ability to conserve biodiversity and ecosystem functions and services.

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**Appendix A**. Scores and ranks of individual species as assigned by NatureServe Climate Change Vulnerability Index (NSCCVI), Forest Service System for Assessing the Vulnerability of Species (SAVS), and the Climate Change Sensitivity Database (CCSD). Individual case studies listed under each heading.

| Species name | Common name | NSCCVI | SAVS | | CCSD |
|---|---|---|---|---|---|
| | | | Case Studies | Mean | |
| *Accipiter cooperii* | Cooper's hawk | Presumed Stable[a] | 5.2[f] | 5.20 | |
| *Accipiter gentillis* | Northern goshawk | Moderately Vulnerable[a] | 6.8[c]; 2.4[d] | 4.60 | 62 - High |
| *Accipiter striatus* | Sharp-shinned hawk | Presumed Stable[a] | | | 39 - Medium |
| *Aechmophorus occidentalis* | Western grebe | Presumed Stable[a] | | | 62 – High |
| *Agelaius tricolor* | Tricolored blackbird | Presumed Stable[a] | | | 53 – Medium |
| *Amphispiza belli* | Sage sparrow | | | | 44 – Medium |
| *Anas acuta* | Northern pintail | Presumed Stable[a] | | | 58 – High |
| *Antrozous pallidus* | Pallid bat | | 1.3[f] | 1.30 | 65 – High |
| *Aquila chrysaetos* | Golden eagle | Presumed Stable[a] | | | 42 – Medium |
| *Arizona elegans* | Glossy snake | Presumed Stable[a] | 1.4[f] | 1.40 | |
| *Asio flammeus* | Short-eared owl | Presumed Stable[a] | | | 52 – Medium |
| *Athene cunicularia hypugaea* | Western burrowing owl | Presumed Stable[a] | | | 29 - Low |
| *Bassariscus astutus* | Ringtail | Presumed Stable[a] | | | 45 – Medium |
| *Brachylagus idahoensis* | Pygmy rabbit | Extremely Vulnerable[a] | | | 64 – High |
| *Bufo boreas* | Boreal toad | Presumed Stable[a] | | | 91 – Extremely High |
| *Bufo cognatus* | Great Plains toad | Presumed Stable[a] | -0.40[f] | -0.40 | |
| *Buteo regalis* | Ferruginous hawk | Presumed Stable[a] | | | 31 – Medium |

| Species name | Common Name | NCSSVI | SAVS | | CCSD |
|---|---|---|---|---|---|
| | | | Case Studies | Mean | |
| *Buteo swainsoni* | Swainson's hawk | Presumed Stable[a] | | | 32 – Medium |
| *Calidris mauri* | Western sandpiper | Presumed Stable[a] | | | 49 - Medium |
| *Carduelis psaltria* | Lesser goldfinch | | -1.1[f] | -1.10 | 22 – Low |
| *Carpodacus cassinii* | Cassin's finch | Presumed Stable[a] | | | 62 – High |
| *Castor canadensis* | American beaver | Presumed Stable[a] | 5.2[f] | 5.20 | 46 – Medium |
| *Centrocercus urophasianus* | Greater sage-grouse | Highly Vulnerable[a] | | | 59 – High |
| *Cervus elephas* | Elk | | 2.1[f] | 2.10 | 29 – Low |
| *Charadrius alexandrines nivosus* | Western snowy plover | Moderately Vulnerable[a] | | | 76 – High |
| *Coccyzus americanus* | Western yellow-billed cuckoo | Moderately Vulnerable[a] | 8.4[c]; 6.1[d]; 7.6[f] | 7.37 | 37 – Medium |
| *Colaptes chrysoides* | Gilded flicker | Presumed Stable[a] | 0.80[g] | 0.80 | |
| *Contopus cooperi* | Olive-sided flycatcher | Increase Likely[a] | | | 56 – Medium |
| *Corynorhinus townsendii* | Townsend's big-eared bat | Presumed Stable[a] | 5.4[c] | 5.40 | 67 – High |
| *Crotalus atrox* | Western diamondback rattlesnake | Presumed Stable[a] | 0.6[f] | 0.60 | |
| *Cygnus buccinators* | Trumpeter swan | Moderately Vulnerable[a] | | | 57 – Medium |
| *Dendaogapus fuliginosus* | Sooty grouse | Presumed Stable[a] | | | 55 – Medium |
| *Dendaogapus obscurus* | Dusky grouse | Presumed Stable[a] | | | 53 – Medium |
| *Diadophis punctatus* | Ringneck snake | Moderately Vulnerable[a] | | | 37 – Medium |
| *Egretta thula* | Snowy egret | Presumed Stable[a] | | | 67 – High |
| *Elgaria coerulea* | Alligator lizard | Moderately Vulnerable[a] | | | 60 – High |
| *Empidonax traillii* | Willow flycatcher | Presumed Stable[a] | 9.9[d;] 11.5[f] | 10.70 | 36 - Medium |

| Species name | Common name | NSCCVI | SAVS Case Studies | SAVS Mean | CCSD |
|---|---|---|---|---|---|
| *Falco peregrinus* | Peregrine falcon | Presumed Stable[a] | 2.9[c]; 3.5[d]; 4.4[g] | 3.60 | 22 – Low |
| *Gavia immer* | Common loon | Presumed Stable[a] | | | 48 – Medium |
| *Geothlypis trichas* | Common yellowthroat | Presumed Stable[a] | 9.2[f] | 9.20 | |
| *Gopherus agassizii* | Desert tortoise | Presumed Stable[a] | 2.9[d]; 7.0[g] | 4.95 | |
| *Grus canadensis* | Sandhill crane | Presumed Stable[a] | | | 51 – Medium |
| *Gymnorhinus cyanocephalus* | Pinyon jay | Presumed Stable[a] | | | 41 – Medium |
| *Haliaeetus leucocephalus* | Bald eagle | Presumed Stable[a] | 2.4[d] | 2.40 | |
| *Icteria virens* | Yellow-breasted chat | Presumed Stable[a] | | | 51 – Medium |
| *Idionycteris phyllotis* | Allen's big-eared bat | Presumed Stable[a] | 4.4[c] | 4.40 | |
| *Ixobychus exilis hasperis* | Western least bittern | Presumed Stable[a] | | | 45 – Medium |
| *Lanius ludovicianus* | Loggerhead shrike | Presumed Stable[a] | | | 30 – Medium |
| *Lasionicterus noctivagans* | Silver-haired bat | Presumed Stable[a] | | | 27 – Low |
| *Lasiurus blossevillii* | Western red bat | Presumed Stable[a] | 5.2[c] | 5.20 | |
| *Lasiurus cinereus* | Hoary bat | Increase Likely[a] | 5.2[f] | 5.20 | |
| *Lasiurus xanthinus* | Western yellow bat | Presumed Stable[a] | 3.6[c] | 3.60 | |
| *Lepus americanus* | Snowshoe hare | Presumed Stable[a] | | | 36 – Medium |
| *Leucosticte atrata* | Black rosy-finch | Highly Vulnerable[a]; Moderately Vulnerable[b] | | | 59 – High |
| *Macrotus californicus* | California leaf-nosed bat | Presumed Stable[a] | 0.5[g] | 0.50 | |
| *Melanerpes lewis* | Lewis's woodpecker | Presumed Stable[a] | | | 35 – Medium |
| *Mustela frenata* | Long-tailed weasel | Presumed Stable[a] | 1.4[f] | 1.40 | |

| Species name | Common name | NSCCVI | SAVS Case Studies | SAVS Mean | CCSD |
|---|---|---|---|---|---|
| *Myotis lucifugus* | Little brown bat | Increase Likely[a] | | | 61 – High |
| *Myotis thysanodes* | Fringed myotis | Increase Likely[a] | 0.5[f] | 0.50 | |
| *Myotis velifer* | Cave myotis | Presumed Stable[a] | 2.2[d]; 2.2[g] | 2.20 | |
| Notiosorex crawfordii | Crawford's gray shrew | Presumed Stable[a] | -2.8[f] | -2.80 | |
| *Ochotona princeps* | American pika | Moderately Vulnerable[a]; Highly Vulnerable[b] | | | 63 – High |
| *Odocoileus hemionus* | Mule deer | Presumed Stable[a] | 2.1[f] | 2.10 | |
| *Oreortyx pictus* | Mountain quail | Presumed Stable[a] | | | 56 – Medium |
| *Oreoscoptes montanus* | Sage thrasher | Moderately Vulnerable[a] | | | 37 – Medium |
| *Oreothlypis luciae* | Lucy's warbler | Presumed Stable[a] | 4.4[f] | 4.40 | |
| *Otospermophilus variegatus* | Rock squirrel | | -1.9[f] | -1.90 | 20 – Low |
| *Otus flammeolus* | Flammulated owl | Presumed Stable[a] | | | 43 – Medium |
| *Ovis canadensis* | Bighorn sheep | Presumed Stable[a] | 1.3[c]; 4.3[g] | 2.80 | 37 – Medium |
| *Patagioenas fasciata* | Band-tailed pigeon | Presumed Stable[a] | | | 32 – Medium |
| *Pelecanus erythrorhynchos* | American white pelican | Moderately Vulnerable[a] | | | 51 – Medium |
| *Peromyscus truei* | Pinyon mouse | | 3.7[f] | 3.70 | 50 – Medium |
| *Phainopepla nitens* | Phainopepla | Presumed Stable[a] | 4.4[f] | 4.40 | |
| *Picoides albolarbatus* | White-headed woodpecker | Presumed Stable[a] | | | 37 – Medium |
| *Picoides arcticus* | Black-backed woodpecker | Increase Likely[a] | | | 46 - Medium |
| *Picoides dorsalis* | American three-toed woodpecker | Increase Likely[a] | | | 67 – High |
| *Pipilo chlorurus* | Green-tailed towhee | Presumed Stable[a] | | | 57 – Medium |

| Species name | Common name | NSCCVI | SAVS | | CCSD |
|---|---|---|---|---|---|
| | | | Case Studies | Mean | |
| *Plegadis chihi* | White-faced ibis | Presumed Stable[a] | | | 39 – Medium |
| *Rana luteiventris* | Columbia spotted frog | Highly Vulnerable[a] | | | 74 – High |
| *Rana pipiens* | Northern leopard frog | Presumed Stable[a]; Moderately Vulnerable[b] | 8.3[f] | 8.30 | |
| *Riparia riparia* | Bank swallow | Moderately Vulnerable[b] | 2.0[d] | 2.00 | |
| *Sayornis nigricans* | Black phoebe | Increase Likely[a] | 1.2[f] | 1.20 | |
| *Sitta carolinensis* | White-breasted nuthatch | | 6.0[f] | 6.00 | 39 – Medium |
| *Sphyrapicus thyroideus* | Williamson's sapsucker | Presumed Stable[a] | | | 54 – Medium |
| *Spizella breweri* | Brewer's sparrow | Moderately Vulnerable[a] | | | 42 – Medium |
| *Strix occidentalis* | Spotted owl | Moderately Vulnerable[a] | 5.3[d] | 5.30 | 71 – High |
| *Thamnophis sirtalis* | Common garter snake | Presumed Stable[a] | 1.5[f] | 1.50 | |
| *Thomomys bottae* | Pocket gopher | Moderately Vulnerable[a] | 0.6[f] | 0.60 | |
| *Toxostoma lecontei* | Le Conte's thrasher | Presumed Stable[a] | 2.4[g] | 2.40 | |
| *Tympanuchus phasianellus* | Sharp-tailed grouse | Moderately Vulnerable[a] | | | 58 - High |
| *Urocitellus canus* | Merriam's ground squirrel | Presumed Stable[a] | | | 34 – Medium |
| *Urocitellus elegans* | Wyoming ground squirrel | Presumed Stable[a] | | | 47 – Medium |
| *Vulpes macrotis* | Kit fox | Presumed Stable[a] | | | 52 - Medium |

[a] – Young et al. 2009
[b] – Young et al. 2009
[c] – Coe et al. 2012
[d] –Bagne and Finch 2010a
[f] – Finch et al. 2010
[g] – Bagne and Finch 2010a

**Appendix B**. List of species ranked by each pair of vulnerability assessments (NatureServe Climate Change Vulnerability Index [NSCCVI], Forest Service System for Assessing the Vulnerability of Species [SAVS], and Climate Change Sensitivity Database [CCSD]). Lists include species ranked similarly by both assessments and those species ranked differently.

(a) SAVS and CCSD (n = 14)

| **Similar Rank** | | **Different Rank** | | |
|---|---|---|---|---|
| **Species** | **Rank** | **Species** | **SAVS** | **CCSD** |
| Lesser goldfinch | Low | Peregrine | High | Low |
| Rock squirrel | Low | Elk | High | Low |
| American beaver | High | | | |
| Bighorn sheep | High | | | |
| Northern goshawk | High | | | |
| Pallid bat | High | | | |
| Pinyon mouse | High | | | |
| Spotted owl | High | | | |
| Townsend's big-eared bat | High | | | |
| Western yellow-billed cuckoo | High | | | |
| White-breasted nuthatch | High | | | |
| Willow flycatcher | High | | | |

(b) NSCCVI and SAVS (n = 34)

| **Similar Rank** | | **Different Rank** | | |
|---|---|---|---|---|
| **Species** | **Rank** | **Species** | **NSCCVI** | **SAVS** |
| Crawford's gray shrew | Low | Allen's big-eared bat | Low | High |
| Great Plains toad | Low | American beaver | Low | High |
| Bank swallow | High | Bald eagle | Low | High |
| Moderate goshawk | High | Bighorn sheep | Low | High |
| Northern leopard frog | High | Black phoebe | Low | High |
| Pocket gopher | High | California leaf-nosed bat | Low | High |
| Spotted owl | High | Cave myotis | Low | High |
| Western yellow-billed cuckoo | High | Common garter snake | Low | High |
| | | Common yellowthroat | Low | High |
| | | Cooper's hawk | Low | High |
| | | Desert tortoise | Low | High |
| | | Fringed myotis | Low | High |
| | | Gilded flicker | Low | High |
| | | Glossy snake | Low | High |
| | | Hoary bat | Low | High |
| | | LeConte's thrasher | Low | High |
| | | Long tailed weasel | Low | High |
| | | Lucy's warbler | Low | High |
| | | Mule deer | Low | High |
| | | Peregrine falcon | Low | High |
| | | Phainopepla | Low | High |
| | | Townsend's big-eared bat | Low | High |
| | | Western diamondback rattlesnake | Low | High |
| | | Western red bat | Low | High |
| | | Western yellow bat | Low | High |
| | | Willow flycatcher | Low | High |

(c) NSCCVI and CCSD (n = 61)

| **Similar Rank** | | **Different Rank** | | |
|---|---|---|---|---|
| **Species** | **Rank** | **Species** | **NSCCVI** | **CCSD** |
| Silver-haired bat | Low | American beaver | Low | High |
| Western burrowing owl | Low | American three-toed woodpecker | Low | High |
| Peregrine falcon | Low | Band-tailed pigeon | Low | High |
| Alligator lizard | High | Bighorn sheep | Low | High |
| American pika | High | Black-backed woodpecker | Low | High |
| American white pelican | High | Boreal toad | Low | High |
| Black rosy-finch | High | Cassin's finch | Low | High |
| Brewer's sparrow | High | Common loon | Low | High |
| Columbia spotted frog | High | Dusky grouse | Low | High |
| Greater sage-grouse | High | Ferruginous hawk | Low | High |
| Northern goshawk | High | Flammulated owl | Low | High |
| Pygmy rabbit | High | Golden eagle | Low | High |
| Sage sparrow | High | Green-tailed towhee | Low | High |
| Sage thrasher | High | Kit fox | Low | High |
| Sharp-tailed grouse | High | Lewis's woodpecker | Low | High |
| Spotted owl | High | Little brown bat | Low | High |
| Trumpeter swan | High | Loggerhead shrike | Low | High |
| Western snowy plover | High | Merriam's ground squirrel | Low | High |
| Western yellow-billed cuckoo | High | Mountain quail | Low | High |
| | | Northern pintail | Low | High |
| | | Olive-sided flycatcher | Low | High |
| | | Pinyon jay | Low | High |
| | | Ringtail | Low | High |
| | | Sandhill crane | Low | High |
| | | Sharp-shined hawk | Low | High |
| | | Short-eared owl | Low | High |
| | | Silver-haired bat | Low | High |
| | | Snowshoe hare | Low | High |
| | | Snowy egret | Low | High |
| | | Sooty grouse | Low | High |
| | | Swainson's hawk | Low | High |
| | | Townsend's big-eared bat | Low | High |
| | | Tricolored blackbird | Low | High |
| | | Western grebe | Low | High |
| | | Western least bittern | Low | High |
| | | Western sandpiper | Low | High |
| | | White-faced ibis | Low | High |
| | | White-headed woodpecker | Low | High |
| | | Williamson's sapsucker | Low | High |

**Appendix C.** Data inputs used to evaluate the Canada lynx (*Lynx canadensis*), woodland caribou (*Rangifer tarandus*), cliff chipmunk (*Neotamias dorsalis*), lesser goldfinch (*Spinus psaltria*), juniper titmouse (*Baelophus ridgewayi*), and the American three-toed woodpecker (*Picoides dorsalis*)

(a) Input data for the Climate Change Sensitivity Database (CCSD)

| **Data Input** | **Canada Lynx** | **Woodland Caribou** | **Cliff Chipmunk** | **Lesser Goldfinch** | **Juniper Titmouse** | **American Three-toed Woodpecker** |
|---|---|---|---|---|---|---|
| **Generalist/Specialist:** Where does this species fall on the spectrum of generalist to specialist? How specific are these relationships on resources and limiting factors? | 6 – High | 6 – High | 3 – Medium | 2 – Medium-Low | 4 – Medium-High | 5 - High |
| **Physiology:** Ability to tolerate changes in temperature, precipitation, salinity, and CO2 that are higher or lower than the range that the species currently experiences | 3 – Medium | 6 – High | 1 – Low | 1 – Low | 2 – Medium-Low | 2 – Medium-Low |
| **Life History:** Species life history strategy (e.g. r or K strategist) | 5 – High | 6 – High | 4 – Medium-High | 3 – Medium | 5 – High | 4 – Medium-High |
| **Sensitive Habitats:** Specify species dependence upon sensitive habitat types (e.g. seasonal streams, grasslands, alpine, etc.) | 7 – Extremely High | 7 – Extremely High | No Sensitive Habitat | No Sensitive Habitat | No Sensitive Habitat | 7 – Extremely High |

| Data Input | Canada Lynx | Woodland Caribou | Cliff Chipmunk | Lesser Goldfinch | Juniper Titmouse | American Three-toed Woodpecker |
|---|---|---|---|---|---|---|
| **Dispersal ability:** The maximum average distance a species will likely move within 1 year to establish a new population in more suitable habitat, must be feasible. | 1 – Low | 2 – Medium-Low | 5 – High | 2 – Medium-Low | 4 – Medium-High | 3 – Medium |
| **Dispersal barriers:** Degree to which landscape elements prevent this species from moving in response to climate change | 1 – Low | 2 – Medium-Low | 5 – High | 2 – Medium-Low | 4 – Medium-High | 3 – Medium |
| **Disturbance Regime:** collects information on the relationship with different disturbance events | 6 – High | 6 – High | 2 – Medium-Low | 1 – Low | 2 – Medium-Low | 4 – Medium-High |
| **Ecological Relationships: How** sensitive is the species' ecological relationships to the effects of climate change (e.g. forage, hydrology, competition, etc.) | 6 – High | 6 – High | 3 – Medium | 2 – Medium-Low | 3 – Medium | 3 – Medium |
| **Interacting non-climatic stressors:** To what degree do other, non-climatic-related threats to the species make it more sensitive to climate change? | 5 – High | 6 – High | 2 – Medium-Low | 2 – Medium-Low | 3 – Medium | 4 – Medium-High |
| **Other:** Additional factors not addressed by the database | 3 – Medium | | | | | |

**b.** Input data for the NatureServe Climate Change Vulnerability Index

| **Data Input** | **Canada Lynx** | **Woodland Caribou** | **Cliff Chipmunk** | **Lesser Goldfinch** | **Juniper Titmouse** | **American Three-toed Woodpecker** |
|---|---|---|---|---|---|---|
| Temperature: % of species range within defined temperature | 10% 5.1-5.5; 45% 4.5-5.0; 45% 3.9-4.4 | 100% 3.9-4.4 | 30% 5.1-5.5; 40% 4.5-5.0; 30% 3.9-4.4 | 45% >5.5; 45% 5.1-5.5; 10% 4.5-5.0 | 50% >5.5; 50% 5.1-5.5 | 10% 5.1-5.5; 60% 4.5-5.0; 30% 3.9-4.4 |
| Precipitation: % of species range within defined moisture ranges | 90% -0.097; 10% -0.074 | 100% -0.097 | 10% <-0.119; 70% -0.097; 10% -0.074; 10% -0.051 | 15% -0.097; 25% -0.074; 30% -0.051; 30% -0.028 | 10% <-0.119; 30% -0.097; 30% -0.074; 30% -0.051 | 5% <-0.119; 85% -0.097; 10% -0.074 |
| B1*: Exposure to sea level rise | Neutral | Neutral | Neutral | Neutral | Neutral | Neutral |
| B2a: Distribution relative to natural barriers | Neutral | Somewhat Increase | Neutral | Neutral | Neutral | Neutral |
| B2b: Distribution relative to anthropogenic barriers | Neutral | Neutral | Somewhat Increase | Somewhat Increase | Somewhat Increase | Neutral |
| B3: Predicted impact of land use changes resulting from human responses to climate change | Neutral | Neutral | Neutral / Somewhat Decrease | Neutral | Neutral | Somewhat Increase |
| C1: Dispersal and movements | Decrease | Decrease | Neutral | Decrease | Neutral | Decrease |
| C2ai: Predicted sensitivity to temperature: historical thermal niche | Somewhat Increase | Somewhat Increase | Neutral | Neutral | Neutral | Increase |

| Data Input | Canada Lynx | Woodland Caribou | Cliff Chipmunk | Lesser Goldfinch | Juniper Titmouse | American Three-toed Woodpecker |
|---|---|---|---|---|---|---|
| C2bi: Predicted sensitivity to changes in hydrology: historical hydrological niche | Neutral | Somewhat Increase | Somewhat Decrease | Increase | Somewhat Increase | Somewhat Increase |
| C2bii: Predicted sensitivity to changes in hydrology: physiological hydrological niche | Somewhat Increase | Neutral | Somewhat Decrease | Increase | Neutral | Neutral |
| C2c: Dependence on a specific disturbance regime likely to be impacted by climate change | Somewhat Increase | Somewhat Increase | Somewhat Increase | Neutral | Somewhat Increase | Increase |
| C2d: Dependence on ice, ice-edge, or snow-cover habitats | Increase | Somewhat Increase | Neutral | Neutral | Neutral | Neutral |
| C3: Restriction to uncommon geological features or derivatives | Somewhat Decrease | Somewhat Decrease | Decrease | Somewhat Decrease | Neutral | Somewhat Increase |
| C4a: Reliance on interspecific interactions: dependence on other species to generate habitat | Neutral | Somewhat Increase | Neutral | Neutral | Neutral | Neutral |
| C4b: Interspecific interactions: Dietary versatility | Somewhat Increase | Increase | Neutral | Neutral | Neutral | Somewhat Increase |

| **Data Input** | **Canada Lynx** | **Woodland Caribou** | **Cliff Chipmunk** | **Lesser Goldfinch** | **Juniper Titmouse** | **American Three-toed Woodpecker** |
|---|---|---|---|---|---|---|
| C4d: Interspecific interactions: Dependence on other species for propagule dispersal | Neutral | Neutral | Neutral | Neutral | Neutral | Neutral |
| C4e: Interspecific interactions: Forms part of an interspecific interaction not covered by a-e | Neutral | Neutral | Somewhat Increase/ Neutral | | | Neutral |
| C5a: Genetic factors: measured genetic variation | | | | | | |
| C5b: Genetic factors: occurrence of bottlenecks in recent evolutionary history (only if 5a unknown) | Neutral | Somewhat Increase | Neutral | Neutral | Neutral | Somewhat Increase |
| C6: Phenological response to changing seasonal temperature and precipitation dynamics | | | Neutral | | | |
| D1: Documented response to recent climate change | Neutral | Somewhat Increase | Neutral | Neutral | Neutral | Somewhat Increase |
| D2: Modeled future (2050) change in population or range size | | | | | | |

| Data Input | Canada Lynx | Woodland Caribou | Cliff Chipmunk | Lesser Goldfinch | Juniper Titmouse | American Three-toed Woodpecker |
|---|---|---|---|---|---|---|
| D2: Modeled future (2050) change in population or range size | | | | | | |
| D3: Overlap of modeled future (2050) range with current range | | | | | | |
| D4: Occurrence of protected areas in modeled future (2050) distribution | | | | | | |

**c.** Input data for the U.S. Forest Service System for Assessing the Vulnerability of Species

| **Data Input** | **Canada Lynx** | **Woodland Caribou** | **Cliff Chipmunk** | **Lesser Goldfinch** | **Juniper Titmouse** | **American Three-toed Woodpecker** |
|---|---|---|---|---|---|---|
| H1*: Area and distribution - breeding | Vulnerable | Vulnerable | Resilient | Vulnerable | Resilient | Vulnerable |
| H2: Area and distribution - non-breeding | Vulnerable | Vulnerable | Resilient | Neutral | Resilient | Vulnerable |
| H3: Habitat components - breeding | Neutral | Neutral | Neutral | Neutral | Neutral | Neutral |
| H4: Habitat components - non-breeding | Neutral | Vulnerable | Neutral | Neutral | Neutral | Resilient |
| H5: Habitat quality | Vulnerable | Vulnerable | Vulnerable | Vulnerable | Neutral | Vulnerable |
| H6: Ability to colonize new areas | Resilient | Resilient | Vulnerable | Resilient | Vulnerable | Resilient |
| H7: Migratory or transitional habitats | Neutral | Neutral | Neutral | Neutral | Neutral | Neutral |
| PS1: Physiological thresholds | Vulnerable | Vulnerable | Neutral | Neutral | Neutral | Vulnerable |
| PS2: Sex ratio | Neutral | Neutral | Neutral | Neutral | Neutral | Neutral |
| PS3: Exposure to weather-related disturbance | Neutral | Vulnerable | Vulnerable | Vulnerable | Neutral | Resilient |
| PS4: Limitations to daily activity period | Vulnerable | Neutral | Neutral | Vulnerable | Neutral | Neutral |

| Data Input | Canada Lynx | Woodland Caribou | Cliff Chipmunk | Lesser Goldfinch | Juniper Titmouse | American Three-toed Woodpecker |
|---|---|---|---|---|---|---|
| PS5: Survival during resource fluctuation | Resilient | Vulnerable | Vulnerable | Vulnerable | Resilient | Resilient |
| PS6: Energy | Neutral | Neutral | Neutral | Vulnerable | Vulnerable | Neutral |
| PH1: Mismatch potential - cues | Neutral | Neutral | Neutral | Neutral | Neutral | Neutral |
| PH2: Mismatch potential - event timing | Vulnerable | Vulnerable | Vulnerable | Vulnerable | Neutral | Vulnerable |
| PH3: Mismatch potential - proximity | Resilient | Neutral | Neutral | Neutral | Neutral | Resilient |
| PH4: Resilience to timing mismatch | Vulnerable | Vulnerable | Vulnerable | Vulnerable | Vulnerable | Vulnerable |
| B1: Food resources | Vulnerable | Vulnerable | Vulnerable | Vulnerable | Neutral | Resilient |
| B2: Predators | Neutral | Neutral | Neutral | Neutral | Neutral | Neutral |
| B3: Symbionts | Neutral | Neutral | Neutral | Neutral | Neutral | Neutral |
| B4: Disease | Vulnerable | Vulnerable | Neutral | Neutral | Neutral | Vulnerable |
| B5: Competitors | Resilient | Vulnerable | Neutral | Neutral | Neutral | Vulnerable |

* Prefixes refer to question number within respective assessment