Guidelines for Using the NatureServe Climate Change Vulnerability Index Release 3.0 - Canada

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Release 3.0 - Canada – *31 January 2016*

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OVERVIEW

Motivated by the need for a means to rapidly assess the vulnerability of species to climate change, NatureServe developed a Climate Change Vulnerability Index. The Index uses a scoring system that integrates a species' predicted exposure to climate change within an assessment area and three sets of factors associated with climate change sensitivity, each supported by published studies: 1) indirect exposure to climate change, 2) species-specific sensitivity and adaptive capacity factors (including dispersal ability, temperature and precipitation sensitivity, physical habitat specificity, interspecific interactions, and genetic factors), and 3) documented response to climate change. Assessing species with this Index facilitates grouping unrelated taxa by their relative risk to climate change as well as identifying patterns of climate stressors that affect multiple taxa. Our primary goal for the Index is to provide valuable input for key planning documents, such as revisions of state wildlife action plans, to allow consideration of change impacts together with other stressors. Further, we hope that this tool will help land managers develop and prioritize strategies for climate change adaptation that lead to actions that increase the resilience of species to climate change. This document explains the Index, how to use it, and how to interpret the results, and is derived from the guidelines for using the United States version of the Index (Young et al. 2015a).

Box 1. Key characteristics of the Index

* Programmed in a Microsoft Excel workbook
* Flexible for use with either suggested downscaled climate predictions or those preferred by users
* Requires knowledge about current distribution and natural history of the species being assessed
* Predicts whether a species will decline or remain stable within an assessment area
* Identifies key factors associated with climate vulnerability for assessed species
* Complementary to NatureServe Conservation Status Ranks

INTRODUCTION

Need Addressed.— Although scientists have been concerned about climate change for decades, most decision makers have only recently recognized the extent to which changes in climate, and human responses to these changes, pose a threat to species of concern. The consequences of ongoing climate change are becoming readily observable, not just to scientists monitoring the decline of the arctic ice pack but also to citizens who notice cherry trees regularly blooming and birds regularly migrating earlier than before. As a result, managers are increasingly being asked which of the species on the lands they manage are most vulnerable to climate change. The answer is difficult in part because assessing exposure to climatic factors is complex, and also because species respond differently to changes. Also, assessing climate change vulnerability is a rapidly developing field of inquiry. The results do not always filter rapidly to field conservationists, creating the need for a tool that translates research findings into useful guidelines for managers.

In most cases, managers will not be able to tailor actions to individual species due to the large number of species for which they have responsibility, and constraints on conservation resources. To handle the complexity posed by this problem, managers need a way to group species based on similar drivers of vulnerability, and a way to flag species for which specific management actions could promote greater resilience to ongoing changes in climate. Tools to help organize and prioritize species in this manner should help increase the efficiency of planning for climate change adaptation and may help target species for which more in-depth work is warranted.

Maintaining vulnerable species that are likely to respond to changes in climate by shifting distributions over significant distances represents an additional challenge, as it requires coordination across state or other jurisdictional boundaries. Having a tool that can be applied in a consistent way by management teams from neighboring areas (especially those oriented in a north-south manner) would help promote coordination of management efforts and adaptation strategy development.

To address these needs, NatureServe has developed the Climate Change Vulnerability Index. This Microsoft Excel-based tool facilitates a fairly rapid assessment of the vulnerability of a plant, animal, or lichen to climate change in a defined geographic area. Because it can be applied to numerous species over a short period of time, the Index can assist in the assessment of climate change vulnerability of a fauna or flora in a state, national park, wildlife refuge, or other region. The Index indicates both relative vulnerability and the relative importance of factors contributing to that vulnerability.

Relationship to NatureServe Conservation Status Rank.—The Index is designed to work in concert with and not replace the time-tested NatureServe conservation status ranks (such as G-ranks and S-ranks; Master et al. 2009). Some factors such as population size, range size, and demographic factors influence both conservation status and vulnerability to climate change (Ohlemüller et al. 2008, Lawler et al. 2009). To avoid duplicating these factors, the NatureServe Climate Change Vulnerability Index does not consider them. Conservation status ranks should therefore be used in concert with Index output to aid in the interpretation of the results (see *Using Vulnerability Index Results to Inform a Conservation Status Assessment*, below).

Target Audience.— The NatureServe Climate Change Vulnerability Index is designed for use by scientists in government, academic, or non-profit natural resources management agencies or departments, or large private landowning entities such as timber companies to assess vulnerability of terrestrial or aquatic plant, animal, and lichen species. The Index has proven to be particularly useful as part of a larger strategy to revise wildlife action plans in the United States to address climate change (Young et al. 2015b). Because the Index uses information on key life history parameters as indicators of likely sensitivity to changes in climate, users should be familiar with the species being assessed. Although a non-specialist can successfully apply the Index, doing so will take additional time due to the amount of research required prior to evaluating the factors. In many cases, a team of scientists, each applying the Index to species in their specialty, would be most efficient.

Approaches to Vulnerability Assessment.—Using species' traits to assess vulnerability to climate change is just one approach to understanding how climate change may influence biodiversity in a particular region (Pacifici et al. 2015). Researchers have developed a number of different approaches to vulnerability assessment in response to increased calls for this information by decision makers. Managers tasked with this job should carefully consider both the NatureServe Climate Change Vulnerability Index and other options in the context of their particular objectives, geographic scale, and resources available. The NatureServe Climate Change Vulnerability Index is particularly useful for addressing questions about which of a list of species are most vulnerable to climate change. However, there are a growing number of alternative approaches available. For more information and case studies highlighting many alternatives, see Glick et al. (2011) and Pacifici et al. (2015). An alternative approach is through spatial analyses such as used in a decision support tool (i.e., NatureServe Vista, www.natureserve.org/vista). A useful new guide to "climate-smart" conservation places vulnerability assessments into the context of the full adaptation planning management cycle (Stein et al. 2014).

Notes on Release 3.0.—Release 3.0 of the Canada version accomplishes two goals. First it updates the previous Canada version, 2.01, and second, it incorporates the changes and enhanced functionality of Release 3.0 of the U.S. version that was released in April 2015. This release includes more examples of plant and animal species occurring in Canada to aid interpretation of the criteria for Canadian users. It makes specific reference to permafrost. This release also incorporates all new climate data, derived from the IPCC's Fifth Assessment Report (IPCC 2013), in both the climate exposure section and the sensitivity sections that address historical exposure to climate variation.

Release 3.0 of the U.S. version incorporates several changes to address users' comments on Release 2.1 (summarized in Young et al. 2015). Major updates include greater guidance for assessing plants, including a new factor that considers plant reproductive systems; a means to assess climate impact on the range of migratory species when they are not present within the assessment area; and elimination of the Decrease Vulnerability categories from all factors and the Increase Likely overall score because increases are hard to predict, especially in the context of a fixed assessment area. (A species may increase, but not within the assessment area.) We modified factors C2bii (Physiological hydrological niche), C3 (Restriction to uncommon landscape/geological features or derivatives), C4a (now called Dependence on other species to generate required habitat), and C4d (Dietary versatility) to increase clarity in their application. We added two interspecific factors, C4e (Sensitivity to pathogens or natural enemies) and C4f (Sensitivity to competition from native or non-native species). When an assessment includes information on section D factors, the results from sections B-C are weighted more heavily in determining the overall vulnerability score (previously the sections were weighted equally). Finally, the algorithm for the Index now has a rule that automatically classifies a species as Extremely Vulnerable if its exposure to sea level rise greatly increases vulnerability, it has strong barriers to dispersal, and it is a poor disperser.

In addition, this version allows for the input and storage of textual comments to document scoring for each factor in sections B, C, and D. To facilitate conversion of existing Release 2.1 assessments to Release 3.0, the new version has an Import worksheet where Release 2.1 assessments can be pasted and then uploaded into the Calculator worksheet.

Although a new global climate assessment has been released by the Intergovernmental Panel on Climate Change since Release 2.1 (IPCC 2013), downscaled climate projections are not yet widely available. Therefore, Release 3.0 continues using projections from the previous assessment (IPCC 2007). The mid-century projections do not vary too much between the two assessments, so using the older projections should not have a major effect on results.

Notes on Release 2.1.—Release 2.1 of the U.S. version represents a minor update to Release 2.0. The principle new feature is a mechanism to revise previously completed assessments. A new button on the upper left of the Results Table will populate the Calculator with the data from the selected assessment in the Results Table. The user can then modify the information in the Calculator and recopy the data to the Results Table. Other changes include formatting improvements in the Assessment Notes box, a color key to the Results Table, and a minor correction of the Monte Carlo calculation for Not Vulnerable/Increase Likely species. Release 2.1 uses Excel 2007 instead of 2003, resulting in a much smaller file. The Index calculations, factors, and criteria remain unchanged from Release 2.0. Users of previous versions can copy their previous data into the Results Table of Release 2.1 and thereafter continue using Release 2.1. Finally, this edition of the guidelines document includes a new appendix for quantitative GIS assessment of factors A, C2ai, and C2bi.

Notes on Release 2.01.—Release 2.01 was the first Canadian version and was based on Release 2.0 of the U.S. version. Release 2.0 represented an evolution of our thinking on vulnerability assessments rather than a radical departure from previous versions. Many of these modifications were responses to feedback from these users. The most significant change was the substitution of a moisture index for precipitation predictions in Section A, Exposure to Local Climate Change. Because increasing temperatures cause more evaporation, an area receiving an increase of precipitation can still have a net loss of moisture available to natural communities. The moisture index reflects conditions for plants and animals better than simple changes in precipitation.

Other changes included a unification of the concept of barriers, whether they are anthropogenic or natural, leading to the grouping of former factors B2 and B3 into factors B2a and B2b. The focus now is not solely on whether potential barriers exist, but whether they actually serve to prevent dispersal by the species being assessed. In addition, we reworked factor C1 to include all aspects of dispersal and movements. We eliminated a factor for migration because most of that concept is contained in factor C1. We renamed the C2 factors in a more descriptive fashion, and modified the criteria somewhat, including reference to the moisture metric for factor 2bii, physiological hydrological niche. We further defined factor C3, emphasizing the connection with geological features or their derivatives (such as rare soil types or stream chemistry). Finally, we renamed factor C4e to expand the concept to all interspecific interactions, not just mutualisms.

We made a concerted attempt to accommodate aquatic species by including more explicit instructions for scoring these species. Also, we added a check-off box for cave obligate and groundwater species to account for the buffering of local climates these habitats confer to their inhabitants. For all factors, we added more examples to aid in the interpretation of the criteria.

HOW THE INDEX WORKS

In accordance with well-established practices (Schneider et al. 2007, Williams et al. 2008), the Index divides vulnerability into three components, the **exposure** to climate change across the range of the species within the assessment area, the **sensitivity** of the species to climate change, and the **adaptive capacity** of the species to withstand environmental changes. A highly sensitive species will not suffer if the climate where it occurs remains stable. An insensitive species will not decline even when experiencing significant changes in temperature and/or precipitation. A species with good adaptive capacity is more likely to change behaviorally or genetically to accommodate new climates than one with poor adaptive capacity. In addition, the Index considers the results of studies documenting or modeling vulnerability to climate change if research of this nature has been conducted on the species.

Exposure to climate change is measured by examining the magnitude of projected temperature and moisture change across the range of the species within the assessment area. The Index accounts for both changes in mean annual temperature and annual climate moisture deficit. Climate moisture deficit is derived from the sum of the monthly difference between atmospheric evaporative demand and precipitation and is used as an indicator of drought (Wang et al. 2012). Climate moisture deficit is a measure of drying as it effects vegetation, and is more meaningful for biodiversity than precipitation because it accounts for the fact that increasing temperatures promote higher rates of evaporation and evapotranspiration. For example, many habitats are projected to experience net drying during the next 50 years, even in areas where precipitation is projected to increase (Brooks 2009).

In the Index, sensitivity is assessed by scoring species against 23 factors divided into two categories, indirect exposure to climate change and species-specific sensitivity and adaptive capacity. For each factor, species are scored on a sliding scale from greatly increasing to having no effect on vulnerability. More than one category can be scored for a particular factor when there is uncertainty. Responses are not required for all factors. The index will calculate a score with as few as 13 responses, although we recommend estimating as many factors as possible, even if more than one category is selected for factors associated with sparse data or high uncertainty.

The Index combines information on exposure and sensitivity to produce a numerical sum. The sum is then converted into a categorical score by comparing it to threshold values. The six possible scores are Extremely Vulnerable, Highly Vulnerable, Moderately Vulnerable, Less Vulnerable, and Insufficient Evidence. Separately, the Index calculates a numerical sum and corresponding categorical score for four factors relating to documented or modeled response to climate change if any of these factors are scored. The final Index score represents just the exposure/sensitivity/adaptive capacity result if there is no information on documented/modeled responses, and a combination of the two sections (weighing the exposure/sensitivity/adaptive capacity result more heavily) if documented/modeled response information is available. See Young et al. (2012) for more details on the scoring mechanics.

Due to the scoring mechanism that allows factors to be skipped when information is lacking, leaving a factor as “unknown” has the same effect on the overall vulnerability score as assigning a factor as “neutral” as long as the minimum number of factors are scored. The Index is therefore slightly more likely to assign a more vulnerable overall score to species for which more factors are assessed.

*Relation between Exposure and Sensitivity/Adaptive Capacity.—*The Index treats exposure to climate change as a modifier of sensitivity and adaptive capacity. If the climate in a given assessment area will not change much, none of the sensitivity/adaptive capacity factors will weigh heavily, and a species is likely to score at the Not Vulnerable end of the range. A large change in temperature or moisture availability will amplify the effect of any related sensitivity/adaptive capacity factor, and will contribute to a score reflecting higher vulnerability to climate change. In most cases, changes in temperature and moisture availability will combine to modify sensitivity and adaptive capacity factors. However, for factors such as sensitivity to temperature change (factor 2a) or precipitation/moisture regime (2b), only the specified climate driver will have a modifying effect.

Two factors related to indirect exposure to climate change, exposure to sea level rise and predicted impact of land use changes resulting from human responses to climate change, are not weighted by the exposure measures in the Index. The magnitude of sea level rise within an assessment area will reflect global rather than local changes. Similarly, land use changes such as the siting of wind towers or the cultivation of crops for biofuel are meant to mitigate global climate change, and the extent to which these activities take place are not expected to be correlated with local climate change.

Figure 1 depicts the relationship between the two climate exposure measures (temperature and moisture) and the sensitivity factors.

*Time and Geographic Scale.—*The Index contemplates vulnerability to climate change by the mid-20^{th} century, a typical cut-off date for predictions made in the Intergovernmental Panel on Climate Change reports (e.g., IPCC 2007).

The Index works best for assessment areas on the scale from the size of a national park or wildlife refuge to a state. It could be used for a regional analysis in the case of several eastern states, but use for more than one or a few western states may mask the vulnerability of local populations to climate change. As the size and topographic complexity of the assessment areas increases, the potential increases for isolated populations to differ in their exposure and vulnerability. Wide-ranging species with isolated populations can be assessed separately by population. Alternatively, differences in vulnerability can be accommodated by scoring a range of categories per factor, although doing so will decrease the confidence in the overall vulnerability score.

In very small assessment areas, most species will occur across the entire area. Climate predictions will not vary appreciably, so the climate exposure factor will be virtually identical for every species assessed. Similarity in exposure suggests that Index scores will show less variance when compared to scores for areas where projections and distribution patterns are more variable. Another issue to consider when determining assessment area is that errors associated with downscaled climate data tend to increase as the scale of assessment is decreased.

The current release of the Index is tailored for use in all of Canada. Use elsewhere may require modification of specific factors and exposure categories. Recognizing the need for Indices that work elsewhere, NatureServe has created versions for the U.S. and the tropical Andes in South America (see www.natureserve.org/ccvi).

Factors Considered.—Here is a brief justification for the factors considered in the Index. Each factor is associated with vulnerability to climate change in the published literature.

Indirect Exposure to Climate Change

1) *Exposure to sea level rise.* Predictions of 0.8-2.0 meter increase in sea level this century suggest that species occurring in coastal zones, low-lying islands, and coral reefs will be subject to rapid loss of habitat and vulnerable to associated storm surge (IPCC 2007, Pfeffer et al. 2008).

2) *Distribution relative to natural and anthropogenic barriers*. The geographical features of the landscape where a species occurs may naturally restrict it from dispersing to inhabit new areas (IPCC 2002, Midgley et al. 2003, Simmons et al. 2004, Koerner 2005, Thuiller et al. 2005, Jiguet et al. 2007, Benito Garzón et al. 2008, Hawkins et al. 2008, Loarie et al. 2008, Lenoir et al. 2008, Price 2008). Similarly, dispersal may be hindered by intervening anthropogenically altered landscapes such as urban or agricultural areas for terrestrial species or dams and culverts for aquatic species (Parmesan 1996).

3) *Predicted impact of land use changes resulting from human responses to climate change*. Strategies designed to mitigate greenhouse gases, such as creating large wind farms, plowing new cropland for biofuel production, or planting trees as carbon sinks, have the potential to affect large tracts of land and the species that use these areas in both positive and negative ways (Johnson et al. 2003).

Sensitivity and Adaptive Capacity

1) *Dispersal and movements*. Species with poor dispersal abilities may not be able to track fast-moving, favorable climates (Dyer 1995, Midgley et al. 2003, Williams et al. 2005, Jiguet et al. 2007).

2) *Predicted sensitivity to temperature and moisture changes*. Species requiring specific moisture and temperature regimes may be less likely to find similar areas as climates change and previously-associated temperature and precipitation patterns uncouple (Saetersdal and Birks 1997, Thomas 2005, Thuiller et al. 2005, Gran Canaria Declaration 2006, Hawkins et al. 2008, Laidre et al. 2008).

a) Predicted sensitivity to changes in temperature.

b) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime.

c) Dependence on a specific disturbance regime likely to be impacted by climate change. Species dependent on habitats such as prairies, longleaf pine forests, and riparian corridors that are maintained by regular disturbances (e.g., fires or flooding) are vulnerable to changes in the frequency and intensity of these disturbances caused by climate change (IPCC 2007, Archer and Predick 2008).

d) Dependence on ice, ice-edge, permafrost, or snow-cover habitats. The extent of oceanic ice sheets and mountain snow fields are decreasing as temperatures increase, imperiling species dependent on these habitats (Stirling and Parkinson 2006, IPCC 2007, Laidre et al. 2008).

3) *Restriction to uncommon geological features or derivatives*. Species requiring specific substrates, soils, or physical features such as caves, cliffs, or sand dunes may become vulnerable to climate change if their favored climate conditions shift to areas without these physical elements (Hawkins et al. 2008).

4) *Interspecific interactions*. Because species will react idiosyncratically to climate change, those with tight relationships with other species may be threatened (Bruno et al. 2003, Hampe 2004, Simmons et al. 2004, Hawkins et al. 2008, Laidre et al. 2008).

a) Dependence on other species to generate habitat.

b) Dietary versatility (animals only).

c) Pollinator versatility (plants only).

d) Dependence on other species for propagule dispersal.

e) Sensitivity to pathogens or natural enemies

f) Sensitivity to competition from native or non-native species

g) Forms part of an interspecific interaction not covered by 4a-d.

5) *Genetic factors*. A species' ability to evolve adaptations to environmental conditions brought about by climate change is largely dependent on its existing genetic variation (Huntley 2005, Aitken et al. 2008, Jones et al. 2013).

a) Measured genetic variation.

b) Occurrence of bottlenecks in recent evolutionary history.

c) Reproductive system (plants only)

6) *Phenological response to changing seasonal temperature and precipitation dynamics*. Recent research suggests that some phylogenetic groups are declining due to lack of response to changing annual temperature dynamics (e.g., earlier onset of spring, longer growing season), including European bird species that have not advanced their migration times (Møller et al. 2008), and some temperate zone plants that are not moving their flowering times (Willis et al. 2008).

Documented or Modeled Response to Climate Change

1) *Documented response to recent climate change.* Although conclusively linking species declines to climate change is difficult (Parmesan 2006), convincing evidence relating declines to recent climate patterns has begun to accumulate in a variety of species groups (Parmesan 1996, Parmesan and Yohe 2003, Root et al. 2003, Enquist and Gori 2008). This criterion incorporates the results of these studies when available into the calculation of the Index.

2) *Modeled future change in range or population size.* The change in area of the predicted future range relative to the current range is a useful indicator of vulnerability to climate change (Midgley et al. 2003, Thomas et al. 2004).

3) *Overlap of modeled future range with current range*. A spatially disjunct predicted future range indicates that the species will need to disperse in order to occupy the newly favored area, and geographical barriers or slow dispersal rates could prevent the species from getting there (Peterson et al. 2002, Schwartz et al. 2006).

4) *Occurrence of protected areas in modeled future distribution*. For many species, future ranges may fall entirely outside of protected areas and therefore compromise their long-term viability (Williams et al. 2005).

Factors not Considered.—The Index development team took care not to include factors that are already considered in conservation status assessments. These factors include population size, range size, and demographic factors. The goal is for the NatureServe Climate Change Vulnerability Index to complement NatureServe Conservation Status Ranks and not to partially duplicate factors. Ideally, Index values and status ranks should be used in concert as described below under Interpreting Results.

Factor B3, predicted impact of land use changes resulting from human responses to climate change, arguably overlaps with the short-term threat factor for NatureServe conservation status ranks. However, the majority of species currently ranked for conservation status has not yet been reviewed in light of this emerging threat. As the conservation status of more species are reassessed with an eye toward the threat of alternative energy development, this factor may need to be removed.

Confidence in Vulnerability Index Score.—The Index calculates a measure of confidence in the vulnerability index score, or how much uncertainty in how species are coded for particular factors may influence the vulnerability category calculated. For example, a species with an overall vulnerability score of Highly Vulnerability may be near the threshold for Moderately Vulnerable. If several factors were scored in multiple categories, then the confidence in the vulnerability index score might be low because of the possibility that the species may be Moderately rather than Highly Vulnerable. In these cases, a Monte Carlo simulation (provided at the bottom of the Calculator page of the Index) will show that both scores are possible with the data entered.

PREPARING TO USE THE INDEX: PLANNING FOR PROJECT SUCCESS

The Index has now been used in dozens of projects throughout the United States and Canada. Feedback from the user community has led to a list of "best practices" for carrying out a climate change vulnerability assessment. Following these practices will help to ensure a successful project and increase the likelihood that the results influence management decisions about the species assessed. A brief summary of these considerations follows.

a) **Involve diverse stakeholders**. Identify the stakeholders that may be affected by the results of your assessment or that should be influenced by your results, and engage them early in the project. Doing so will prevent them from being caught off guard when results are released, especially if the results are unpopular for a particular audience. Listening to their input early in the planning stages of the project and making modifications if necessary can increase the chances that the results will be fully considered by agencies charged with managing the species assessed.
b) **Work with multiple sectors**. Interacting with other sectors including private industry, academics, indigenous groups, nonprofits, and government agencies can yield unexpected benefits such as the identification of valuable data sets and informational resources, additional uses for your results, and broader awareness about the need for climate change vulnerability assessments.
a) **Build capacity**. Having a training session with all scientists involved in the assessment process can help build repeatability in how the criteria are interpreted. It often helps to have written conventions on how specific aspects of the species assessed will be handled in scoring particular factors. Also, the more stakeholders understand about climate change and conservation, the more accurately vulnerability assessment results will be interpreted and used.
b) **Understand the limits of assessments**. The Index uses a trait-based approach to rapidly address vulnerability to climate change. This approach does not, for example, produce spatially explicit results (unless geographically distinct populations are assessed separately). Other in-depth techniques such as bioclimatic modeling are better suited to providing a spatially explicit result. Also, the Index does not directly address population dynamics; demographic models would be a better choice if population-level information are an objective.
c) **Tailor communication to different audiences**. A detailed written report of vulnerability assessment results may not be the best way to communicate results to all audiences. A single-page briefing paper with the high-level results might be better for a policy-maker, whereas a presentation using lay terms may be better for a non-scientist audience. Sometimes publishing the results in a peer-reviewed

journal may be required for certain decision-makers to be able to act on your results.

d) **Budget and schedule for communication and outreach**. Your outreach will be more likely to succeed if you have an identified budget and time in your project schedule for these activities.
e) **Integrate consideration for climate change into existing planning cycles and processes**. Connecting with existing management processes will generally be more sustainable for incorporating vulnerability assessment results into management actions than creating a new, stand-alone method.

PREPARING TO USE THE INDEX: GATHERING INFORMATION

Assessment Area and Species Distribution Data.—The first step is to define the geographical area to be assessed, whether it be a state, protected area, or some other geographical unit. Next, you will need to know the distribution within the assessment area of the species to be assessed. Some common sources of species distribution maps include NatureServe Explorer (http://www.natureserve.org/explorer/) and the Flora of North America (http://www.efloras.org/flora_page.aspx?flora_id=1). Distribution maps can also be developed using occurrence data available from specimen and observation databases such as GBIF (http://www.gbif.org) and BISON (http://http://bison.usgs.ornl.gov). For rare species, state natural heritage program data on locations of populations ("element occurrences") will be useful. Fine scale distribution maps, such as those derived from element occurrence data, are especially useful in regions with high elevational relief. Element occurrence data can be requested directly from state heritage programs (see directory at http://www.natureserve.org/natureserve-network/directory) or, thorough NatureServe if the request covers multiple states (http://www.natureserve.org/conservation-tools/custom-data-services).

Species-specific Sensitivity or Life History Data.—To complete the Index, you will need information about dispersal and movement ability, temperature/precipitation regime, dependence on disturbance events, relationship with ice or snow-cover habitats, physical specificity to geological features or their derivatives, interactions with other species including diet and pollinator specificity, genetic variation, and phenological response to changing seasons. Recognizing that some of this information is unknown for many species, the Index is designed such that only 10 of the 19 sensitivity factors require input in order to obtain an overall Index score. Sources of this information include NatureServe Explorer (http://www.natureserve.org/explorer), Fire Effects Information (http://www.fs.fed.us/database/feis/plants/index.html), and the published literature.

Data on Exposure to Climate Change.—Most predictions about future climates are made with global circulation models. These models involve so many calculations that they typically run on supercomputers. To keep computational time reasonable, the models often consider climate interactions within large cells on the order of one degree of latitude and longitude. Predictions are made at the same scale as the computations. While very useful for understanding global patterns of climate change, this scale is not helpful when trying to understand fine-scale variation in climate change across a state. Scientists use sophisticated models incorporating the effects of elevational relief, oceanic influence, and other factors on climate to produce "downscaled" projections at scales as fine as 1 km^2 or even finer.

To facilitate use of the Index, we have provided climate data in the format required for the Exposure section (available at http://www.natureserve.org/ccvi). Data for projected future changes across Canada are based on downscaled forecasts from the Climate North America dataset at 1km resolution (AdaptWest 2015, Hamann et al. 2013). This dataset uses the Parameter Regression of Independent Slopes Model (PRISM) interpolation method for current climate for British Columbia, Yukon, and the Prairie Provinces in Canada. The rest of Canada was filled out with climate data using the ANUSPLIN method to interpolate weather station data. Future climate is an ensemble of 15 general circulation models (GCMs) from the Coupled Model Intercomparison Project phase 5 (CMIP5) based on the IPCC 5th Assessment Report (IPCC 2013) using the mid-century projection (2041-2070, referred to as the 2050s) and one emission scenario (representative conservation pathway [RCP] 4.5). Future time periods are downscaled to the reference period (1961-1990) to 1km resolution using a delta approach by adding anomalies from original future GCM outputs (difference between a GCM's projected future and it's 20th century reanalysis) to the baseline data (Wang et al. 2012).

To fill in the values required in Section A, you can download the relevant climate data to use in a desktop GIS and calculate exposure variables following the instructions in Appendix 3. For a "quick and dirty" preliminary assessment, you can visualize the range of the species under evaluation on the map of climate projections for your assessment area using the mapped climate data appearing in Figures 2-6. Obviously your results will have greater precision if you download the data and overlay distribution maps of the species you will evaluate.

The climate data that we provide use an "ensemble" of climate predictions that represent essentially a median of 16 major global circulation models (GCMs). Each GCM has its own strengths and weaknesses. If you know that one model works particularly well in your assessment area, then by all means use that model instead of the ensemble model. Historically, we have suggested the "middle of the road" scenario (A1B, in the IPCC fourth assessment scheme or RCP 4.5 in the terminology of the fifth assessment). Actual emissions, however, have tracked more extreme scenarios. Assessors can choose either one, but they should be aware that the differences in predictions from the two scenarios for the mid-21st century are not very different in most areas.

APPLYING THE INDEX

After gathering the necessary data, you are ready to begin filling out the information needed to calculate an Index value on the Calculator worksheet of the Excel workbook. The Calculator is divided into a section for preliminary information, four lettered sections (A-D), and a section for displaying the Index score and confidence values. Four worksheets (A. Climate Exposure, B. Climate-Indirect, C. Sens & AC, and D. Docum) provide guidance for completing each corresponding section of the Calculator. The same guidance is reproduced here for convenience, together with additional information to help interpret the criteria.

Preliminary Information.—When opening the Excel workbook, be sure to enable macros (if asked) for proper functioning. Fill out the header information for the geographic area assessed, assessor, species name, English name, major taxonomic group, relation of species range to assessment area, G- and S-ranks, and whether the species is a cave or groundwater obligate. Because some factors are specific to either plants or animals (note lichens are treated as plants except for the pollination factor), the box for major taxonomic group must be completed for Index calculations to perform accurately.

Assessment Notes.—The Assessment Notes box allows you to enter details about the methods used (for example, whether Climate Wizard Data were analyzed in a GIS or by on-screen visualization) and information resources consulted to complete the Index for the species under consideration. Note that clicking in the Comments box next to each factor allows you to enter and store comments specific to how you scored each factor.

Completing Sections A-D.—In Section A, you will indicate the magnitude of climate change predicted to occur across the range of the species within the assessment area. For Sections B-D, you will score species according to how each factor increases or does not affect vulnerability to climate change. Note that more than one box can be checked to indicate a range of values, either as an indication of uncertainty or as a way to include differing responses in different parts of the species' range within the assessment area. No more than three boxes should be checked for any one factor. Pay attention to the minimum number of factors required for each section of the Index, as an overall score will not be calculated until all required fields and minimum numbers of factors in sections B and C are scored.

Scoring indirect effects of climate change.—Indirect effects of climate change occur when a separate species or phenomenon is affected by climate change and subsequently influences a focal species. For example, climate change may favor the spread of a disease to a previously unoccupied region, negatively influencing a species that occurs there. Climate change may also influence human land use decisions, which in turn can negatively or positively affect populations of some species. Many cases of indirect effects are covered by Index factors such as B3 (impact of land use changes resulting from human responses to climate change) or C4 (interspecific interactions). Most other cases of indirect effects are not scored unless there is good evidence of the phenomenon taking place. The following examples should help to determine whether and how to score indirect effects.

Example 1: It is thought that a predator of a pollinator is likely to become more abundant due to climate change but there is no evidence of it actually happening. The specificity of pollinator to the plant is assessed under C4c (pollinator versatility) but the predator-prey relationship should not be considered in the assessment.

Example 2: A lichen is host specific to one or a few species of trees which show a strong affinity for a specific geological substrate. The host specificity of the lichen should be scored under C4a (dependence on other species to generate habitat) but the host's specificity for a particular soil type should not be assessed (such as under C3, restriction to uncommon landscape/geological features or derivatives).

Example 3: A species is negatively impacted by an invasive grass and is sensitive to fires that are increasing due climate change. Fire is also increasing the spread of the invasive grass. The species is scored for two stressors: factors C2c (dependence on a specific disturbance regime likely to be impacted by climate change) for the fire sensitivity and C4f (sensitivity to competition from native or non-native species) for sensitivity to competition from the invasive grass which is becoming more abundant due to climate-change induced increases in fire frequency.

Avoiding double counting.—The guidelines for each factor explain how to score species with different characteristics, but there will inevitably be situations that are not clearly addressed in the guidelines. In these cases you should use judgment to assess how the particular characteristic influences vulnerability to climate change. Avoid "double counting" individual factors by using them as justification to score a species as having increased or not affected vulnerability for more than one factor.

Using the Results Table.—The Index provides a simple mechanism to keep track of your results for multiple species. After completing the fields on the Calculator to satisfaction, click the button "Copy Data to Results Table" at the bottom of the form. A summary of the information will be transferred to a new row in the Results Table worksheet. Then, at the top of the Calculator form, you can click the "Clear Form" button to start over on a new species. Once you have completed scoring the species on your list, you can export the data in the Results Table to other applications for further analysis.

Note that the Results Table serves as a repository for data entered in the Calculator worksheet. If you change a value for a factor in the Results Table, the Index score will not automatically be recalculated. However, you can change data in the Results Table and then use them to repopulate the Calculator by clicking on the Copy Data to Calculator for Editing button in the upper left corner of the Results Table. In the Calculator, you can make additional changes if necessary, and then resave the information to the Results Table.

The ability to copy data from the Results Table to the Calculator can facilitate work on large numbers of species. For example, you can enter the header information for a list of species in a separate Excel workbook, paste the information into the Results Table, and then copy the data for individual species into the Calculator to complete the assessments.

Using the Import from 2.01 Feature.—To update assessments completed in Release 2.01 to the current release, copy all assessment data from the Results Table of Release 2.01 and paste it into the table in the Import from 2.01 tab in Release 3.0. Then, use the Copy Data to Calculator for Editing button to paste the data from a species into the Calculator. In the Calculator, complete the missing information for the species and then copy the data in the Results Table. Repeat this process for the remaining species.

Special Kinds of Species

Aquatic Species.—The criteria for most factors provide guidelines and examples for application to a wide range of aquatic vertebrates, invertebrates, and plants. Calculate exposure for extent of occurrence of the species within the assessment area. Climate change upstream of a population of aquatic organisms will clearly have an impact, but the complexities of how these changes integrate over distance, substrate makeup, water depth, and riparian vegetation are complex and beyond the scope of this index.

Obligate Cave and Groundwater Species.—Observations that many obligate cave species persisted in situ through recent glaciations suggest that caves and groundwater-fed aquatic systems are well buffered from aboveground climate (Culver et al. 2003, Hamilton-Smith and Finlayson 2003, Lamoreux 2004). Check the box at the top of the Calculator page for these species, which will have the effect of moderating the exposure weightings for the indirect exposure and sensitivity factors.

Migratory Species.—Climate change can influence migratory species at their breeding and nonbreeding sites as well as along their migratory pathways. The climate on the nonbreeding can even have a carryover effect on the breeding success of a migratory bird (Nott et al. 2002, Studds and Marra 2011, Wilson et al. 2011). The primary focus of the Index, however, is to highlight how conditions within the assessment area can affect species as a way to identify local management actions that can promote adaptation to climate change. The climate change vulnerability of migratory species should be assessed focusing on their seasonal presence within the study area. This approach is analogous to S-ranking migratory species, in which only factors acting within a state or province are considered when assigning conservation status. Cognizant that climate exposure on migratory species when they are not in the assessment area is of interest to managers (Small-Lorenz et al. 2013), the Index allows an estimation of climate exposure in the migratory range in section A, Exposure. An exposure score, High, Moderate, or Low, is calculated from these data and presented together with the overall vulnerability score.

Marine Species.—The Index is not currently designed to address the vulnerability of marine species, including sea turtles, to climate change.

Section A. Exposure to Local Climate Change

This section must be completed for the Index to calculate a vulnerability score. All factors refer to ranges and populations within the assessment area. Because of the relatively coarse scale of the climate data, use extent of occurrence maps of species distributions rather than point maps of actual populations. Download the climate data from the Index website (www.natureserve.org/ccvi), or use your preferred climate data set. For temperature, calculate the percentage of the range of the species in each of the following categories and enter the results in the corresponding boxes for temperature under Section A on the Calculator:

- > 3.80° C warmer
- 3.49 - 3.80° C warmer
- 3.17 - 3.48° C warmer
- 2.85 - 3.16° C warmer
- 2.53 - 2.84° C warmer
- < 2.53° C warmer

Then do the same for climate moisture deficit (downloading data from the Index website, www.natureserve.org/ccvi), calculating the percentage of the range of the species in each of the following categories of climate moisture deficit:

- > 56.68
- 38.87 - 56.68
- 21.05 - 38.86
- 3.23 - 21.04
- -14.59 - 3.22
- < -14.59

Finally, check to make sure that the percentages entered for each climate factor sum to 100.

See Appendix 3 for guidance on quantitative GIS assessment of this factor.

For Neotropical migratory species, be sure to check the corresponding box in the heading area of the Calculator. Then, following the procedure used for temperature and moisture, enter the portions of the migratory range that fall into the different values of a Climate Change Exposure Index (Figure 4):

- >7
- 6-7
- 4-5
- <4

The Climate Change Exposure Index is derived from the Climate South America data set (Hamann et al. 2013) using the IPCC Fourth Assessment A1B scenario for mid-century as a departure from the 1961-1990 baseline. The Climate Change Exposure Index combines temperature and climate moisture deficit variables using standard Euclidean distance (Williams et al. 2007). Climate moisture deficit, the sum of the monthly difference between reference atmospheric evaporative demand and precipitation, is similar to the Hamon moisture metric in measuring the moisture available to plants and animals (Wang et al. 2012). The Climate Change Exposure Index calculates for each pixel the standard Euclidean distance that annual temperature and the climate moisture deficit will differ in 2050 from the 1961-1990 baseline. The Climate Change Exposure Index data set can be downloaded as an img raster file from http://www.natureserve.org/ccvi.

This calculation can only be made for species migrating to areas south of the United States in Latin America and the Caribbean. Determining the geographic region where the species occurs during the nonbreeding season can be difficult. Occasionally there are data from stable isotope or other studies that indicate where a population migrates to. If all that is known is the general nonbreeding range, use this area for the migratory exposure calculation.

Section B. Indirect Exposure to Climate Change

B1) Exposure to Sea Level Rise

NOTES: This factor comes into play only in the case that all or a portion of the range within the assessment area may be subject to the effects of a 0.5-1 m or greater sea level rise and the consequent influence of storm surges and intrusion of salt water. Most climate model scenarios predict at least a 0.5 m sea level rise. Because projected sea level rise (0.5-2 m by 2100) is great compared to historical sea level changes, the negative impact on habitats for most affected species is expected to be high.

TOOL: For information on sensitivity of the Canadian coast to potential sea level rise, see http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/b2bfb45c-7039-5b11-ab16-ac855e14641e.html.

Greatly Increase Vulnerability:	>90% of range occurs in area subject to sea level rise (on low-lying island(s) or in coastal zone).
Increase Vulnerability:	50-90% of range occurs in area subject to sea level rise (on low-lying island(s) or in coastal zone).
Somewhat Increase Vulnerability:	10-49% of range occurs in area subject to sea level rise (on low-lying island(s) or in coastal zone).
Neutral:	<10% of range occur in area subject to sea level rise (on low-lying island(s) or in coastal zone). Includes inland areas not subject to sea level rise. Also, species that occur in an intertidal habitat that is expected to increase in extent with a rising sea level.

B2) Distribution Relative to Barriers

NOTES: This factor assesses the degree to which natural (e.g., topographic, geographic, ecological) or anthropogenic barriers limit a species' ability to shift its range in response to climate change. Barriers are defined here as features or areas that completely or almost completely prevent movement or dispersal of the species (currently and for the foreseeable future). Species for which barriers would inhibit distributional shifts with climate change-caused shifts in climate envelopes likely are more vulnerable to climate change than are species whose movements are not affected by barriers. Barriers must be identified for each species (but often are the same for a group of closely related species). Natural and anthropogenic barriers are defined for many species and taxonomic groups in NatureServe's Element Occurrence Specifications (viewable in the *Population/Occurrence Delineation* section of species accounts on Natureserve Explorer, http://www.natureserve.org/explorer), but usually these readily can be determined by considering a species' basic movement capacity and ecological tolerances.

The distinction between a barrier and unsuitable habitat sometimes may be unclear; in these cases assume the feature or area is unsuitable habitat (habitat through which the species can disperse or move but that does not support reproduction or long-term survival) and score the species here and/or in factor C1 as appropriate. Note that caves are considered under factor C3: Restriction to Uncommon Landscape/Geological Features, and not here where the focus is on barriers that affect the wide array of nonsubterranean species.

A) NATURAL BARRIERS: Examples of features that may function as natural barriers for various species: upland habitat (i.e., absence of aquatic stream, lake, or pond habitat) is a barrier for fishes (but not for semiaquatic or amphibious species that may occupy the same body of water); high mountain ranges (especially those that extend west-east) are a barrier for many lowland plants and nonvolant lowland animals; warm lowlands are a barrier for some alpine species such as American pika but not for elk or American pipit; large expanses of water are barriers for pocket gophers and many other small terrestrial animals (but not for many volant species, or for plant species that are dispersed by wide-ranging birds, or for species that readily swim between land areas if the distance is not too great); a high waterfall is a barrier for fishes (but not for American dippers or gartersnakes that occur along the same stream).

B) ANTHROPOGENIC BARRIERS: Examples of features that may function as anthropogenic barriers: large areas of intensive urban or agricultural development are barriers for many animals and plants; waters subject to chronic chemical pollution (e.g., acid mine drainage) can be a barrier for fishes and other strictly aquatic species; waters subject to thermal pollution (e.g., from power plants) may be a barrier for some strictly aquatic species but not for others (note thermal alterations associated with reservoirs often produce unsuitable habitat rather than impose a barrier); dams without fish passage facilities and improperly installed culverts can be barriers for fishes and certain other strictly aquatic species; tortoise-proof fencing may be barrier for small reptiles and certain other nonvolant animals (but not for most plants, large mammals, or large snakes).

Note that no barriers exist for most temperate-zone bird species that simply fly over or around potential obstructions. Species restricted to habitats that are believed to persist unchanged in spite of climate change are scored as *Neutral* (because in these situations barriers do not contribute to vulnerability even if climate changes). If a feature or area does not completely or almost completely prevent dispersal or movement then it is categorized here as unsuitable or suitable habitat, and the dispersal/movement of individuals across that feature or area is assessed under factor C1 (Dispersal and Movements). In most cases, unsuitable habitat is habitat through which propagules or individuals may move but that does not support reproduction or long-term survival.

The degree to which a barrier may affect a species' ability to shift its range in response to climate change depends in part on the distance of the barrier from the species' current distribution. Barriers that are separated from a species' range by a long distance of relatively flat topography can nevertheless affect range shifts because in gentle terrain relatively small changes in climate can result in large shifts in the location of a particular climate envelope. If a species changed its range accordingly (to track a particular climate envelope), it might encounter barriers that were far from its original range. In contrast, in landscapes in which climatic conditions change rapidly over small horizontal distances (e.g., mountainous areas, steep slopes, or other topographically diverse landscapes) a species' distribution would have to shift a relatively small distance in order to track a particular climate envelope, so the species is less likely to encounter distant barriers.

To count as a barrier for the purposes of this factor, a feature can be up to 50 km from the species' current range when measured across areas where climate changes gradually over latitude or longitude (e.g., relatively flat terrain) and up to 10 km when measured across areas where climate changes abruptly over latitude or longitude (e.g., mountainous or steep terrain). Use 25 km for species that occur in intermediate topography, such as moderate hill country. These distances apply to both terrestrial and aquatic species. These distances are derived from Loarie et al. (2009).

The following categories and criteria apply to both natural and anthropogenic barriers, but the two types of barriers are scored separately. Note that it is illogical for natural and anthropogenic barriers to both cause greatly increased vulnerability to climate change for a single species (only one or the other can completely surround a species' range). If both barriers occur, estimate the relative portions of the circumference of the range blocked by each and then score accordingly.

Box 2. Examples of culverts

Culverts can be anthropogenic barriers to the dispersal of some aquatic organisms. Upper left: vented low-water crossing; upper right, perched culvert; lower left, hanging culvert; lower right, proper culvert. All but the proper culvert can be barriers. Upper left photo by Keith Krantz; all others by Daniel Bennett.

TOOLS: One useful data source for assessing intensity of land use as a potential anthropogenic barrier is the Global Land Cover Facility (NASA; http://glcfapp.glcf.umd.edu/data/), though this may require advanced GIS capabilities. Readily available online sources of satellite imagery also may be useful in assessing anthropogenic or certain other barriers.

Greatly Increase Vulnerability:	Barriers completely OR almost completely surround the current distribution such that the species' range in the assessment area is unlikely to be able to shift significantly with climate change, or the direction of climate change-caused shift in the species' favorable climate envelope is fairly well understood and barriers prevent a range shift in that direction. See *Neutral* for species in habitats not vulnerable to climate change.
	Examples for natural barriers: lowland terrestrial species completely surrounded by high mountains (or bordered closely and completely on the north side by high mountains); cool-water stream fishes for which barriers would completely prevent access to other cool-water areas if the present occupied habitat became too warm as a result of climate change; most nonvolant species that exist only on the south side of a large water body (ocean, or very large lake) in an area where habitats are expected to shift northward with foreseeable climate change.
	Examples for anthropogenic barriers: species limited to small habitats within intensively developed urban or agricultural landscapes through which the species cannot pass; species essentially limited to mountainous wilderness areas that are isolated by developed transportation corridors that completely or almost completely eliminate significant demographic or genetic interactions with other occupied habitats (e.g., certain grizzly bear populations in British Columbia).
Increase Vulnerability:	Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be greatly but not completely or almost completely impaired.
	Examples for natural barriers: certain lowland plant or small mammal species whose ranges are mostly (50-90%) bordered by high mountains or a large lake.
	Examples for anthropogenic barriers: most streams inhabited by a fish species have dams that would prevent access to suitable habitat if the present occupied habitat became too warm as a result of climate change; intensive urbanization surrounds 75% of the range of a salamander species.
Somewhat Increase Vulnerability:	Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be significantly but not greatly or completely impaired.
	Examples for natural barriers: certain lowland plant or small mammal species whose ranges are partially but not mostly bordered by high mountains or a large lake.
	Examples for anthropogenic barriers: 10-50% of the margin of a plant species' range is bordered by intensive urban development; 25% of the streams occupied by a fish species include dams that are likely to impede range shifts driven by climate change.
Neutral:	Significant barriers do not exist for this species, OR small barriers exist in the assessment area but likely would not significantly impair distributional shifts with climate change, OR substantial barriers exist but are not likely to contribute significantly to a reduction or loss of the species' habitat or area of occupancy with projected climate change in the assessment area.
	Examples of species in this category: most birds (for which barriers do not exist); terrestrial snakes in extensive plains or deserts that may have small barriers that would not impede distributional shifts

	with climate change; small alpine-subalpine mammal (e.g., ermine, snowshoe hare) in extensive mountainous wilderness area lacking major rivers or lakes; fishes in large deep lakes or large main-stem rivers that are basically invulnerable to projected climate change and lack dams, waterfalls, and significant pollution; a plant whose climate envelope is shifting northward and range is bordered on the west by a barrier but for which no barriers exist to the north.

B3) Predicted Impact of Land Use Changes Resulting from Human Responses to Climate Change (e.g., plantations for carbon offsets, new seawalls in response to sea level rise, and renewable energy projects such as wind-farms, solar arrays, or biofuels production)

NOTES: Strategies designed to mitigate or adapt to climate change have the potential to affect very large areas of land, and the species that depend on these areas, in both positive and negative ways. This factor arguably should be considered in conservation status assessments, but considering that for most species this factor has not yet been considered in these assessments, we include it here. If the land use changes for alternative energy projects have already been considered in the conservation status assessment for the species, consider not scoring this factor, especially if the vulnerability assessment results will be used to revise status ranks.

This factor is NOT intended to include habitat loss or destruction due to on-going human activities, as these should already be reflected in existing conservation status ranks. Include only new activities related directly to climate change mitigation here. There is much uncertainty about the types of mitigation action that are likely to threaten habitats and species. Remember that multiple categories can be checked for each factor to capture uncertainty. As federal and state climate change legislation is enacted, some of the mitigation directions (and associated threats or benefits to species) will become clearer.

TOOLS: See Natural Resources Canada/Wind Energy (http://www.nrcan.gc.ca/energy/renewable-electricity/wind/7323) and Canadian Wind Energy Atlas (http://www.windatlas.ca/en/) for information and maps related to wind energy in Canada.

Increase Vulnerability:	The natural history/requirements of the species are known to be incompatible with mitigation-related land use changes that are likely to very likely to occur within its current and/or potential future range. This includes (but is not limited to) the following:
	- Species requiring open habitats within landscapes likely to be reforested or afforested. If the species requires openings within forests that are created/maintained by natural processes (e.g., fire), and if those processes have a reasonable likelihood of continuing to operate within its range, a lesser impact category may be appropriate.
	- Bird and bat species whose migratory routes, foraging territory, or lekking sites include existing and/or suitable wind farm sites and for which studies indicate substantial negative impact (e.g., mortality from or avoidance of turbines). If such studies indicate a relatively low impact from wind energy development, a lesser impact category may be appropriate.
	- Greater than 20% of the species' range within the assessment area occurs on marginal agricultural land, such as CRP land or other open areas with suitable soils for agriculture ("prime farmland", etc.) that are not currently in agricultural production OR > 50% of the species' range within the assessment area occurs on any non-urbanized land with suitable soils, where there is a reasonable expectation that such land may be converted to biofuel production.
	- The species occurs in one or more river/stream reaches not yet developed for hydropower, but with the potential to be so developed.
	- Species of deserts or other permanently open, flat lands with potential for placement of solar arrays.
	- Species dependent on dynamic shoreline habitats (e.g., active dunes or salt marshes) likely to be destroyed by human fortifications against rising sea levels.
Somewhat Increase Vulnerability:	The natural history/requirements of the species are known to be incompatible with mitigation-related land use changes that *may possibly* occur within its current and/or potential future range, including any of the above (under Increase).
Neutral:	The species is unlikely to be significantly affected by mitigation-related land use changes that may occur within its current and/or potential future range, including any of the above; OR it is unlikely that any mitigation-related land use changes will occur within the species' current and/or potential future range; OR it may benefit from mitigation-related land use changes.

Section C. Sensitivity and Adaptive Capacity

Specific instructions for each factor are as follows. At least 10 of the 19 factors must be assessed. Note that these factors relate to characteristics of the species only. Anthropogenic effects, such as on the availability of dispersal corridors, should not be considered in this section.

C1) Dispersal and Movements

NOTES: This factor pertains to known or predicted dispersal or movement capacities and characteristics and ability to shift location in the absence of barriers as conditions change over time as a result of climate change. Species in which individuals exhibit substantial dispersal, readily move long distances as adults or juveniles, or exhibit flexible movement patterns should be better able to track shifting climate envelopes than are species in which dispersal and movements are more limited or inflexible. This factor pertains specifically to dispersal through unsuitable habitat, which, in most cases, is habitat through which propagules or individuals may move but that does not support reproduction or long-term survival. If all habitat is regarded as suitable (i.e., species can reproduce and persist in every habitat in which it occurs), then dispersal ability is assessed for suitable habitat. If appropriate, scoring of species whose dispersal capacity is not known can be based on characteristics of closely related species (or species of similar body size in the same major group) with similar and relevant morphological features.

Barriers, which are here defined as features or areas that completely or almost completely block dispersal, are treated in factor B2. If a species requires other species for propagule dispersal, please also complete factor C4d. The following categorization for plants is loosely based on Vittoz and Engler (2007).

A small number of species are confined by barriers to areas that are smaller than the species' potential dispersal distance (fishes in small isolated springs or plants that only occur in vernal pools are classic examples). Most if not all of the fish species that occur in the smallest such habitat patches could disperse farther than the greatest extent of the occupied patch if a larger extent of habitat were available to them. For the purposes of this factor, the dispersal ability of these species is scored as if the species occurred in a large patch of habitat (longer than the dispersal distance), based on dispersal or movement patterns or capabilities of closely related species (or species of similar body size in the same major group of animals).

Migratory species should be scored according to their ability to shift their distribution within the assessment area during the period of occupation or from one year to the next (whichever is larger).

TOOLS: Seed biological trait data for some species can be found at http://data.kew.org/sid/sidsearch.html.

Greatly increase Vulnerability:	Species is characterized by severely restricted dispersal or movement capability. Species is represented by sessile organisms that almost never disperse more than 10 meters per dispersal event. Examples: plants with large or heavy propagules for which the disperser is extinct or so rare as to be ineffective; species with dispersal limited to vegetative shoots, buds, or similar structures that do not survive (at least initially) if detached from the parent; plants dispersed only ballistically.
Increase Vulnerability:	Species is characterized by highly restricted dispersal or movement capability. Species rarely disperses through unsuitable habitat more than about 10-100 meters per dispersal event; OR dispersal beyond a very limited distance (or outside a small isolated patch of suitable habitat) periodically or irregularly occurs but is dependent on highly fortuitous or rare events; OR species has substantial movement capability but exhibits a very high degree of site fidelity. Examples: branchiopods whose resting stages sometimes are transported in mud attached to birds or mammals; small clams that may disperse while clamped onto bird feathers or frog toes; small, nonvolant animals of relatively low vagility, including small, slow-moving animals such as slugs, snails, and the smallest terrestrial salamanders that rarely shift location by more than 100 meters

	within a single year; many ant-dispersed plant species; plant or animal species with free-living propagules or individuals that may be carried more than 100 meters by a tornado or unusually strong hurricane or large flood but that otherwise rarely disperse more than 100 meters; plants that do not fit criteria for *Greatly Increase Vulnerability* but lack obvious dispersal adaptations (i.e., propagules lack any known method for moving more than 100 meters away from the source plant); birds that exhibit an extremely high degree of site fidelity or exceptionally low rate of colonization of vacant suitable habitat.
Somewhat Increase Vulnerability:	Species is characterized by limited or moderate but not highly or severely restricted dispersal or movement capability. A significant percentage (at least approximately 50%) of propagules or individuals disperse approximately 100-1,000 meters per dispersal event (rarely farther); OR species has substantial movement capability but exhibits a moderate to high degree of site fidelity and has very limited existing or potential habitat within the assessment area; OR dispersal likely is consistent with one of the following examples. Examples: species that exist in small isolated patches of suitable habitat but regularly disperse or move among patches that are up to 1,000 meters (rarely farther) apart; plants whose propagules are dispersed primarily by small animals (e.g., some rodents) that typically move propagules approximately 100-1,000 meters from the source (propagules may be cached or transported incidentally on fur or feathers); plants dispersed by wind with low efficiency (e.g., species with inefficiently plumed seeds and/or that occur predominantly in forests); many small but somewhat vagile animals (e.g., many small mammals and lizards); species whose individuals exist in small isolated patches of suitable habitat but regularly disperse or move among patches that are 100-1,000 meters (rarely farther) apart; plant and animal species whose propagules or individuals are dispersed by small animals (e.g., rodents, grouse) that regularly but perhaps infrequently move propagules approximately 100-1,000 meters from the source; many denning snakes and some pond-breeding amphibians that are otherwise terrestrial as adults) (note that these short-distance migratory animals may exhibit strong fidelity to natal areas but nevertheless generally include individuals that colonize or move into other nearby areas); birds that exhibit a high degree of site fidelity or relatively low rate of colonization of vacant suitable habitat (as in *Increase Vulnerability* but the degree site fidelity or colonization rate is not as extreme)
Neutral:	Species is characterized by good to excellent dispersal or movement capability. Species has propagules or dispersing individuals that commonly move more than 1 kilometer from natal or source areas; OR species tends to occupy all or most areas of suitable habitat, or readily or predictably moves more than 1 kilometer to colonize newly available habitat (e.g., recently restored areas, areas that become suitable as a result of fire, insect infestations, or other environmental changes, etc.); OR dispersal capability likely is consistent with one of the following examples. Note that species in the Neutral category are not necessarily "early successional" or "r-selected" species but also may include certain

	"late successional" or equilibrium ("K-selected") species that have excellent innate or vector-aided dispersal capability. Examples: plant species regularly dispersed more than 1 km by large or mobile animals (e.g., plant has seeds that are cached, regurgitated, or defecated at least 1 km from the source by birds [e.g., corvids, songbirds that eat small fleshy fruits] or mammals or that are transported on fur of large mobile animals such as most Carnivora or ungulates); animal species that regularly disperse or move long distances via their own locomotory abilities (e.g., most large and some medium-sized mammals, most bats, many common birds); many plant species dispersed by wind with high efficiency (e.g., species with efficiently plumed seeds or very small propagules that occur predominantly in open areas); plant or animal species whose individuals often or regularly are dispersed more than 1 kilometer by air or ocean currents, or humans, including species that readily become established outside their native ranges as a result of intentional or unintentional translocations by humans; animal species whose populations within the assessment area are known to migrate facultatively according to changing environmental conditions (e.g., some northern finches and owls exhibit short or long migrations in some years but not in others); nonmigratory species whose populations may shift location by 1 kilometer or more in response to changing environmental conditions (e.g., the black-backed woodpecker [*Picoides arcticus*] often makes substantial shifts in its distribution in accordance with concentrations of wood-boring insects); migratory species that show clear ability to track variable resources over broad geographies; bird species lacking a high degree of site fidelity; bird species that readily colonize vacant suitable habitat.

C2) Predicted Sensitivity to Temperature and Moisture Changes

NOTES: This factor pertains to the breadth of temperature and precipitation conditions, at both broad and local scales, within which a species is known to be capable of reproducing, feeding, growing, or otherwise existing. Species with narrow environmental tolerances/requirements may be more vulnerable to habitat loss from climate change than are species that thrive under diverse conditions.

a) Predicted sensitivity to changes in temperature, based on current/recent past temperature tolerance

i) Historical thermal niche (exposure to past variations in temperature)

NOTES: This factor measures large-scale temperature variation that a species has experienced in recent historical times (i.e., 1961-1990), as approximated by mean seasonal temperature variation (difference between highest mean monthly maximum temperature and lowest mean monthly minimum temperature) for occupied cells within the assessment area. It is a proxy for species' temperature tolerance at a broad scale. This factor may be evaluated by using GIS data downloaded from NatureServe (http://www.natureserve.org/ccvi). An image of these data can be found at the bottom of this sheet. For aquatic species, follow the same procedure as for terrestrial species, since this factor measures broad regional patterns.

Use the annual map for both resident and migratory species. Although migratory species are not physically present to experience temperature variations, they nonetheless are affected by these variations through effects on food supply and habitat availability.

Follow the instructions in Appendix 3 to calculate this value.

Greatly Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **very small (< 20.8° C)** temperature variation in recent historical times. Includes cave obligates and species occurring in thermally stable groundwater habitats.
Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **small (20.8 - 26.3° C)** temperature variation in recent historical times. Includes facultative cave invertebrates.
Somewhat Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **slightly lower than average (26.3 - 31.8° C)** temperature variation in recent historical times.
Neutral:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **average or greater than average (>31.8° C)** temperature variation in recent historical times.

ii) Physiological thermal niche

NOTES: Current projections indicate that climate warming will be nearly pervasive in North America over the next several decades. Species associated with cool or cold conditions likely will experience a reduction in habitat extent or quality and may experience declines in distribution or abundance within a given assessment area. This factor assesses the degree to which a species is restricted to relatively cool or cold above-ground terrestrial or aquatic environments that are thought to be vulnerable to loss or significant reduction as a result of climate change. Species that depend on these cool/cold environments include (but may not be limited to) those that occur in the assessment area's highest elevational zones, northernmost areas, or the coldest waters. The restriction to these relatively cool environments may be permanent or seasonal.

Species that occur in frost pockets, on north-facing slopes, in shady ravines, in alpine areas, or similar cool sites are scored here if those areas represent or are among the coldest environments in the assessment area; lacking this stipulation, species occurring in such sites may not be vulnerable to climate change because favorable sites may simply shift in location without reduction or loss. Species that are associated specifically with snow or ice are assessed separately in factor C2d. Note that temperature conditions and hydrological regimes often covary and often are not neatly separable; these situations should be scored here if temperature per se appears to be the overriding factor; otherwise they should be scored under factor C2bii: Physiological Hydrological Niche.

Greatly Increase Vulnerability:	Species is completely or almost completely (> 90% of occurrences or range) restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.
Increase Vulnerability:	Species is moderately (50-90% of occurrences or range) restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.
Somewhat Increase Vulnerability:	Species is somewhat (10-50% of occurrences or range) restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.

Neutral:	Species distribution is not significantly affected by thermal characteristics of the environment in the assessment area, species occupies habitats that are thought to be not vulnerable to projected climate change, or species shows a preference for environments at the warmer end of the spectrum.

b) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime

i) Historical hydrological niche (exposure to past variations in precipitation)

NOTES: This factor measures large-scale precipitation variation that a species has experienced in recent historical times (i.e., 1961-1990), as approximated by mean annual precipitation variation across occupied cells within the assessment area. This factor may be evaluated by using GIS data downloaded from NatureServe (http://www.natureserve.org/ccvi). An image of these data can be found at the bottom of this sheet. Subtract the lowest pixel value from the highest value to assess this factor. Use the extreme pixel values for this calculation. Use annual data for migratory species, as this measure reflects the precipitation regime of the ecosystem as a whole.

Follow the instructions in Appendix 3 to calculate this value.

Greatly Increase Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **very small (<100 mm)** precipitation variation in recent historical times.
Increase Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **small (100 - 254 mm)** precipitation variation in recent historical times.
Somewhat Increase Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **slightly lower than average (255 - 508 mm)** precipitation variation in recent historical times.
Neutral:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **average or greater than average (>508 mm)** precipitation variation in recent historical times.

ii) Physiological hydrological niche

NOTES: This factor pertains to a species' dependence on a narrowly defined precipitation/hydrologic regime, including strongly seasonal precipitation patterns and/or specific aquatic/wetland habitats (e.g., certain springs, vernal pools, seeps, seasonal standing or flowing water) or localized moisture conditions that may be highly vulnerable to loss or reduction with climate change. Dependence may be permanent or seasonal, and for migratory species may include staging areas, migration stops, and wintering areas outside the assessment area. Aquatic cave obligate species are considered here according to their hydrological needs and habitat vulnerability. Species nesting on islands in lakes, reservoirs, and/or wetlands that prevent predator access can be scored here to the extent that a changed hydrological regime may influence the availability of these predator-free breeding sites (for example, birds nesting on islands to avoid predation by mammals). If a species is dependent on aquatic/wetland habitats that are actively managed to maintain a particular hydrology, consider whether this management would be sufficient to ameliorate projected climate change impacts (and, if so, score as *Neutral*).

For plant species, the advantage of the C4 photosynthetic pathway for water use efficiency will likely enable C4 plants to be less vulnerable to decline under drying conditions than C3 plants (Taylor et al. 2010). The predicted vulnerability of these plants with respect to this factor has been adjusted accordingly.

For nonmigratory species, "range" refers to the range within the assessment area. For migratory species, “range” encompasses the assessment area and additional areas (e.g., migration stops, staging areas, wintering areas) that are used to a significant extent by the populations being assessed. For example, a migratory bird species for which 95% of the significant migration stops are in shallow inland/interior wetlands should be assigned to the *Greatly Increase Vulnerability* category, even if the species is not dependent on such habitats within the assessment area.

Note that temperature conditions and hydrological regimes often covary and often are not neatly separable. These situations should be scored under factor C2aii (Physiological Thermal Niche) if temperature per se appears to be the overriding factor; otherwise they should be scored here.

Greatly Increase Vulnerability:	Completely or almost completely (>90% of occurrences or range) dependent on a specific aquatic/wetland habitat or localized moisture regime that is likely to be highly vulnerable to loss or reduction with climate change. Examples: species dependent on small/isolated/shallow water-bodies or wetlands in arid landscapes; ephemeral-pool-dependent branchiopods; plants that are exclusively or very strongly associated with localized moist microsites (e.g., "hanging gardens" in arid landscapes).
Increase Vulnerability:	Moderately (50-90% of occurrences or range) dependent on a strongly seasonal hydrologic regime and/or a specific aquatic/wetland habitat or localized moisture regime that is likely to be highly vulnerable to loss or reduction with climate change. Examples: certain amphibians that often breed in vernal pools but also regularly use other aquatic or wetland habitats; certain plants whose life cycles are highly synchronized with Mediterranean precipitation patterns in areas vulnerable to large changes in the amount and seasonal distribution of precipitation; desert or semidesert plants that frequently occur in but are not restricted to or almost restricted to moisture-accumulating microsites; plants (and animals that depend on these species) for which >50% of populations occur in areas such as sandy soils that are highly prone to desiccation; plants that use the C4 photosynthetic pathway and that otherwise qualify for the *Greatly Increase Vulnerability* category.
Somewhat Increase Vulnerability:	Somewhat (10-50%) dependent on a strongly seasonal hydrologic regime and/or a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change. Examples: plants (and animals that depend on these species) for which 10-50% of populations occur in areas such as sandy soils that are sensitive to changes in precipitation; certain plants with ranges restricted to seasonal precipitation environments (e.g., summer rainfall deserts) and which have a moderate degree of adaptation to that seasonality; plants that use the C4 photosynthetic pathway and that otherwise qualify for the *Increase Vulnerability* category.
Neutral:	Species has little or no dependence on a strongly seasonal hydrologic regime and/or a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change; OR hydrological requirements are not

	likely to be significantly disrupted in major portion of the range; OR species tolerates a very wide range of moisture conditions. Examples: water-limited species in areas with increasing water availability; arid-adapted species in areas with decreasing moisture availability; species dependent on springs tied to a regional aquifer that would not be expected to change significantly with climate change; aquatic species inhabiting caves fed by groundwater aquifers that are not expected to change significantly with climate change; plants that use the C4 photosynthetic pathway and that otherwise qualify for the *Somewhat Increase Vulnerability* category.

c) Dependence on a specific disturbance regime likely to be impacted by climate change

NOTES: This factor pertains to a species' response to specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events. It includes disturbances that impact species directly as well as those that impact species via abiotic aspects of habitat quality. For example, changes in flood and fire frequency/intensity may cause changes in water turbidity, silt levels, and chemistry, thus impacting aquatic species sensitive to these aspects of water quality. The potential impacts of altered disturbance regimes on species that require specific river features created by peak flows should also be considered here; for example, some fish require floodplain wetlands for larval/juvenile development or high peak flows to renew suitable spawning habitat. Use care when estimating the most likely effects of increased fires; in many ecosystems, while a small increase in fire frequency might be beneficial, a greatly increased fire frequency could result in complete habitat destruction.

Be sure to also consider species that benefit from a lack of disturbance and may suffer due to disturbance increases when scoring this factor.

TOOLS: Information on fire effects: www.fs.fed.us/database/feis/plants/index.html. For a map of modeled future fire regime, see Figure 2 in Krawchuk et al. (2009).

Increase Vulnerability:	Strongly affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that reduces the species' distribution, abundance, or habitat quality. For example, many sagebrush-associated species in regions predicted to experience increased fire frequency/intensity would be scored here due to the anticipated deleterious effects of increased fire on their habitat.
Somewhat Increase Vulnerability:	Moderately affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that reduces the species' distribution, abundance, or habitat quality, OR strongly affected by specific disturbance regime, and climate change is likely to change that regime in a way that causes minor disruption to the species' distribution, abundance, or habitat quality. For example, plants in a riverscour community that are strongly tied to natural erosion and deposition flood cycles, which may shift position within the channel rather than disappear as a result of climate change.
Neutral:	Little or no response to a specific disturbance regime, OR climate change is unlikely to change the frequency, severity, or extent of that disturbance regime in a way that affects the range or abundance of the species, OR climate change is likely to change the characteristics of the disturbance regime in a way that increases the species' distribution.

d) Dependence on ice, ice-edge, permafrost, or snow cover habitats

NOTES: This factor pertains to a species' dependence on habitats associated with ice (e.g., sea ice, glaciers), permafrost, or snow (e.g., long-lasting snow beds, avalanche chutes) throughout the year or seasonally during an essential period of the life cycle. For aquatic species, the importance of snowpack for maintaining downstream water temperatures should be considered here. "Range" refers to the range within the assessment area.

Greatly Increase Vulnerability:	Highly dependent (>80% of subpopulations or range) on ice-, permafrost-, or snow-associated habitats; or found almost exclusively on or near ice or snow during at least one stage of the life cycle. For example, polar bear (*Ursus maritimus*) is strongly dependent on sea ice throughout its range.
Increase Vulnerability:	Moderately dependent (50-80% of subpopulations or range) on ice-, permafrost-, or snow-associated habitats; or often found most abundantly on or near ice or snow but also regularly occurs away from such areas. For example, Kittlitz's murrelet (*Brachyramphus brevirostris*) feeding habitat is moderately to strongly associated with tidewater glaciers.
Somewhat Increase Vulnerability:	Somewhat (10-49% of subpopulations or range) dependent on ice-, permafrost-, or snow-associated habitats, or may respond positively to snow or ice but is not dependent on it. For example, certain alpine plants are often associated with long-lasting snowbeds but also commonly occur away from such areas; certain small mammals experience increased survival and may develop relatively large populations under winter snow cover but do not depend on snow cover. Species that benefit from a minimum thickness of ice or snowpack for winter insulation should also be scored here.
Neutral:	Little dependence on ice-, permafrost-, or snow-associated habitats (may be highly dependent in up to 10% of the range).

C3) Restriction to Uncommon Landscape/Geological Features or Derivatives

NOTES: This factor pertains to a species' need for a particular soil/substrate, geology, water chemistry, or specific physical or landscape feature (e.g., caves, cliffs, active sand dunes, islands) for reproduction, feeding, growth, shelter, or other aspects of the life cycle. It focuses on the commonness of suitable conditions for the species on the landscape, as indicated by the commonness of the features themselves combined with the degree of the species' restriction to them. Climate envelopes may shift away from the locations of fixed (within at least a 50 year timeframe) landscape or geological features or their derivatives, making species tied to these uncommon features potentially more vulnerable to habitat loss from climate change than are species that thrive under diverse conditions.

This factor does NOT include habitat preferences based on temperature, hydrology, or disturbance regime, as these are covered elsewhere in the Index. For example, species dependent on springs or ephemeral pools should not be scored as more vulnerable for this factor solely on that basis (addressed under factor C2bii: Physiological Hydrological Niche). However, restriction to aquatic features with regionally uncommon water chemistry should be considered here. This factor also does NOT include habitat features such as stream riffles or basking rocks. Finally, this factor does NOT include biotic habitat components; for example, species that require features such as tree snags or a particular type/condition of plant community (e.g., old growth forest) should not be scored as more vulnerable for this factor.

If the idea of specificity to soil/substrate, geology, or specific physical or landscape features is not relevant to the species (e.g., many birds and mammals), choose *Neutral.*

TOOLS: Map of serpentine areas of North America: http://botany.si.edu/projects/cpd/na/map5.htm.

Increase Vulnerability:	Highly dependent upon (i.e., more or less endemic to, or > 85% of occurrences found on) a particular highly uncommon landscape or geological feature or derivative (e.g., soil, water chemistry). Examples: serpentine (broad and strict) endemic plants; plants of calcareous substrates where such substrates are uncommon; plants restricted to one or a few specific rock strata; species more or less restricted to inland sand dunes or shale barrens; obligate cave-dwelling organisms; springsnails restricted to springs with high dissolved CO_2; fish species that require a highly uncommon substrate particle size for effective spawning; many colonially nesting seabirds that are essentially restricted to predator-free islands for successful reproduction.
Somewhat Increase Vulnerability:	Moderately dependent upon a particular uncommon landscape or geological feature or derivative, i.e., (1) an indicator of but not an endemic to (65-85% of occurrences found on) the types of features described under Increase, OR (2) more or less restricted to a landscape or geological feature or derivative that is not highly uncommon within the species' range, but is not one of the dominant types. Examples: as in Increase Vulnerability but with a lesser degree of dependence; species moderately restricted to active coastal sand dunes, cliffs, salt flats (including shorebirds that require sodic soils), inland waters within a particular salinity range, or nondominant rock types such as occasional igneous rock intrusions within a landscape mostly dominated by sedimentary and/or metamorphic rocks; species that inhabit multiple geological features each of which is uncommon; fish species that require a specific substrate particle size, if that of stream bottom type is not one of the dominant types within the species' range.
Neutral:	Having a clear preference for (> 85% of occurrences found on) a particular landscape or geological feature or derivative, but the feature/derivative is among the dominant types within the species' range; OR somewhat flexible in dependence upon geological features or derivatives (i.e., found on a subset of the dominant substrate/water chemistry types within its range); OR highly generalized relative to dependence upon geological features or derivatives; species is described as a generalist and/or occurrences have been documented on widely varied substrates or water chemistries. Examples: plants (e.g., red spruce) that are usually associated with acidic organic soils that are not uncommon within the range; many species whose habitat descriptions specify one pH category (acidic, neutral, or basic) and/or one soil particle size (e.g., rocky, sandy, or loamy) but that substrate type is not particularly uncommon within the species' range; species inhabiting multiple relatively widespread geological features; species with many occurrences associated with

	both acidic and basic soils or waters, or with both sandy and clay soils); species not strongly tied to any specific landscape or geological feature or derivative, such as common yarrow (*Achillea millefolium*), coyote (*Canis latrans*), and many other plants and animals.

C4) Interspecific Interactions

NOTES: The primary impact of climate change on many species may occur via effects on synchrony with other species on which they depend (Parmesan 2006), rather than through direct physiological stress.

a) Dependence on other species to generate habitat

NOTES: This factor pertains to a species' dependence on uncommon/restricted habitats that are generated or maintained by other species. Species that are dependent on a small number of other species likely are more vulnerable to climate change than are species that have more flexibility or that do not have specialized habitat requirements.

Habitat refers to any habitat (e.g., for reproduction, feeding, hibernation, seedling establishment) necessary for completion of the life cycle, including those used only on a seasonal basis. This includes specific (often structural) features within a more generalized habitat type (e.g., burrows created by other species in a grassland habitat; woodpecker-created cavities in a forest habitat). These habitats must be required for completion of the life cycle (e.g., reproduction, feeding, hibernation, seedling establishment, etc.) and may include habitats used only on a seasonal basis. For plants, species-specific relationships involved in creating specific habitat conditions necessary for seedling establishment should be considered here; nutritional relationships necessary for seedling establishment (e.g., parasitic or obligately myco-heterotrophic plants) should be considered under C4g. The relationship between freshwater mussels and their larval hosts should be scored only under factor C4d (Dependence on other species for propagule dispersal).

This factor is concerned specifically with habitats generated or maintained by particular species and does NOT include ecological dependencies based primarily on disturbance regime, geological features, or diet, as these are covered elsewhere in the Index. Required habitats involving temperature/hydrological conditions that are generated by a small number of particular species are included in this factor, but temperature/hydrology-related habitats that are not primarily species dependent are considered under C2aii and C2bii (thermal and hydrological niches); if in doubt, score under C2aii or C2bii.

Increase Vulnerability:	Required habitat is generated primarily by one species. Examples: animals that require marshes dominated by a single plant species (such as *Spartina* sp. or *Typha* sp.) (e.g., in most areas, seaside sparrows nest only in marsh areas that contain the tall form of *Spartina alterniflora*).
Somewhat Increase Vulnerability	Required habitat is generated by only a few species. Examples: certain cacti that depend on a few specific plant species for creating required specific habitat conditions necessary for seedling establishment; plants species that depend on biological soil crusts for favorable conditions for seed germination, water and nutrient flow to vegetation, and soil stability; plant species with preference for particular canopy species like long leaf pine (*Pinus palustris*); species such as nesting burrowing owls (*Athene cunicularia*) that depend on excavations made by relatively few

	species of burrowing mammals; birds such as marbled murrelets (*Brachyramphus marmoratus*) that strongly depend on a few species of large trees to provide suitable nesting platforms; lichens (e.g., *Nephroma occultum*) strongly associated with old-growth Douglas-fir/western hemlock forests in the Pacific Northwest; certain plant species that depend on large grazing animals to generate habitats (localized disturbances) required for establishment and early growth.
Neutral:	Required habitat is generated by more than a few species; or species does not require any uncommon/restricted habitats; or habitat requirements do not involve species-specific processes. Examples: many mammal species that do not rely on burrows or shelters made by one or a few other species; many bird species that do not depend on one or a few other species to provide suitable nesting or foraging sites; most species of reptiles, amphibians, fishes, aquatic invertebrates, and butterflies and moths; epiphytic species (orchids, lichens, bromeliads) with no host preference; many species of forest understory plants that thrive under a wide range of forest tree species.

b) Dietary versatility (animals only)

NOTES: This factor pertains to the diversity of food types consumed by animal species. Dietary specialists are more likely to be negatively affected by climate change than are species that readily switch among different food types.

Note that the relationship between freshwater mussels and their larval hosts should be scored only under factor C4d (Dependence on other species for propagule dispersal).

Increase Vulnerability:	Completely or almost completely (>90%) dependent on one species during any part of the year; equivalent alternatives to this single-species food resource are not readily available. Examples: Clark's nutcracker (*Nucifraga columbiana*), which depends heavily on the seeds of whitebark pine (*Pinus albicaulis*); red knot, some populations of which during spring migration may be completely or almost completely dependent on horseshoe crab (*Limulus*) eggs; bog elfin (*Callophrys lanoraieensis*), the larval diet of which consists entirely on black spruce.
Somewhat Increase Vulnerability:	Completely or almost completely (>90%) dependent during any part of the year on (1) a few species from a restricted taxonomic group or (2) a narrow guild the members of which are thought to respond similarly to climate change. Examples: larvae of various fritillary butterflies that rely heavily on a few species of *Viola* violets; western pine elfin (*Callophrys eryphon*), the larval diet of which generally includes only a few pine (*Pinus*) species; swifts and swallows that are dependent on aerial insects (often a limited number of species at any particular time) that may become unavailable or less available as a result of climate change (e.g., through increased incidence of prolonged rainy conditions that restrict aerial feeding opportunities, or increased incidence of conditions that reduce populations of aerial insects).

Neutral:	Diet flexible; during any season species readily switches among multiple food resources according to availability; not strongly dependent on one or a few species; omnivorous, with diet including numerous species of both plants and animals. Examples: most Carnivora, ungulates, nonmigratory birds, amphibians, reptiles, fishes, and many Lepidoptera (e.g., mule deer seasonally may focus their foraging on only a few favored plant species, but in the absence of those species they readily switch to other species); great horned owl (*Bubo virginianus*), which has a flexible diet and is not strongly dependent on one or a few species (although its diet may be dominated by one or a few readily available species in a particular location or season); black-capped chickadee (*Poecile atricapillus*) and other birds that are highly opportunistic during any season and readily switch among different food resources as availability changes.

c) Pollinator versatility (plants only)

NOTES: Quantitative thresholds loosely follow data in Waser et al. (1996). If appropriate, scoring of species whose pollinators is not known can be based on characteristics of closely related species that have similar and relevant morphological floral features that may have similar pollination syndromes (Willmer 2011).

In some cases, sympatric, sequentially flowering species may enhance reproductive success for each other through maintenance of pollinator populations. Species that are documented to benefit from such interactions with one or only a few sympatric species should be scored one category higher (Hegland et al. 2009).

TOOLS: The Inouye Pollinator Reference Database is a source for literature references to pollination: https://www.mendeley.com/groups/2544001/inouye-pollinator-reference-database/. A table describing traits of pollinator syndromes can be found at http://www.fs.fed.us/wildflowers/pollinators/What_is_Pollination/syndromes.shtml.

Increase Vulnerability:	Completely or almost completely dependent on one species for pollination (> 90% of effective pollination accomplished by 1 species) or, if no observations exist, morphology suggests very significant limitation of potential pollinators (e.g., very long corolla tube).
Somewhat Increase Vulnerability:	Completely or almost completely dependent on 2-4 species for pollination (> 90% of effective pollination accomplished by 2-4 species) or, if no observations exist, morphology suggests conformation to a specific "pollination syndrome" (e.g., van der Pijl 1961, http://www.fs.fed.us/wildflowers/pollinators/syndromes.shtml).
Neutral:	Pollination apparently flexible; five or more species make significant contributions to pollination or, if no observations exist, morphology does not suggest pollinator limitation or pollination syndrome. Score wind-pollinated species as Neutral.

d) Dependence on other species for propagule dispersal

NOTES: Can be applied to plants or animals. Examples: Different species of freshwater mussels can be dispersed by one to many fish species; fruit dispersal by animals.

Increase Vulnerability:	Completely or almost completely (roughly > 90%) dependent on a single species for propagule dispersal.For example, whitebark pine would fit here because Clark's nutcracker is the primary dispersal agent.
Somewhat Increase Vulnerability:	Completely or almost completely (roughly > 90%) dependent on a small number of species for propagule dispersal. For example, a freshwater mussel for which only a few species of fish can disperse larvae.
Neutral:	Disperses on its own (most animals, wind-dispersed plants) OR propagules can be dispersed by more than a few species (many plants).

e) Sensitivity to pathogens or natural enemies

NOTES: This factor refers to pathogens and natural enemies (e.g., predators, parasitoids, or herbivores) that can increase or become more pathogenic due to climate change, or vectors of disease when they expand their distributions due to changes in climate and therefore become more harmful or influence a greater portion of the distribution of the species being evaluated. Examples: the chytrid fungal pathogen that can become more harmful to frogs because of climate change (Pounds et al. 2006); 5-needled pines are sensitive to white pine blister rust (caused by *Cronartium ribicola*) and mountain pine beetle (*Dendroctonus ponderosae*), the spread and incidence of which may be affected by climate change (Tomback and Achuff 2010).

Increase Vulnerability:	Species is negatively affected to a high degree by a pathogen or natural enemy that is likely to increase in distribution, abundance, or impact as a result of climate change. Example: The cold-sensitive non-native hemlock woolly adelgid commonly causes a high level of mortality in eastern hemlock, and the distribution/abundance/impact of the adelgid may increase in areas where winter temperatures become milder.
Somewhat Increase Vulnerability:	Species is negatively affected to a moderate degree by a pathogen or natural enemy that is likely to increase in distribution, abundance, or impact as a result of climate change.
Neutral:	There is no indication that the species is currently or in the foreseeable future likely to be significantly affected by a pathogen or natural enemy that is likely to increase in distribution, abundance, or impact as a result of climate change; OR the negative impact of pathogens or natural enemies is likely to decrease with climate change. Example: A warmer/drier climate may reduce the negative impact of certain fungal pathogens that depend/thrive on relatively cold/moist conditions.

f) Sensitivity to competition from native or non-native species

NOTES. Species may suffer when competitors are favored by both changing climates and the effects these climates have on disturbance regimes (Abatzoglou and Kolden 2011, Dukes et al. 2011, Pintó-Marijuan and Munné-Bosch 2013, Grossman and Rice 2014). However, in some cases climate change will decrease the spread of particular invasive species (Bradley et al. 2010). To score this factor, some indication is needed that a potential competitor is favored by projected future climates.

Increase Vulnerability:	Strongly affected by a native or non-native competing species that is likely to be favored by climate change.

Somewhat Increase Vulnerability:	Moderately affected to a moderate degree by a native or non-native competing species that is likely to be favored by climate change.
Neutral:	Little or no response to a native or non-native species that is likely to shift its distribution or abundance due to climate change OR climate change is likely to decrease or have no effect on the spread or abundance of a native or non-native species that negatively impacts the species.

g) Forms part of an interspecific interaction not covered by C4a-f

NOTES: Can be applied to plants or animals. Here an interspecific interaction can include mutualism, parasitism, or commensalism. Refers to interactions unrelated to habitat, seedling establishment, diet, pollination, or propagule dispersal. For example, an acacia bush requiring an ant colony for protection against herbivores.

Increase Vulnerability:	Requires an interaction with a single other species for persistence.
Somewhat Increase Vulnerability:	Requires an interaction with a one member of a small group of taxonomically related species for persistence. Could also include cases where specificity is not known for certain, but is suspected. Many Orchidaceae will be in this category because of their requirement for a specific fungal partner for germination (Tupac Otero and Flanagan 2006).
Neutral:	Does not require an interspecific interaction or, if it does, many potential candidates for partners are available.

C5) Genetic Factors

a) Measured genetic variation

NOTES: Species with less standing genetic variation will be less able to adapt because the appearance of beneficial mutations is not expected to keep pace with the rate of 21st century climate change. Throughout this question, "genetic variation" may refer neutral marker variation, quantitative genetic variation, or both. To answer the question, genetic variation should have been assessed over a substantial proportion of a species' range.

Because measures of genetic variability vary across taxonomic groups, there cannot be specific threshold numbers to distinguish among the categories. The assessor should interpret genetic variation in a species relative to that measured in related species to determine if it is low, high, or in between.

Increase Vulnerability:	Genetic variation reported as "very low" compared to findings using similar techniques on related taxa, i.e., lack of genetic variation has been identified as a conservation issue for the species.
Somewhat Increase Vulnerability:	Genetic variation reported as "low" compared to findings using similar techniques on related taxa.
Neutral:	Genetic variation reported as "average" or "high" compared to findings using similar techniques on related taxa.

b) Occurrence of bottlenecks in recent evolutionary history (*<u>use only if C5a is "unknown"</u>*)

NOTES: In the absence of rangewide genetic variation information (C5a), this factor can be used to infer whether reductions in species-level genetic variation that would potentially impede its adaptation to climate change may have occurred. Only species that suffered population reductions and then subsequently rebounded qualify for the Somewhat Increase or Increase Vulnerability categories.

Increase Vulnerability:	Evidence that total population was reduced to ≤ 250 mature individuals, to one occurrence, and/or that occupied area was reduced by >70% at some point in the past 500 years.
Somewhat Increase Vulnerability:	Evidence that total population was reduced to 251-1000 mature individuals, to less than 10 occurrences, and/or that occupied area was reduced by 30-70% at some point in the past 500 years.
Neutral:	No evidence that total population was reduced to ≤ 1000 mature individuals and/or that occupied area was reduced by > 30% at some point in the past 500 years.

c) Reproductive system (plants only; *use only if C5a and C5b are "unknown"*)

NOTES: In plants, genetic variation is strongly linked to reproductive mode. Therefore, in the absence of measured genetic variation and knowledge of recent genetic bottlenecks, a plant's reproductive system may serve as a proxy for a species' genetic variation or capacity to adapt to novel climatic conditions. For example, species that can outcross may be better able to adapt to novel environments (Morran et al. 2009, Morran et al. 2011). Species with mixed mating systems, which make up 42% of the world's flora, appear to favor selfing as a buffering mechanism to climate change (Jones et al. 2013).

Increase Vulnerability:	Genetic variation of the species is assumed to be "very low" in the assessment area because the species is restricted to asexual reproduction (vegetatively or apomicticly). These species are expected to be negatively impacted because rapid climate change can strongly impact genetic variation, ultimately reducing fitness (Jump and Penuelas 2005).
Somewhat Increase Vulnerability:	Genetic variation assumed to be "low" in the assessment area due to known disruptions or barriers to gene flow among subpopulations, range disjunctions, or documented outbreeding depression (Franks et al. 2014). Reproductive system may be either mixed or obligate outcrossing.
Neutral:	Genetic variation is assumed to be "average" in the assessment area based on reproductive system. Includes species that have either mixed mating systems or are obligate outcrossers AND there are no known major disruptions to gene flow.

C6) Phenological Response to Changing Seasonal Temperature or Precipitation Dynamics

NOTES: Recent research suggests that some phylogenetic groups are declining due to lack of response to changing annual temperature dynamics (e.g., earlier onset of spring, longer growing season), including European bird species that have not advanced their migration times (Moller et al. 2008), and some temperate zone plants that are not moving their flowering times (Willis et al. 2008) to correspond to earlier spring onset.

TOOLS: Some phenological information can be gleaned from papers listed in the Inouye Phenology Database, https://www.mendeley.com/groups/2544001/inouye-pollinator-reference-database/.

Increase Vulnerability:	Seasonal temperature or precipitation dynamics within the species' range show detectable change, but phenological variables measured for the species show no detectable change.
Somewhat Increase Vulnerability:	Seasonal temperature or precipitation dynamics within the species' range show detectable change, and phenological variables measured for the species show some detectable change, but the change is significantly less than that of other species in similar habitats or taxonomic groups.
Neutral:	Seasonal temperature or precipitation dynamics within the species' range show detectable change, and phenological variables measured for the species show detectable change that is similar to, or significantly greater than, that of other species in similar habitats or taxonomic groups; OR seasonal dynamics within the species' range show no detectable change.

Section D. Documented or Modeled Response to Climate Change (*optional*)

D1) Documented Response to Recent Climate Change (e.g., range contraction or phenology mismatch with critical resources)

This factor pertains to the degree to which a species is known to have responded to recent climate change based on published accounts in the peer-reviewed literature. Time frame for the reduction or increase is 10 years or three generations, whichever is longer. Some global examples include population declines due to phenology mismatches between species and critical food or pollinator resources, e.g., great tits (*Parus major*) or pied flycatchers (*Ficedula hypoleuca*) with winter moth (*Operophtera brumata*) caterpillars, or European honey-buzzards (*Pernis apivorus*) with wasps.

Note that not all responses to climate change necessarily indicate vulnerability. Species that respond to climate change by shifting (but not contracting) their range, for example, show adaptability to climate change and should be scored as *Neutral* for this factor. Similarly, species that respond by changing their phenology (without a related decline in population) should also be scored as *Neutral*.

Greatly Increase Vulnerability:	Distribution or abundance undergoing major reduction (>70% over 10 years or three generations) believed to be associated with climate change..
Increase Vulnerability:	Distribution or abundance undergoing moderate reduction (30-70% over 10 years or three generations) believed to be associated with climate change.
Somewhat Increase Vulnerability:	Distribution or abundance undergoing small but measureable (10-30% over 10 years or three generations) believed to be associated with climate change.
Neutral:	Distribution and abundance not known to be decreasing with climate change. Includes species undergoing range shifts without loss of distributional area or species undergoing changes in phenology but no net loss in range size or population size. Includes species in which climate change is documented to be causing an increase in range size or abundance.

D2) Modeled Future (2050) Change in Range or Population Size

This factor can include both distribution models and population models. Models should be developed based on reasonably accurate locality data (error < 5km) using algorithms that are supported by peer-reviewed literature. Areas of obvious overprediction should be removed from current and predicted future distributions. Projections should be based on "middle of the road" climate scenarios for the year 2050. Range size should be based on "extent of occurrence" sensu IUCN Red List. Population models should be based on known processes as described in peer-reviewed literature. Examples include (a) phenological changes that are likely to result in a mismatch with critical dietary, pollination, or habitat resources (Visser and Both 2005) or (b) documented narrow temperature tolerances and thermal safely levels, particularly in insects (Deutsch et al. 2008, Calosi et al. 2008).

If necessary, check multiple boxes to reflect variation in model output.

Greatly Increase Vulnerability:	Predicted future range disappears entirely from the assessment area OR predicted future abundance declines to zero as a result of climate change processes.
Increase Vulnerability:	Predicted future range represents 50-99% decrease relative to current range within the assessment area OR predicted future abundance represents 50-99% decrease associated with climate change processes.
Somewhat Increase Vulnerability:	Predicted future range represents a 20-50% decrease relative to current range within the assessment area OR predicted future abundance represents 20-50% decrease associated with climate change processes.
Neutral:	Predicted future range represents an increase, no change, or a decrease of less than a 20% relative to current range within the assessment area OR predicted future abundance increases, remains stable, or decreases < 20% as a result of climate change processes.

D3) Overlap of Modeled Future (2050) Range with Current Range

NOTES: Distribution models of current and projected future ranges should meet standards described in the notes for D2. Overlap is calculated as the percent of the current range represented by an intersection of the predicted future and current ranges. If the range disappears or declines > 70% within the assessment area, such that factor D2 is coded as *Greatly Increase Vulnerability*, this factor should be skipped to avoid double-counting model results.

Greatly Increase Vulnerability:	There is no overlap between the current and predicted future range within the assessment area.
Increase Vulnerability:	Predicted future range overlaps the current range by 30% or less within the assessment area.
Somewhat Increase Vulnerability:	Predicted future range overlaps the current range by 30-60% within the assessment area.
Neutral:	Predicted future range overlaps the current range by > 60% within the assessment area.

D4) Occurrence of Protected Areas in Modeled Future (2050) Distribution

NOTES: "Protected area" refers to existing parks, refuges, wilderness areas, and other designated conservation areas that are relatively invulnerable to outright habitat destruction from human activities and that are likely to provide suitable conditions for the existence of viable populations of the species. Models of current and projected future ranges should meet standards described in the notes for D2. Modeled future distribution may refer to a single season (e.g., breeding season distribution or winter distribution) for migratory species. This factor considers ranges and protected areas within the assessment area only.

Increase Vulnerability:	< 5% of the modeled future distribution within the assessment area is encompassed by one or more protected areas.
Somewhat Increase Vulnerability:	5-30% of the modeled future distribution within the assessment area is encompassed by one or more protected areas.
Neutral:	>30% of the modeled future distribution within the assessment area is encompassed by one or more protected areas.

Results

Index Scores.—The final section displays the calculated Index scores and measures of confidence. The Index score defaults to "Insufficient Evidence" until the required heading information, Section A data, and the minimum number of factors in Sections B and C are completed. The Index scores (Box 3) provide a relative measure of vulnerability to climate change among the species assessed. Because the Index is based on factors that are associated with climate change, it is impossible to calculate numerical probabilities for decline. Nevertheless, the Index does separate species with numerous risk factors and a fast changing climate from those with fewer risk factors and/or a slower changing climate.

Box 3. Definitions of Index Scores

Extremely Vulnerable: Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

Highly Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.

Moderately Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease by 2050.

Less Vulnerable: Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.

Insufficient Evidence: Information entered about a species' vulnerability is inadequate to calculate an Index score.

Measures of Confidence.—To estimate confidence in the overall vulnerability score, the Index uses a Monte Carlo simulation to recalculate the Index using just one of the checked boxes for factors in which more than one box is checked. The simulation runs for 1,000 iterations and assumes that all checked boxes for a particular factor are equally likely. An accompanying histogram summarizes the frequency at which each vulnerability score resulted from the simulation runs, providing a graphical depiction of the confidence in the overall Index score. Species that score close to a threshold for a particular overall vulnerability score are more likely to have lower confidence in the score than species scoring in the middle of the range for a particular vulnerability score. In cases in which only one box was checked for each factor, the Monte Carlo results will always be exactly the same as the calculated Index score.

The Index also provides a measure of data completeness, or the number of factors scored in each of sections B, C, and D. Confidence in the score for a species is lower if fewer factors are scored because of the chance that a factor for which no information is available could in fact incur high vulnerability to the species. Note that the number of factors for section C varies between plants and animals (16 for each group), and lichens (15).

INTERPRETING YOUR RESULTS

A typical use of Index results is to sort species based on their vulnerability scores. Here are some ideas about how to interpret these lists.

Combining Results with Conservation Status.—Because the factors used for calculating Index scores are different from those used in evaluating conservation status, rankings from both systems should be combined in final analyses. After applying the Index, species within each vulnerability category should be compared based on their conservation status rank before setting priorities. Within the group of species that scored Extremely Vulnerable, those with more imperiled conservation status (i.e., lower G- or S-rank) would represent higher priorities, and so forth for the other categories of vulnerability. The simplest approach, therefore, is to sort species based first on their climate change vulnerability, and then within vulnerability categories by their conservation status. For an example, see Appendix 1.

Species placed in threatened conservation status categories on the basis of population size, range size, and/or demographic factors should be carefully considered because each factor can significantly increase vulnerability to climate change. Species with small populations tend to have less genetic variation that can allow adaptation to new climates and may be more vulnerable to stochastic events such as unusually extreme weather conditions or a disease outbreak (Hampe 2004, Aitken et al. 2008). If climate change will cause a large range displacement, then species with small ranges will be more likely to have future preferred ranges disjunct from current distributions, suffering greater extinction risk due to possible dispersal failure or greatly decreased range size (Schwartz et al. 2006). Species with long generation times may not be able to respond quickly enough to keep up with change (Simmons et al. 2004, Hawkins et al. 2008). Species with these characteristics should be placed as the highest priorities in their vulnerability group.

Using Vulnerability Index Results to Inform a Conservation Status Assessment.—Currently NatureServe does not have official guidance on the relation between Index scores and conservation status ranks. As mentioned previously, the Index uses factors that are largely different from those used in NatureServe conservation status assessments via the Rank Calculator (Master et al. 2012). Therefore, using Index output could, in theory, be used to inform the threat portion of a status assessment. The key challenge, though, is the issue of time horizon. Threats are scored in the Rank Calculator based on their scope within the next 10-20 years and severity over the next 3 generations or 10 years, whichever is longest. The Index assesses vulnerability using a climate exposure horizon of mid 21st century. Although Master et al. (2012) suggest that the time frame can be extended for threats such as global warming, so far there are no guidance on how to do this. If the generation time is in the 10-15 year range, then the time horizons of the two tools match up and the Index score could directly indicate the severity to use for the threat score. If the species has a shorter generation time, the threat severity should be scored lower than indicated by the Index score.

Factors Causing Vulnerability.—Examination of factors that repeatedly cause species to fall into categories of high vulnerability can point to useful management strategies. The Results Table provides an easy way to scan how multiple species scored against the Index factors. See Appendix 2 for an example. Box 7 lists some sample suggestions for management actions to address some of these4factors.

Species Moving Into or Out of the Assessment Area.—Receiving an Index score of Less Vulnerable does not mean that a species will remain in the assessment area. The species may be a good disperser and track changing climate well, moving its distribution north and/or upslope and potentially out of the assessment area. Vulnerable species may also disperse out of the assessment area, whereas other species currently distributed to the south or down slope may move in. Managers may want to place more attention on species moving in than on those moving out. Species that are vulnerable to climate change throughout their ranges are potentially at the greatest risk.

Box 4. Possible management actions.

Developing adaptation strategies requires careful consideration to many management issues. The following suggestions are illustrative to the many options potentially available to managers. See Stein et al. (2014) for an in-depth discussion of adaptation strategies.

Vulnerability Factor	Possible Management Actions
Distribution limited by anthropogenic barriers	• construct dispersal corridors • translocate individuals* to suitable habitats
Distribution limited by natural barriers or dispersal ability; occurs in ice-edge or snow-cover habitat	• translocate individuals* to suitable habitats
Impacted by mitigation activities such as windfarms or biofuels development	• work with implementing industries to adopt wildlife friendly practices • initiate research to identify best practices
Aquatic species threatened by increased water temperature	• release cooler water from the bottoms of reservoirs rather than the warmer surface water
Impacted by changed disturbance regime	• implement management practices to minimize fire intensity
Lack of genetic variability	• translocate individuals* or facilitate gene flow between populations to increase genetic diversity

* Also known as assisted migration or assisted translocation. Note that translocating individuals is a controversial action because of potentially conflicting goals, one of which may be to preserve unique subpopulations and genotypes (Hoegh-Guldberg et al. 2008), and should be considered with caution.

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BIBLIOGRAPHY

Abatzoglou, J. T., and C. A. Kolden. 2011. Climate Change in Western US Deserts: Potential for Increased Wildfire and Invasive Annual Grasses. Rangeland Ecology & Management 64:471-478.

AdaptWest Project. 2015. Gridded current and projected climate data for North America at 1km resolution, interpolated using the ClimateNA v5.10 software (T. Wang et al., 2015). Available at adaptwest.databasin.org

Aitken, S. N., S. Yeaman, J. A. Holliday, T. Wang, and S. Curtis-McLane. 2008. Adaptation, migration, or extirpation: climate change outcomes for tree populations. Evolutionary Applications 1:95-111.

Archer, S. R., and K. I. Predick. 2008. Climate change and ecosystems of the southwestern United States. Rangelands 2008(June):23-28.

Association of Fish and Wildlife Agencies (AFWA). 2009. Voluntary guidance for states to incorporate climate change into state wildlife action plans and other management plans. AFWA, Washington, D.C. Available: www.fishwildlife.org/pdfs/ClimateChangeGuidance%20Document_Final_reduced%20size.pdf.

Benito Garzón, M., R. Sánchez de Dios, and H. Sainz Ollero. 2008. Effects of climate change on the distribution of Iberian tree species. Applied Vegetation Science 11:169-178.

Bradley, B. A., D. M. Blumenthal, D. S. Wilcove, and L. H. Ziska. 2010. Predicting plant invasions in an era of global change. Trends in Ecology & Evolution 25:310-318.

Brooks, R. T. 2009. Potential impacts of global climate change on the hydrology and ecology of ephemeral freshwater systems of the forests of the northeastern United States. Climatic Change 95:469–483. Available: www.nrs.fs.fed.us/pubs/9674.

Bruno, J. F., J. J. Stachowicz, and M. D. Bertness. 2003. Inclusion of facilitation into ecological theory. Trends in Ecology and Evolution 18:119-125.

Calosi, P., D. T. Bilton, and J. I. Spicer. 2008. Thermal tolerance, acclimatory capacity and vulnerability to global climate change. Biology Letters 4:99-102.

Culver, D. C., M. C. Christman, W. R. Elliott, H. H. Hobbs, III, and J. R. Reddell. 2003. The North American obligate cave fauna: regional patterns. Biodiversity and Conservation 12:441-468.

Cushing, P. E. 1997. Myrmecomorphy and myrmecophily in spiders: a review. Florida Entomologist 80:165-193.

Deutsch, C. A., J. J. Tewksbury, R. B. Huey, K. S. Sheldon, C. K. Ghalambor, D. C. Haak, and P. R. Martin. 2008. Impacts of climate warming on terrestrial ectotherms across latitude. Proceedings of the National Academy of Sciences (USA) 105:6668-6672.

Dukes, J. S., N. R. Chiariello, S. R. Loarie, and C. B. Field. 2011. Strong response of an invasive plant species (Centaurea solstitialis L.) to global environmental changes. Ecological Applications 21:1887-1894.

Dyer, J. M. 1995. Assessment of climatic warming using a model of forest species migration. Ecological Modeling 79:199-219.

Enquist, C., and D. Gori. 2008. A Climate Change Vulnerability Assessment for Biodiversity in New Mexico, Part I: Implications of Recent Climate Change on Conservation Priorities in New Mexico. The Nature Conservancy, New Mexico.

Franks, S. J., J. J. Weber, and S. N. Aitken. 2014. Evolutionary and plastic responses to climate change in terrestrial plant populations. Evolutionary Applications 7:123-139.

Girvetz, E. H., C. Zganjar, G. T. Raber, E. P. Maurer, P. Kareiva, and J. J. Lawler. 2009 Applied climate-change analysis: the climate wizard tool. PLoS ONE 4: e8320. doi:10.1371/journal.pone.0008320.

Glick, P., B. A. Stein, and N. A. Edelson (editors). 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, DC. Available: www.nwf.org/vulnerabilityguide

The Gran Canaria Declaration II on Climate Change and Plant Conservation. 2006. Published by the Area de Medio Ambiente y Aguas del Cabildo de Gran Canaria Jardín Botánico Canario "Viera y Clavijo" and Botanic Gardens Conservation International. Available: www.bgci.org/files/All/Key_Publications/gcdccenglish.pdf.

Grossman, J. D., and K. J. Rice. 2014. Contemporary evolution of an invasive grass in response to elevated atmospheric CO2 at a Mojave Desert FACE site. Ecology Letters 17:710-716.

Hamann, A., T. Wang, D. L. Spittlehouse, and T. Q. Murdock. 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. Bulletin of the American Meteorological Society 94: 1307-1309.

Hamon, W. R. 1961. Estimating potential evapotranspiration: Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 87:107-120.

Hampe, A. 2004. Bioclimatic envelope models: what they detect and what they hide. Global Ecology and Biogeography 13:469-471.

Hamilton-Smith, E. and B. Finlayson. 2003. Beneath the surface: a natural history of Australian caves. University of New South Wales Press Ltd, Sydney, Australia.

Hawkins, B., Sharrock, S. and Havens, K., 2008. Plants and climate change: which future? Botanic Gardens Conservation International, Richmond, United Kingdom.

Hegland, S. J., Nielsen, A., Lázaro, A., Bjerknes, A.-L. and Totland, Ø. 2009 How does climate warming affect plant-pollinator interactions? Ecology Letters 12:184-195. doi: 10.1111/j.1461-0248.2008.01269.x

Hoegh-Guldberg, O., L. Hughes, S. McIntyre, D. B. Lindenmayer, C. Parmesan, H. P. Possingham, C. D. Thomas. 2008. Assisted colonization and rapid climate change. Science

Huntley, B. 2005. North temperate responses. pg. 109-124 in Lovejoy, T. E. and L. Hannah, eds. Climate Change and Biodiversity. Yale University Press, New Haven, Connecticut.

Intergovernmental Panel on Climate Change (IPCC). 2002. Climate Change and Biodiversity (IPCC Technical Paper V). Gitay, H., A. Suárez, R. T. Watson, and D. Jon Dokken, eds. Available: www.grida.no/climate/ipcc_tar/biodiv/pdf/bio_eng.pdf.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. Available: www.ipcc.ch/ipccreports/ar4-wg2.htm.

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY. Available: http://ipcc.ch/report/ar5/wg1/

Jiguet, F., A.-S. Gadot, R. Julliard, S. E. Newson, and D. Couvet. 2007. Climate envelope, life history traits and the resilience of birds facing climate change. Global Change Biology 13:1672-1684.

Johnson, G. D., W. P. Erickson, M. D. Strickland, M. F. Shepherd, D. A. Shepherd, and S. A. Sarappo. 2003. Mortality of bats at a large-scale wind power development at Buffalo Ridge, Minnesota. American Midland Naturalist 150:332-342.

Jones, N. T., B. C. Husband, and A. S. MacDougall. 2013. Reproductive system of a mixed-mating plant responds to climate perturbation by increased selfing. Proceedings of the Royal Society B 280: 20131336.

Jump, A. S. and J. Peñuelas. 2005. Running to stand still: adaptation and the response of plants to rapid climate change. Ecology Letters 8:1010-1020.

Koerner, C. 2005. The Green Cover of Mountains in a Changing Environment, pp. 367-375 in Huber, U. M., M. A. Reasoner, and H. K. M. Bugmann (eds.). Global Change and Mountain Regions: An Overview of Current Knowledge. Springer-Verlag, New York.

Krawchuk, M. A. Krawchuk, M. A. Moritz, M.-A. Parisien, J. Van Dorn, and K. Hayhoe. 2009. Global pyrogeography: The current and future distribution of wildfire. PLoS ONE 4:e5102. Available: www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0005102

Laidre, K. L., I. Stirling, L. F. Lowry, O. Wiig, M. P. Heide-Jørgensen, and S. H. Ferguson. 2008. Quantifying the sensitivity of arctic marine mammals to climate-induced habitat change. Ecological Applications 18:S97-S125.

Lamoreux, J. 2004. Stygobites are more wide-ranging than troglobites. Journal of Cave and Karst Studies 66 :18-19.

Lawler, J. J., S. L. Shafer, and A. R. Blaustein. 2009. Projected climate impacts for the amphibians of the Western Hemisphere. Conservation Biology 24:38-50.

Lenoir, J., J. C. Gégout, P. A. Marquet, P. de Ruffray, and H. Brisse. 2008. A significant upward shift in plant species optimum elevation during the 20th century. Science 320:1768-1771.

Loarie, S. R., B. E. Carter, K. Hayhoe, S. McMahon, R. Moe, C. A. Knight, and D. D. Ackerly. 2008. Climate change and the future of California's endemic flora. PLoS ONE 3:e2502.

Loarie, S. R., P. B. Duffy, H. Hamilton, G. P. Asner, C. B. Field, and D. D. Ackerly. 2009. The velocity of climate change. Nature 462:1052-1055.

Marsh, D. L. 1977. The taxonomy and ecology of cane, *Arundinaria gigantea* (Walter) Muhlenburg. Ph.D. dissertation, University of Arkansas, Fayetteville, Arkansas.

Master, L. L., D. Faber-Langendoen, R. Bittman, G. A. Hammerson, B. Heidel, L. Ramsay, and A. Tomaino. 2009. NatureServe conservation status assessments: factors for assessing extinction risk. NatureServe, Arlington, Virginia, U.S.A. Available: www.natureserve.org/sites/default/files/publications/files/natureserveconservationstatusfactors_apr12.pdf .

Mathews, K. G., J. Huguelet, M. Lanning, T. Wilson, and R. S. Young. 2009. Clonal diversity of *Arundinaria gigantea* (Poaceae; Bambusoideae) in western North Carolina and its relationship to sexual reproduction: an assessment using AFLP fingerprints. Castanea 74:213-223.

Meentemeyer, R. K., N. J. Cunniffe, A. R. Cook, J. A. N. Filipe, R. D. Hunter, D. M. Rizzo, and C. A. Gilligan. 2011. Epidemiological modeling of invasion in heterogeneous landscapes: spread of sudden oak death in California (1990–2030). Ecosphere 2:1-24.

Midgley, G. F., L. Hannah, D. Millar, W. Thuiller, and A. Booth. 2003. Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. Biological Conservation 112:87-97.

Møller, A. P., D. Rubolini, and E. Lehikoinen. 2008. Populations of migratory bird species that did not show a phenological response to climate change are declining. Proceedings of the National Academy of Sciences (USA) 105:16195-16200.

Morran, L. T., M. D. Parmenter, P. C. Phillips. 2009. Mutation load and rapid adaptation favour outcrossing over self-fertilization. Nature 462:350-352.

Morran, L. T., O. G. Schmidt, I. A. Gelarden, R. C. Parrish II, C. M. Lively. 2011. Running with the Red Queen: host-parasite coevolution selects for biparental sex. Science 333:216-218.

Nott, M. P., D. F. Desante, R. B. Siegel and P. Pyle. 2002. Influences of the El Niño/Southern Oscillation and the North Atlantic Oscillation on avian productivity in forests of the Pacific Northwest of North America. Global Ecology and Biogeography 11:333–342.

Ohlemüller, R., B. J. Anderson, M. B. Araújo, S. H. M. Butchart, O. Kudrna, R. S. Ridgely, and C. D. Thomas. 2008. The coincidence of climatic and species rarity: high risk to small-range species from climate change. Biology Letters 4:568-572.

Pacifici, M., W. B. Foden, P. Visconti, J. E. M. Watson, S. H.M. Butchart, K. M. Kovacs, B. R. Scheffers, D. G. Hole, T. G. Martin, H. R. Akçakaya, R. T. Corlett, B. Huntley, D. Bickford, J. A. Carr, A. A. Hoffmann, G. F. Midgley, P. Pearce-Kelly, R. G. Pearson, S. E. Williams, S. G. Willis, B. E. Young, and C. Rondinini. 2015. Assessing species vulnerability to climate change. Nature Climate Change DOI: 10.1038/NCLIMATE2448

Parmesan, C. 1996. Climate change and species' range. Nature 382:765-766.

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

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

Peterson, A. T., M. A. Ortega-Huerta, J. Bartley, V. Sanchez-Cordero, J. Soberon, R. H. Buddemeier, and D. R. B. Stockwell. 2002. Future projections for Mexican faunas under global climate change scenarios. Nature 416:626-629.

Pfeffer, W. T., J. T. Harper, and S. O'Neil. 2008. Kinematic constraints on glacier contributions to 21st-century sea-level rise. Science 321:1350-1343.

Pintó-Marijuan, M., and S. Munné-Bosch. 2013. Ecophysiology of invasive plants: osmotic adjustment and antioxidants. Trends in Plant Science 18:660-666.

Pounds, J. A., M. R. Bustamante, L. A. Coloma, J. A. Consuegra, M. P L. Fogden, P. N. Foster, E. La Marca, K. L. Masters, A. Merino-Viteri, R. Puschendorf, S. R. Ron, G. A. Sánchez-Azofeifa, C. J.

Still, and B. E. Young. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. Nature 439:161-167.

Price, M. F. 2008. Maintaining mountain biodiversity in an era of climate change In Borsdorf, A, J. Stötter and E. Veulliet (eds.) Managing Alpine Future. Proceedings of International Conference October 15-17, 2007: Austrian Academy of Sciences Press, Vienna: 17-33.

Root T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig, and J. A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. Nature 421:57-60.

Saetersdal, M., and H. J. B. Birks. 1997. A comparative ecological study of Norwegian mountain plants in relation to possible future climatic change. Journal of Biogeography 24:127-152.

Schwartz, M. W., L. R. Iverson, A. M. Prasad, S. N. Mathews, and R. J. O'Conner. 2006. Predicting extinctions as a result of climate change. Ecology 87:1611-1615.

Schneider, S. H., S. Semenov, A. Patwardhan, I. Burton, C. H. D. Magadza, M. Oppenheimer, A. B. Pittock, A. Rahman, J. B. Smith, A. Suarez, and F. Yamin. 2007. Assessing key vulnerabilities and the risk from climate change. Pages 779-810 in Climate Change 2007: Impacts, Adaptation and Vulnerability, edited by M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Simmons, R. E., P. Barnard, W. R. J. Dean, G. F. Midgley, W. Thuiller, and G. Hughes. 2004. Climate change and birds: perspectives and prospects from southern Africa. Ostrich 75:295-308.

Small-Lorenz, S.L., L. A. Culp, T. B. Ryder, T. C. Will, and P. P. Marra. 2013. A blind spot in climate change vulnerability assessments. Nature Climate Change 3:91-93.

Stein, B. A., P. Glick, N. Edelson, and A. Staudt. 2014. Climate-Smart Conservation: Putting Principles into Practice. National Wildlife Federation, Washington, DC.

Stirling, I., and C. L. Parkinson. 2006. Possible effects of climate warming on selected populations of polar bears (*Ursus maritimus*) in the Canadian arctic. Arctic 59:261-275.

Studds, C. E., and P. P. Marra. 2011. Rainfall-induced changes in food availability modify the spring departure programme of a migratory bird. Proceedings of the Royal Society B. doi:10.1098/rspb.2011.0332

Taylor, S.H., S.P. Hulme, M. Rees, B.S. Ripley, F.I. Woodward and C.P. Osborne. 2010. Ecophysiological traits in C3 and C4 grasses: a phylogenetically controlled screening experiment. New Phytologist 185: 780-791.

Thomas, C. D. 2005. Recent evolutionary effects of climate change. Pages 75-88 in Climate change and biodiversity, edited by T. E. Lovejoy and L. Hannah. Yale University Press, New Haven, Connecticut.

Thomas, C. D., A. Cameron, R. E. Green, et al. 2004. Extinction risk from climate change. Nature 427:145-148.

Thuiller, W., S. Lavorel, M. B. Araújo, M. T. Sykes, and I. C. Prentice. 2005. Climate change threats to plant diversity in Europe. Proceedings of the National Academy of Sciences 102: 8245–8250.

Tupac Otero, J., and N. S. Flanagan. 2006. Orchid diversity – beyond deception. Trends in Ecology and Evolution 21:64–65.

van der Pijl, L. 1961. Ecological aspects of flower evolution. III. Zoophilous flower classes. Evolution 15: 44-59.

Visser, M. E., and C. Both. 2005. Shifts in phenology due to global climate change: the need for a yardstick. Proceedings of the Royal Society B 272:2561-1569.

Vittoz, P., and R. Engler. 2007. Seed dispersal distances: a typology based on dispersal modes and plant traits. Bot. Helv. 117:109–124.

Wang, T., A. Hamann, D. L. Spittlehouse, and T. Q. Murdoch. 2012. ClimateWNA—high-resolution spatial climate data for western North America. Journal of Applied Meteorology and Climatology 51:16-29.

Waser, N. M., L. Chittka, M. V. Price, N. M. Williams and J. Ollerton. 1996. Generalization in pollination systems, and why it matters. Ecology 77:1043-1060.

Williams, J. W., S. T. Jackson, and J. E. Kutzbach. 2007. Projected distributions of novel and disappearing climates by 2100 AD. Proceedings of the National Academy of Sciences (USA) 104: 5738-5742.

Williams, P., L. Hannah, S. Andelman, G. Midgley, M. Araújo, G. Hughes, L. Manne, E. Martinez-Meyer, and R. Pearson. 2005. Planning for climate change: identifying minimum dispersal corridors for the Cape Proteaceae. Conservation Biology 19:1063-1074.

Williams, S. E., L. P. Shoo, J. L. Isaac, A. A. Hoffmann, and G. Langham. 2008. Towards an integrated framework for assessing the vulnerability of species to climate change. Plos Biology 6:2621-2626.

Willis, C. G., B. Ruhfel, R. B. Primack, A. J. Miller-Rushing, and C. C. Davis. 2008. Phylogenetic patterns of species loss in Thoreau's woods are driven by climate change. Proceedings of the National Academy of Sciences (USA) 105:17029-17033.

Willmer, P. 2011. Pollination and Floral Ecology. Princeton University Press, Princeton, New Jersey, USA. 778 pp.

Wilson, S. S. L. Ladeau, A. P. Tøttrup, and P. P. Marra. 2011. Range-wide effects of breeding- and nonbreeding-season climate on the abundance of a Neotropical migrant songbird. Ecology 92:1789-1798.

Young, B. E., K. R. Hall, E. Byers, K. Gravuer, G. Hammerson, A. Redder, and K. Szabo. 2012. Rapid assessment of plant and animal vulnerability to climate change. Pages 129-150 in Wildlife Conservation in a Changing Climate, edited by J. Brodie, E. Post, and D. Doak. University of Chicago Press, Chicago, IL.

Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2015a. Guidelines for Using the NatureServe Climate Change Vulnerability Index, Release 3.0. NatureServe, Arlington, VA.

Young, B. E., N. S. Dubois, and E. L. Rowland. 2015b. Using the Climate Change Vulnerability Index to inform adaptation planning: lessons, innovations, and next steps. Wilson Society Bulletin 39:174-181.

GLOSSARY

Alpine life zone: The vegetative life zone above the climatic treeline. Climatic treeline (as opposed to anthropogenically cleared areas below treeline) occurs at elevations where the mean monthly temperature during the growing season is below 44^{o}F +-1^{o}F.

Climate envelope: The suite of climatic conditions (such as temperature, precipitation, and seasonality) that represent the conditions under which populations of a species currently persist in the face of competitors and natural enemies.

Hanging garden: A vegetation community formed on cliff faces where water permanently seems out of a crack in the rock. The vegetation typically drapes over the cliff face.

Lek: A traditional place where males assemble during the mating season and engage in competitive displays that attract females.

Monocarpic: Plants that flower and set seeds once and then die.

Occurrence: An occurrence is an area of land and/or water in which a species or ecosystem is, or was, present. An occurrence should have practical conservation value for the species or ecosystem as evidenced by historical or potential continued presence and/or regular recurrence at a given location. For species, the occurrence often corresponds with the local population, but when appropriate may be a portion of a population (e.g., long distance dispersers) or a group of nearby populations (e.g., metapopulation).

Sodic soils: Soils with high sodium content, often found in arid regions.

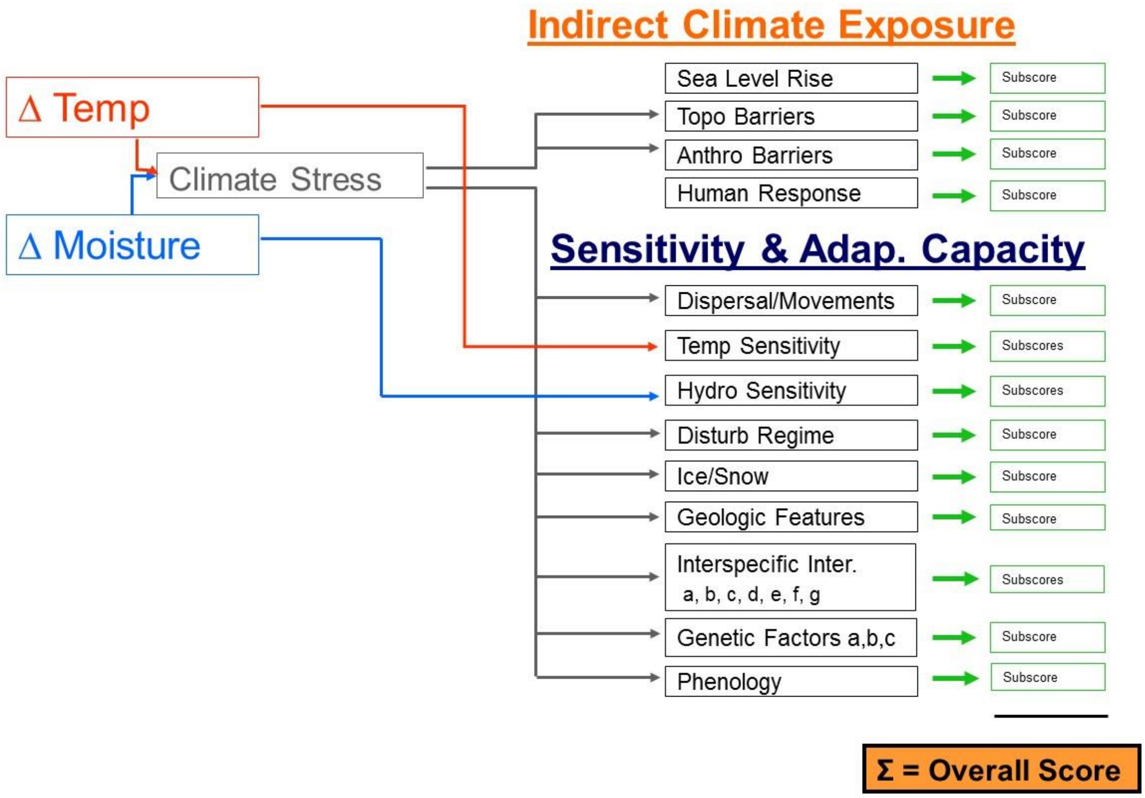

Figure 1. Relation between exposure to local climate change and sensitivity factors.

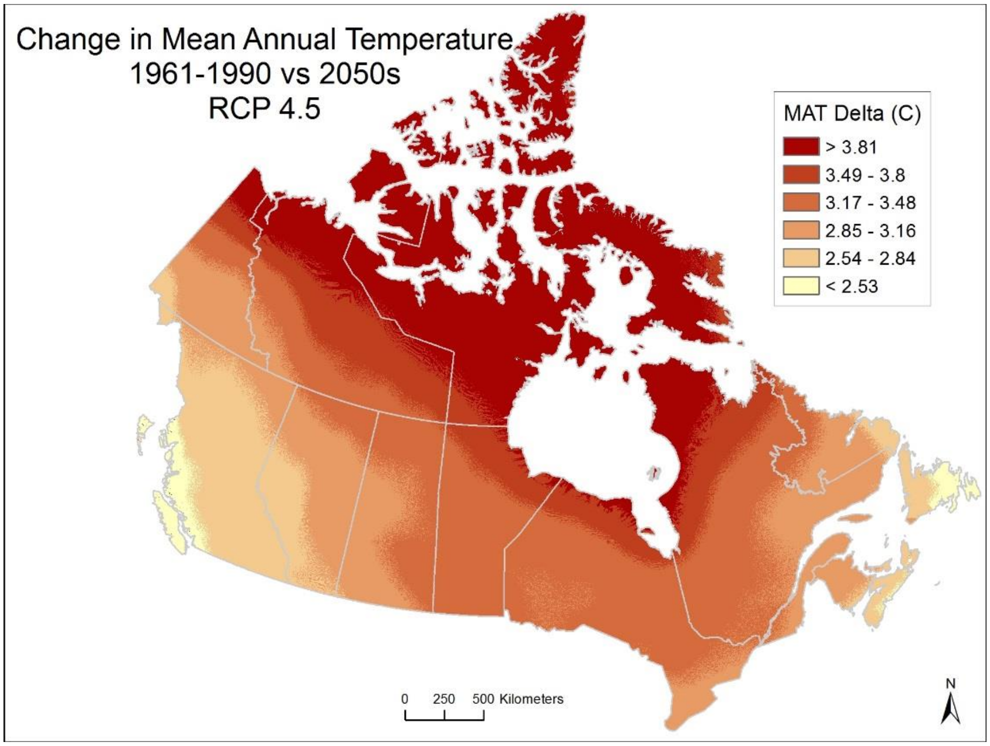

Figure 2. Projected change in mean annual temperature.

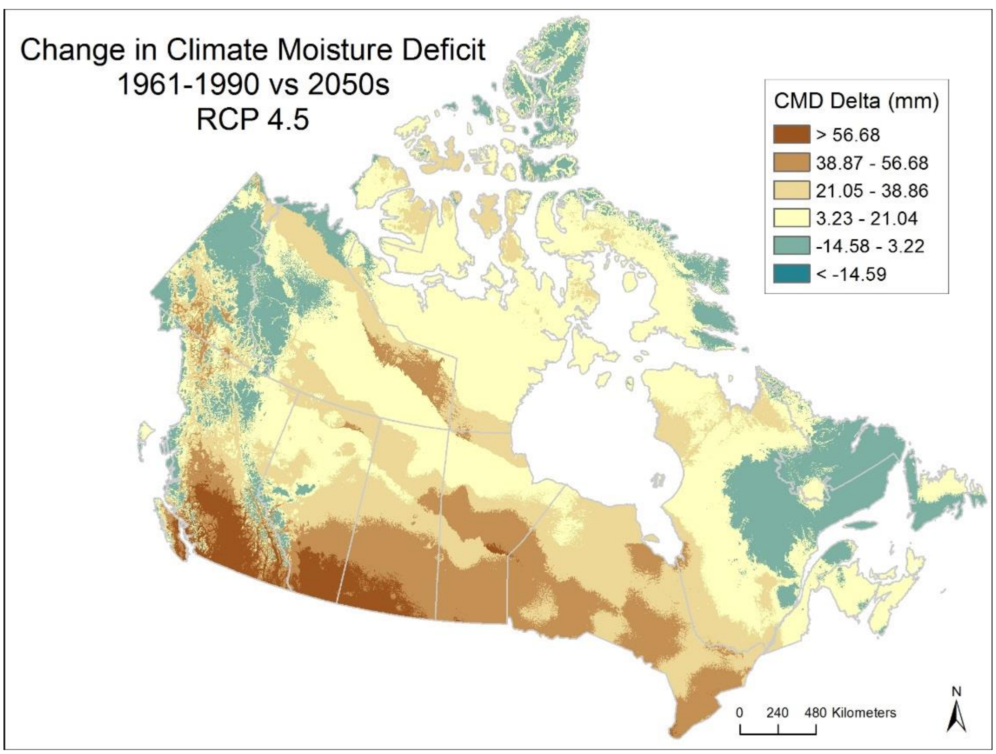

Figure 3. Projected change in moisture availability using climate moisture metric.

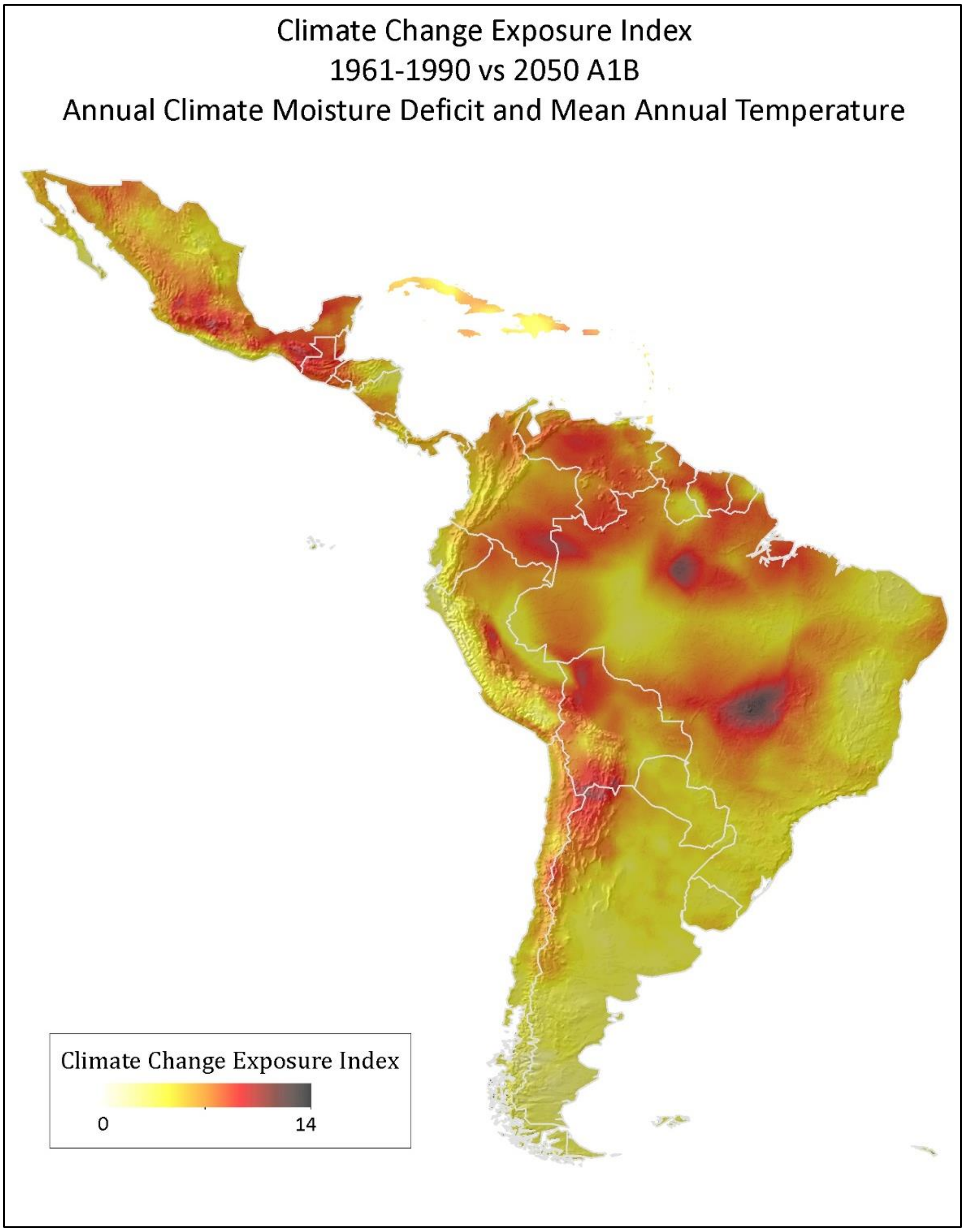

Figure 4. Climate Change Exposure Index for ranges of migratory species.

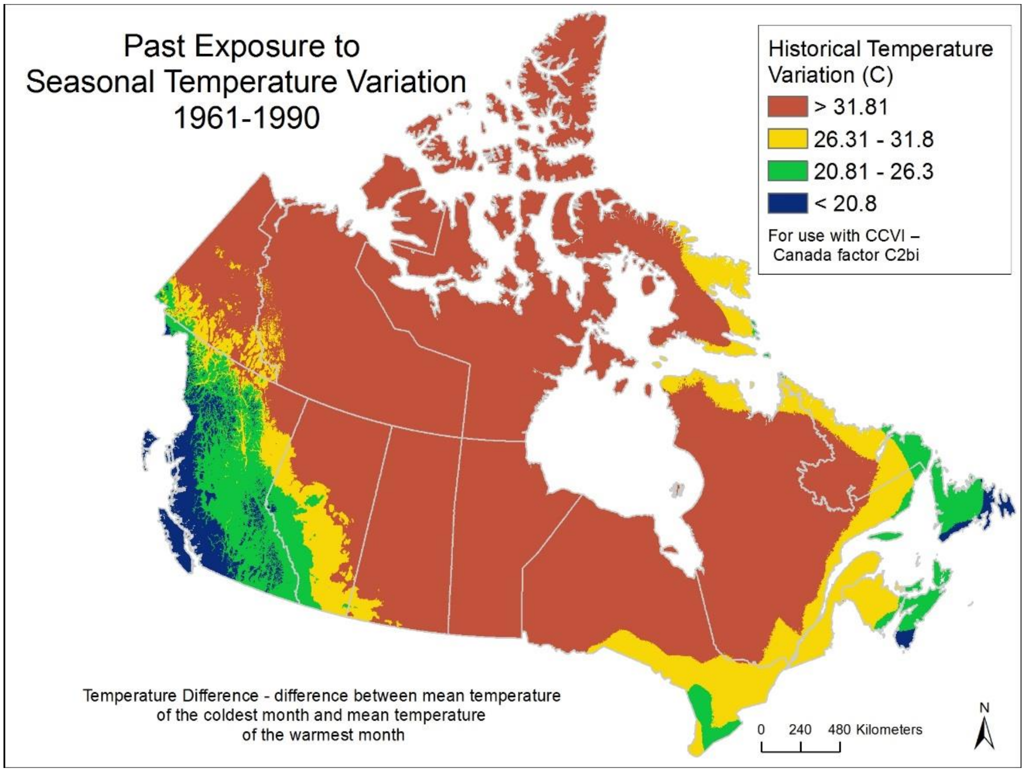

Figure 5. Past exposure to temperature variation for factor C2ai.

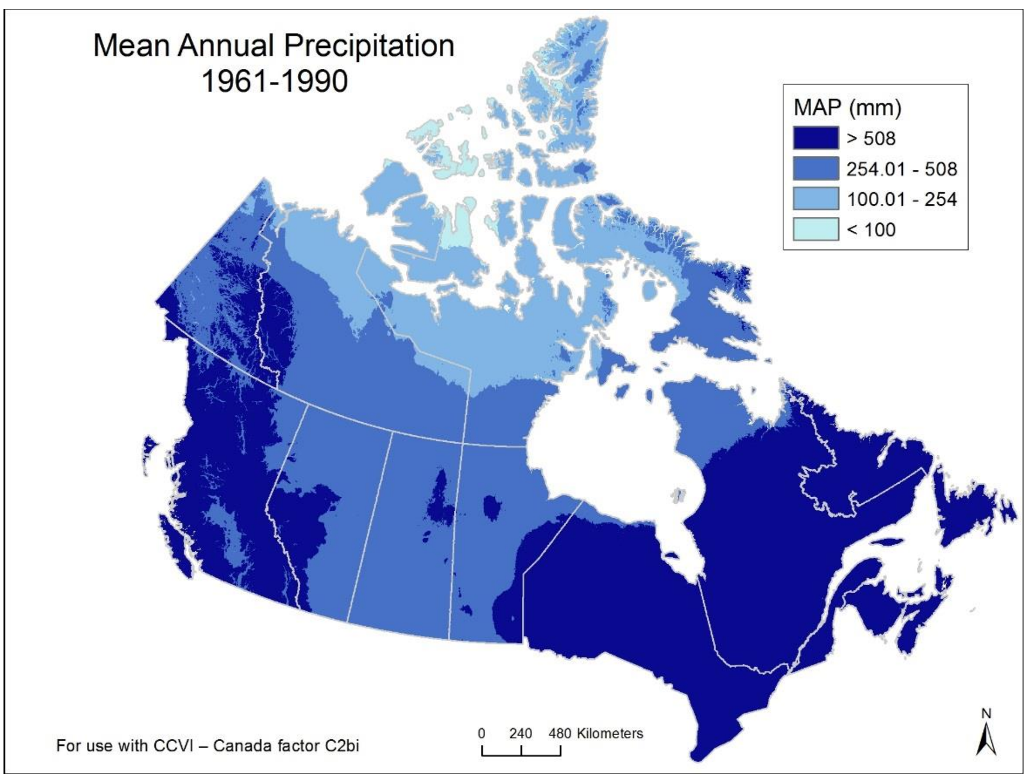

Figure 6. Past exposure to precipitation variation for factor C2bi.

Appendix 1. Vulnerability to climate change of 13 plant and animal species from Nevada. The species were chosen because of concern that they might either decline or increase and displace other species as a result of climate change. The species are ordered by Index score and then S-rank. Scores are from preliminary assessments completed in 2009 using a previous version of the Index and are presented for illustration purposes.

Group	Species	English Name	Index Score	S-rank	G-rank
Mammal	*Aplodontia rufa*	Mountain beaver	Extremely Vulnerable	S1	G5
Fish	*Rhinichthys osculus oligoporus*	Clover Valley speckled dace	Highly Vulnerable	S1	G5T1
Butterfly	*Limenitis archippus lahontani*	Nevada viceroy	Highly Vulnerable	S1S2	G5T1T2
Mammal	*Ochotona princeps*	American pika	Highly Vulnerable	S2	G5
Mammal	*Sorex palustris*	Water shrew	Highly Vulnerable	S2	G5
Fish	*Oncorhynchus clarkii henshawi*	Lahontan cutthroat trout	Highly Vulnerable	S3	G4T3
Amphibian	*Rana pipiens*	Northern leopard frog	Moderately Vulnerable	S2	G5
Plant	*Draba cusickii* var. *pedicellata*	Cusick's whitlow-grass	Moderately Vulnerable	S3	G4T3
Bird	*Leucosticte atrata*	Black rosy-finch	Moderately Vulnerable	S3	G4
Plant	*Populus tremuloides*	Quaking aspen	Moderately Vulnerable	SNR	G5
Plant	*Asclepias eastwoodiana*	Eastwood milkweed	Less Vulnerable	S2	G2
Reptile	*Phrynosoma platyrhinos*	Desert horned lizard	Less Vulnerable	S4	G5
Bird	*Quiscalus mexicanus*	Great-tailed grackle	Less Vulnerable	S5	G5

Appendix 2. Factors contributing to vulnerability status of selected Nevada plants and animals. The factors shown are a subset of the factors used in the Index, and more colors are used than the default for the Results Table of the Index. Species are scored on how a factor affects its vulnerability (GI, Greatly Increase; Inc, Increase; SI, Somewhat Increase; N, Neutral; U, Unknown). The abbreviations for Index Score refer to the corresponding scores shown in Appendix 1. For these species, natural dispersal barriers, dispersal ability, and micro-scale precipitation tolerance are the most important factors causing vulnerability to climate change. Scores are from preliminary assessments completed in 2009 using a previous version of the Index and are presented for illustration purposes.

Species	Natural barriers	Anthropogenic barriers	Dispersal & movements	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydrological niche	Dependence on ice/snow	Restriction to geological feature	Dietary versatility	Genetic variation	**Index Score**
Aplodontia rufa	Inc	N	Inc	SI	SI	Inc-SI	N	N	N	N	U	EV
Rhinichthys osculus oligoporus	N	N	Inc	N	N	GI-Inc	GI	N	N	N	U	HV
Limenitis archippus lahontani	N	N	Inc	N	SI	SI	GI	N	N	Inc	U	HV
Ochotona princeps	GI-Inc	N	SI	SI-N	N	SI-N	N	N	Inc	N	U	HV
Sorex palustris	Inc	N	Inc	N	SI	SI-N	GI-Inc	N	N	N	U	HV
Oncorhynchus clarkii henshawi	N	N	N	N	Inc-SI	SI	Inc-SI	N	N	N	U	HV
Rana pipiens	N	N	N	N	SI	SI	GI-Inc	N	N	N	U	MV
Draba cusickii var. *pedicellata*	N	N	Inc	N	SI-N	SI	N	N	SI	N/A	U	MV
Leucosticte atrata	GI	N	N	SI	U	SI	N	SI	Inc-SI	N	U	MV
Populus tremuloides	N	N	GI	N-SD	Inc	SI-N	SI	N	N	N/A	N	MV
Asclepias eastwoodiana	N	N	SI	N	N	SI	Inc	N	N	N/A	U	LV
Phrynosoma platyrhinos	N	N	N	N	SD	Inc-SI	N	N	N	SI	U	LV
Quiscalus mexicanus	N	N	N	N	N	N	N	N	N	N	U	LV

Appendix 3. Notes on quantitative GIS assessment of factors A, C2ai, and C2bi

There are many ways to come up with the quantitative data needed to score the map-based factors (A, C2ai, C2bi). They can be simply visually estimated from the maps. If you have species range maps in a GIS file, you can calculate the factors and automate the process to some extent. This appendix explains one method of quantifying the scores for the map-based factors. Experienced GIS users should feel free to use any method they choose.

Species Range Map

You will need a species range map that is as accurate as possible. The assessor providing the map should include notes explaining the relationship of the map to the actual species range. For example, if the map is based on county occurrences, it may overestimate the actual species range. Conversely, if the map is based on known occurrences, it may underestimate the true range. If there are known habitat restrictions within the range (e.g., north-facing slopes, riparian zones) that are not already delineated by the range map, these should be noted as well.

Most range maps will be submitted as shapefiles or as hand-drawn maps which can be digitized into shapefiles. You will want to convert your shapefile(s) into a raster file for easier calculation of some of the factors. This can be done in ArcGIS as follows:

1. Open the attribute file of the range shapefile in ArcMap. Add a numeric (byte) field which you can name Field1. Start editing the file, and set all the values for Field1 = 1. Save your edits, stop editing, and close the attribute file.
2. Open ArcToolbox and select "Conversion Tools/To Raster/Polygon to Raster". Set your output to GRID (add no file extension to specify an Esri Grid raster format) and be sure to keep the filename to 13 characters or less. Set the cell size to the same as or smaller than the raster climate files you will be working with, i.e., cell size = 0.04 for the Index files downloaded from the NatureServe website. Specify Value as Field1.
3. Display (in ArcMap) the raster file you have just created to verify that it matches the input shapefile.

Factor A: Predicted Exposure to Temperature and Moisture Changes

For this factor, you will overlay the range map on the temperature and moisture maps and calculate the percentage of the range that falls into each category, as specified in Factor A of the Index. Remember to consider any explanatory notes relating the range map to the actual range of the species in creating your final percentages.

1. Make your GRID range map and the "Annual Temperature 2040-2069" coverages visible in ArcMap. For ease of checking results, set your temperature display thresholds to match those on the Index jpeg files if you will be performing a visual analysis.
2. Calculate the predicted temperature for each cell of your range map: In Arc Toolbox, open Spatial Analyst Tools > Map Algebra > Raster Calculator. Multiply the species raster by the Temperature raster (using the actual names of the files that appear in the window) and click 'OK'. (These output raster files may not be worth saving, so you can let them default to a temp folder.) This multiplies the value for predicted temperature times "1" (the value you set when you created the GRID range map), to give you the predicted temperatures for each cell on your range map. A "Calculation" layer will appear on the left-hand menu bar in your ArcMap project, showing the results of the calculation.

3. Calculate the percentage of the range in each Index category: R-click the "Calculation" layer and select "Properties/Symbology/Classify…" Create classes as per the Index thresholds (choose # classes and click "classify"). Number of classes can be adjusted in the "Classes" box in top left of the window. Type in the Index thresholds under "Break Values". Read the number of elements in each class (bottom of window) as you highlight each break value. Calculate the percentage for each class as the # elements in each class divided by the total # elements (found in box in top right of the window).
4. Check your results against the visual display in ArcMap to be sure your calculations make sense.
5. Repeat steps 1-4 for the predicted moisture layer.

Factor C2ai: Historic Temperature Variation

For this factor, you will overlay the range map on the historic temperature variation map and pick the highest category that includes as least 10% of the range. If the range map notes that the species occurs but does not thrive in a portion of the range, then do not include that marginal part of the range for this factor.

1. Quick method (for most species): Make your range map (shapefile or GRID) and the "Historic Temperature Variation" coverages visible in ArcMap. Set your temperature display thresholds to match those on the Index jpeg files. Pick the highest category that includes at least 10% of the range and use it to score this factor.
2. Slower method (when it is difficult to tell whether 10% of the range falls in a particular category):
    a. Make your GRID range map and the "Historic Temperature Variation" coverages visible in ArcMap. Set your temperature display thresholds to match those on the Index jpeg files.
    b. Calculate the historic temperature variation for each cell of your range map: In Arc Toolbox, open Spatial Analyst Tools > Map Algebra > Raster Calculator. Multiply the species raster by the Temperature raster (using the actual names of the files that appear in the window) and click 'OK'. (These output raster files may not be worth saving, so you can let them default to a temp folder.) This multiplies the value for historic temperature times "1" (the value you set when you created the GRID range map), to give you the temperature variation for each cell on your range map. A "Calculation" layer will appear on the left-hand menu bar in your ArcMap project, showing the results of the calculation.
    c. Pick the highest category that includes at least 10% of the range: R-click the "Calculation" layer and select "Properties/Symbology/Classify…" Set the number of classes = 2. Click "Classify" and in the classification window, drag the vertical category line across the histogram until the class you have selected contains 10% of the total elements. You can read the number of elements in each class (bottom of window) as you highlight the break value. Use the break value at 10% of the total elements as the category for scoring this factor.
    d. Check your result against the visual display in ArcMap to be sure your calculations make sense.

Factor C2bi: Past Precipitation

For this factor, you will overlay the range map on the past precipitation map and calculate the difference between the highest and lowest pixels. This gives you the range of annual precipitation under which the species occurs.

1. Quick method (for species with very small ranges): Make your GRID range map and the "Past Precipitation" coverages visible in ArcMap. Set your display thresholds to match those on the Index jpeg files for ease in checking results. Use your "I" (identify) tool to see that past precipitation value for the highest and lowest pixels in the range. Calculate the difference and use this value to score the factor.

2. Slower method (for most species):
    a. Make your GRID range map and the "Past Precipitation" coverages visible in ArcMap. Set your display thresholds to match those on the Index jpeg files for ease in checking results.
    b. Calculate the past precipitation for each cell of your range map: In Arc Toolbox, open Spatial Analyst Tools > Map Algebra > Raster Calculator. Multiply the species raster by the past precipitation raster (using the actual names of the files that appear in the window) and click 'OK'. (These output raster files may not be worth saving, so you can let them default to a temp folder.) This multiplies the value for past precipitation times "1" (the value you set when you created the GRID range map), to give you the past precipitation for each cell on your range map. A "Calculation" layer will appear on the left-hand menu bar in your ArcMap project, showing the results of the calculation.
    c. It is tempting at this point to simply pick the highest and lowest value from the left-hand menu bar, but this risks including an unrepresentative outlier based on small mapping errors, especially if you are near a rain shadow or orographic divide. Therefore, continue on…
    d. Pick the highest and lowest representative pixels: R-click the "Calculation" layer and select "Properties/Symbology/Classify…" In the classification window, examine the histogram. If your range map includes outliers that are not typical of the species range, this should be quite apparent when you view the histogram. Carefully review any outliers, or any values more than two standard deviations away from the mean. There is a box in the upper right-hand corner of the classification window that lists the mean and standard deviation for the histogram. It may be helpful to go back to your visual display map in ArcMap to see where these outliers occur. Delete or disregard any outliers that you don't think are representative, and use the remaining values to calculate the difference between the highest and lowest pixels.
    e. Check your result against the visual display in ArcMap to be sure your calculations make sense.