Guidelines for Using the NatureServe Climate Change Vulnerability Index

NatureServe

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Release 2.1 *7 April 2011*

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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 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 taxa by their relative risk to climate change, and by sensitivity factors, which we expect will help users to identify adaptation options that could benefit multiple species. Our primary goal for the Index is to provide valuable input for key planning documents, such as revisions of state wildlife action plans, such that climate change impacts can be addressed and integrated 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.

Box 1. Key characteristics of the Index

* Programmed in a Microsoft Excel workbook
* Uses downscaled climate predictions provided by the Climate Wizard
* Requires knowledge about current distribution and natural history of the species being assessed
* Predicts whether a species will decline, remain stable, or increase in numbers or distribution within an assessment area
* Identifies key factors associated with vulnerability for assessed species
* Complementary to NatureServe Conservation Status Ranks (assessment factors do not overlap)

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 blooming and birds 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 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), and that highlights species that are likely to move out of a given assessment area, 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 or animal species 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.

Target Audience.— The NatureServe Climate Change Vulnerability Index is designed for use by scientists in state departments of natural resources or related agencies, refuges or parks, or large private landowning entities such as timber companies or conservation organizations to assess vulnerability of terrestrial or aquatic plant and animal species. We anticipate that the Index will be particularly useful as part of a larger strategy to revise a state wildlife action plan to address climate change. 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.—Assessing the vulnerability of individual species to climate change is just one approach to understanding how climate change may influence biodiversity in a particular region. 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 needs, 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 the Association of Fish and Wildlife Agencies' recent (2009) publication, *Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans and Other Management Plans*. An alternative approach is through spatial analyses such as used in a decision support tool (i.e., NatureServe Vista, http:///www.natureserve.org/vista).

Notes on Release 2.0.—Users of Releases 1.0 and 1.2 will find several modifications in Release 2.0 that represent an evolution of our thinking on vulnerability assessments rather than a radical departure from previous versions. Many of these modifications are responses to feedback from these users. The most significant change is 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 include 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 have added more examples to aid in the interpretation of the criteria.

Notes on Release 2.1.—Release 2.1 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.

HOW THE INDEX WORKS

In accordance with well-established practices (Schneider et al. 2007, Williams et al. 2008), the Index divides vulnerability into two components, the **exposure** to climate change across the range of the species within the assessment area and the **sensitivity** of the species to climate change. A highly sensitive species will not suffer if the climate where it occurs remains stable. Similarly, an adaptable species will not decline even in the face of significant changes in temperature and/or precipitation. 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 predicted temperature and moisture change across the range of the species within the assessment area. The Climate Wizard (http://climatewizard.org) provides a convenient source of downscaled temperature predictions that can be visualized on screen or downloaded into a GIS for further analysis (Girvetz et al. 2009). Alternatively, climate predictions derived from other data sources may also be used.

Although projections for changes in precipitation are also available in Climate Wizard, precipitation estimates alone are often an unreliable indicator of moisture availability because increasing temperatures promote higher rates of evaporation and evapotranspiration. Moisture availability, rather than precipitation per se, is a critical resource for plants and animals and therefore forms part of the exposure measure together with temperature. Modeling moisture is difficult because of its dependence on both regional climate and local habitat characteristics, including temperature, precipitation, soil type, vegetation cover, and snow pack. However, approximate trends of wetting and drying may be estimated using climate data. For example, many habitats in the U.S. are predicted to experience net drying during the next 50 years, even in areas where precipitation is predicted to increase (Brooks 2009). We use the Hamon AET:PET moisture metric (Hamon 1961), as prepared by the Climate Wizard team, to assess this exposure factor for a species' range within an assessment area. The Hamon AET:PET moisture metric integrates temperature and precipitation through a ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET), with consideration of total daylight hours and saturated vapor pressure. Although it is a useful measure, this metric does not include components of habitat moisture retention such as water holding capacity, effect of snow pack on water availability, and different vegetation types, all of which are challenging to incorporate at a national scale.

In the Index, sensitivity is assessed by scoring species against 20 factors divided into two categories, indirect exposure to climate change and species-specific sensitivity. For each factor, species are scored on a sliding scale from greatly increasing, to having no effect on, to decreasing vulnerability. 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, Not Vulnerable/Presumed Stable, Not Vulnerable/Increase Likely, 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 result if there is no information on documented/modeled responses, and an average of the two sections if documented/modeled response information is available. See Young et al. (in press) for more details on the scoring mechanics.

Relation between Exposure and Sensitivity.— The Index treats exposure to climate change as a modifier of sensitivity. If the climate in a given assessment area will not change much, none of the sensitivity 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, 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 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.

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 year 2050, a typical cut-off date for predictions made in the International 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 western state may cause complications due to the size of these states. For wide ranging species in these large landscapes, the variation in climate predictions, especially for precipitation, can be large and lead to difficulty in predicting the direction and magnitude of population and range 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.

In very small assessment areas, most species will occur across the entire area. Climate predictions will not vary much, 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. Errors associated with downscaled data tend to increase as you decrease the scale of assessment, so in general we recommend applying the index to relatively large areas.

The current release of the Index is tailored for use in North America north of Mexico. Use elsewhere may require modification of specific factors and exposure categories. Also, the resolution of downscaled climate predictions may be lower than that currently available for North America, especially the conterminous U.S. states. In the future, NatureServe may create a version of the Index to assess entire ranges of species if there is sufficient interest.

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.

<u>Indirect Exposure to Climate Change</u>

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

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, 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) *Reliance on 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) 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).

a) Measured genetic variation.

b) Occurrence of bottlenecks in recent evolutionary history.

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.

Confidence.—The Index calculates a measure of **confidence in species information**, or how much uncertainty in how to code species for particular factors may influence the vulnerability category calculated. Checking a range of values for particular factors tends to decrease confidence in species information.

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 USDA Plants database (http://plants.usda.gov/). For rare species, 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.

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 16 sensitivity factors require input in order to obtain an overall Index score. Sources of this information include NatureServe Explorer (http://www.natureserve.org/explorer), Natural Heritage Program files, 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" predictions at scales as fine as 1 km^2 or even finer.

Fortunately the Climate Wizard gives quick and simple access to downscaled climate predictions at a resolution suitable for application of the Index. Before starting, it is worthwhile exploring the different kinds of data available on the Climate Wizard, including options for visualizing past and predicted future change in temperature and precipitation data.

To fill in the values required in Section A, you can either download the relevant climate data to use in a desktop GIS or visualize the range of the species under evaluation on the map of climate predictions for the state encompassing your assessment area. Obviously your results will have greater precision if you download the data and overlay distribution maps of the species you will evaluate. If you download data to your own GIS, you can save time by adjusting the classification scale to match the temperature and moisture scale used in Section A of the Index. You can also change the color scheme for greater legibility.

Unless you have reason to do otherwise, we recommend that you use the "ensemble" 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 choose that model instead of the ensemble model. For emissions scenario, we suggest the medium (A1B) "middle of the road" scenario. Box 2 describes how to display temperature predictions on the Climate Wizard and Box 3 explains how to download these data into ArcGIS.

Climate Wizard does not currently display the Hamon AET:PET moisture metric, so NatureServe has posted the data set for download (http://www.natureserve.org/climatechange). Figure 2 shows maps of change in annual and seasonal Hamon AET:PET moisture. If you have access to more detailed models of moisture availability for the assessment area, you can use these instead to assess whether habitats are likely to experience drier or moister conditions by mid-century.

For species with narrow distributions in mountainous areas, the scale of the Climate Wizard climate data might be too broad. For these species, you may want to use the 400 m data set for past climate available for download from the Climate Source (http://www.climatesource.com).

Once you have these data loaded on your GIS, you can use them for all of the species that you evaluate for your assessment area.

Box 2. Using Climate Wizard to Obtain Downscaled Temperature Prediction Data

1. On the Climate Wizard home page, select your state in the drop-down menu under Analysis Area.
2. Under Time Period, select Mid Century (2050s).
3. Under Map Options, select Map of Change.
4. Under Measurement, choose Average Temperature. Make sure Annual is selected on the drop-down menu.
4. Under Emission Scenario choose Medium A1B.
5. Under General Circulation Model, choose Ensemble Average.

Box 3. How to Download Climate Wizard Data to ArcGIS

1. In ClimateWizard, display exactly the data you want to download, then click the Data option in the Resources box. Save the file with .asc extension (if you don't have this option, save as .txt and then rename the file with the extension changed to .asc).
2. Open ArcCatalog, then open ArcToolbox.
3. In ArcToolbox, go to Conversion Tools→To Raster→ASCII to Raster→Input ASCII Raster File. Navigate to your downloaded .asc file. Your Output Raster file should be renamed with 13 letters or less, leaving the extension blank (this will give you a GRID file, which is easiest to use for math). The Output Data Type must be set to FLOAT.
4. In ArcToolbox, go to Data Management Tools→Projections and Transformations→Define Projection. Select your new file for input.
5. Under Coordinate System, select Geographic Coordinate Systems→World→WGS 1984.prj.
6. The file is now ready to add to your ArcGIS project using the Add Data button.

Land Use Data.—To evaluate factor B2b, *Distribution relative to anthropogenic barriers*, you may need land cover maps for your region if you are assessing a terrestrial species for which urban and agricultural lands are dispersal barriers. We recommend the Wildland-Urban Interface data to assess the intensity of land use in the 48 contiguous states of the U.S. (Silvis Lab, University of Wisconsin-Madison and the USDA Forest Service North Central Research Station, http://silvis.forest.wisc.edu/library/wuilibrary.asp). Like the Climate Wizard data, the Silvis data can be either viewed online or downloaded to your GIS for greater precision. If you are outside of the 48 contiguous states or are working on a state that borders either Canada or Mexico such that a 100 km buffer around the distributions of the species you will evaluate falls outside of the U.S., you can use NASA Global Land Cover Facility (GLCF) data (http://glcf.umiacs.umd.edu). Note that you will need greater GIS capacity to be able to handle the GLCF data than the Silvis Lab data. Box 4 provides tips for downloading the Silvis Lab data.

Box 4. How to Download Silvis Wildland-Urban Interface Maps

1. Open the Silvis Lab ftp site at: ftp://ftp.silvis.forest.wisc.edu/ and navigate to FTP directory /SILVIS/data/WUI00Coverages/

2. Download and unzip the files for your state. The unzipped state files have an extension of ".e00", also known as an "Interchange file". The USA file (5 gigabytes) is already compatible with ArcGIS as a "File Geodatabase".

3. For state files, use ArcCatalog to convert. You may need to add the conversion tools using Tools→Customize→Toolbars→ArcView 8x Tools. From the Conversion Tools dropdown list, select Import from Interchange File. Select the state ".e00" file and name the output dataset (don't use an extension). The resulting coverage will probably be compatible with your ArcGIS project. If it is not, you can right-click the coverage and create a layer from it. The layer can then be added to your ArcGIS project. The display field is WUIALLOCHDEN90.

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 worksheet is the only place where you will enter data. It is divided into a section for preliminary information, four lettered sections, and a section for displaying the Index score and confidence values. The four lettered worksheets 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, the box for major taxonomic group must be completed for Index calculations to perform accurately. Also fill in the Assessment Notes box with 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.

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 decreases 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.

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 characters by using them as justification to score a species as having increased or decreased 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 only 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 be recalculated. For this reason, you should avoid changing values or manipulating data in any way in the Results Table.

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 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. Therefore, migratory species should be assessed focusing solely 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.

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. Obtain Climate Wizard data as instructed in Box 2. For temperature, calculate or estimate 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:

- >5.5° F (3.1° C) warmer
- 5.1-5.5° F (2.8-3.1° C) warmer
- 4.5-5.0° F (2.5-2.7° C) warmer
- 3.9-4.4° F (2.2-2.4° C) warmer
- < 3.9° F (2.2° C) warmer

Then do the same for moisture (downloading data from http://www.natureserve.org/climatechange or viewing the map in Figure 2a), calculating or estimating the percentage of the range of the species in each of the following categories:

- < -0.119
- -0.097 - -0.119
- -0.074 - -0.096
- -0.051 - -0.073
- -0.028 - -0.050
- >-0.028

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

See Appendix 3 for a quantitative GIS assessment of this factor.

Section B, Indirect Exposure to Climate Change

Specific instructions for each factor are as follows. At least three of the four factors must be assessed.

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 sea level rise and the consequent influence of storm surges. 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. See http://www.geo.arizona.edu/dgesl/research/other/climate_change_and_sea_level/sea_level_rise/

sea_level_rise.htm for an interactive map to visualize the effect of sea level rise in your area. We recommend the lowest available (1 m) setting.

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 occurs in area subject to sea level rise (on low-lying island(s) or in coastal zone).
Somewhat Decrease Vulnerability:	Occurs 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 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 include: 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 (*Ochotona princeps*) but not for elk (*Cervus canadensis*) or American pipit (*Anthus rubescens*); 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 [*Cinclus mexicanus*] or gartersnakes [*Thamnophis* spp.] that occur along the same stream).

B) ANTHROPOGENIC BARRIERS: Examples of features that may function as anthropogenic barriers include: 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 (see Box 5) 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).

One useful data source for assessing intensity of land use as a potential anthropogenic barrier in the 48 contiguous United States is the published maps and downloadable GIS data for Wildland-Urban Interface of the Silvis Lab (University of Wisconsin-Madison and the USDA Forest Service North Central Research Station, http://silvis.forest.wisc.edu/library/wuilibrary.asp). See Box 4 for instructions on how to download this GIS layer. Other data sets, such as the Global Land Cover Facility (NASA; http://glcf.umiacs.umd.edu) are also acceptable (and offer wider coverage) but may require more advanced GIS capabilities. Readily available online sources of satellite imagery also may be useful in assessing anthropogenic or certain other barriers.

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 5. 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.

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 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, A specific example of this category is provided by the quino checkerspot butterfly (*Euphydryas editha quino*), a resident of northern Baja California and southern California; warming climates are forcing this

	butterfly northward, but urbanization in San Diego blocks its movement (Parmesan 1996).
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. This factor is NOT intended to capture habitat loss or destruction due to on-going human activities, as these should already be included 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.

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. If numerous wind farms already exist along the species' migratory route, negative impacts have been found in relevant studies; if such studies exist but negative impacts have not been found, 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.
Somewhat Decrease Vulnerability:	The species is likely to benefit from mitigation-related land use changes that may occur within its current and/or potential future range. This includes (but is not limited to) the following:
	- Forest-associated species currently found within a landscape with < 40% forest cover, where increases in forest cover may occur as a result of reforestation or afforestation projects.
	- Species currently subject to a higher frequency of fires than experienced historically, where there may now be greater incentive to control such fires.
	- Species occurring on unprotected lands which may be protected and managed for conservation due to their carbon storage and/or sequestration ability.
Decrease Vulnerability:	The species is likely to benefit from mitigation-related land use

	changes that are likely to very likely to occur within its current and/or potential future range, including any of the above (under Somewhat Decrease).

Section C, Sensitivity

Specific instructions for each factor are as follows. At least 10 of the 16 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 immatures, 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 is assessed conservatively and 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).

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 are a classic example). 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).

Most migratory species will satisfy criteria for the decrease vulnerability criteria. Use their ability to shift their distribution within the assessment during the period of occupation or from one year to the next (whichever is larger) as the measure of dispersal distance.

Species in which propagule dispersal is both synchronous among all members of the population in the assessment area and infrequent (average of several years between successful reproduction events) should be scored as one category more vulnerable than the category that would otherwise apply. An example is the monocarpic giant cane (*Arundinaria gigantea*), a bamboo species that reproduces synchronously every 25-50 years and then dies (Marsh 1977, Matthews et al. 2009).

Greatly increase Vulnerability:	Species is characterized by severely restricted dispersal or movement capability. This category includes species represented by sessile organisms that almost never disperse more than a few meters per dispersal event. Examples include: 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.
Increase Vulnerability:	Species is characterized by highly restricted dispersal or movement capability. This category includes species that rarely disperse through unsuitable habitat more than about 10 meters per dispersal event, and species in which 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. Examples include: plants dispersed ballisticly; branchiopods whose resting stages sometimes are transported in mud attached to duck or deer feet or legs; small clams that may disperse while clamped onto bird feathers or frog toes; plant or animal species with free-living propagules or individuals that may be carried more than 10 meters by a tornado or unusually strong hurricane or large flood but that otherwise rarely disperse more than 10 meters; plants that do not fit criteria for Greatly Increase but lack obvious dispersal adaptations (i.e., propagules lack any known method for moving more than 10 meters away from the source plant).
Somewhat Increase Vulnerability:	Species is characterized by limited but not severely or highly restricted dispersal or movement capability. A significant percentage (at least approximately 5%) of propagules or individuals disperse approximately 10-100 meters per dispersal event (rarely farther), or dispersal capability likely is consistent with one of the following examples. Examples include some small, nonvolant animals of relatively low vagility (including small, slow-moving animals such as slugs, snails, and the smallest terrestrial salamanders that regularly (albeit perhaps infrequently) move more than 10 meters when conditions are favorable; species that exist in small isolated patches of suitable habitat but regularly disperse or move among patches that are up to 100 meters (rarely farther) apart; many ant-dispersed plant species; plants whose propagules are dispersed primarily by small animals (e.g., some rodents) that typically move propagules approximately 10-100 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).
Neutral:	Species is characterized by moderate dispersal or movement capability. A significant percentage (at least approximately 5%) of propagules or individuals disperse approximately 100-1,000 meters per dispersal event (rarely farther), or dispersal capability likely is consistent with one of the following examples. Examples include: 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; 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 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).
Somewhat Decrease Vulnerability:	Species is characterized by good dispersal or movement capability. Species has propagules or dispersing individuals that readily move 1-10 kilometers from natal or source areas (rarely farther), or dispersal capability likely is consistent with one of the following examples. Examples include: many medium-sized mammals (e.g., certain rabbit species) that commonly disperse up to several kilometers; plant species regularly dispersed up to 10 km (rarely farther) by large or mobile animals (e.g., plant has seeds that are cached, regurgitated, or defecated 1-10 kilometers 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).
Decrease Vulnerability:	Species is characterized by excellent dispersal or movement capability. Species has propagules or dispersing individuals that readily move more than 10 kilometers from natal or source areas, or dispersal capability likely is consistent with one of the following examples.
	Examples include: 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, most birds); plant or animal species whose individuals often or regularly are dispersed more than 10 kilometers by migratory or otherwise highly mobile animals, 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 in the assessment area may shift distribution up to tens or hundreds of kilometers 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).
	In essence, this category includes the species that tend to occupy all or most areas of suitable habitat or that readily or predictably 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.). Note that these species 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.

C2) Predicted Sensitivity to Temperature and Moisture Changes

NOTES: This factor pertains to the breadth of temperature and moisture 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., the past 50 years), 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 comparing the species range with the Annual Temperature Variation map 1951-2006 (Figure 3) or calculated using GIS data downloaded from NatureServe (http://www.natureserve.org/climatechange). 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.

Note that tropical species in high deserts or alpine environments may experience daily temperature variations as high as seasonal variations in the temperate zone. Species in these tropical settings should either be assessed using daily temperature variation, or if data is not available, they may be ranked one category less vulnerable for this factor.

See Appendix 3 for a quantitative GIS assessment of this factor.

Greatly Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **very small (< 37° F/20.8° C)** temperature variation in the past 50 years. 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 (37 - 47° F/20.8 - 26.3° C)** temperature variation in the past 50 years. Includes facultative cave invertebrates.
Somewhat Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **slightly lower than average (47.1 - 57° F/26.3 - 31.8° C)** temperature variation in the past 50 years.
Neutral:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **average (57.1 - 77° F/31.8 - 43.0° C)** temperature variation in the past 50 years.
Somewhat Decrease Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **greater than average (> 77° F/43.0° C)** temperature variation in the past 50 years.

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, or species occupies habitats that are thought to be not vulnerable to projected climate change.
Somewhat Decrease Vulnerability:	Species shows a preference for environments toward 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., the past 50 years), as approximated by mean annual precipitation variation across occupied cells within the assessment area. Overlay the species' range on the Climate Wizard mean annual precipitation map 1951-2006 (see also Figure 4). 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.

See Appendix 3 for a quantitative GIS assessment of this factor.

Greatly Increase Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **very small (< 4 inches/100 mm)** precipitation variation in the past 50 years.
Increase Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **small (4 - 10 inches/100 - 254 mm)** precipitation variation in the past 50 years.

Somewhat Increase Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **slightly lower than average (11 - 20 inches/255 - 508 mm)** precipitation variation in the past 50 years.
Neutral:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **average (21 - 40 inches/509 - 1,016 mm)** precipitation variation in the past 50 years.
Somewhat Decrease Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years.

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. Aquatic cave obligate species are considered here according to their hydrological needs**. 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).

Many habitats in the U.S. are predicted to experience net drying (see annual and seasonal Hamon AET:PET moisture metric maps in Figure 2 or as downloadable GIS files at http://www.natureserve.org/climatechange), even in areas where precipitation is predicted to increase. Consider the direction, strength, and seasonality of moisture change in ranking this factor, along with the level of dependence of the species on particular hydrologic conditions.

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). As such, C4 plants whose ranges are predicted to experience net drying during the growing season (see Hamon AET:PET Moisture Metric maps in Figure 2) should be scored one category less vulnerable than they otherwise would be for this factor.

As a result of geographical differences in modeled future hydrological conditions, a species may fall into more than one of the following categories. In such cases select all categories that apply; if the categories are not contiguous (e.g., Increase Vulnerability and Somewhat Decrease Vulnerability), select only those categories and do not select the nonapplicable intermediate categories. 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. "Range" refers to the range within the assessment area.

*Note that springs fed by bedrock groundwater sources are less likely to be significantly impacted by precipitation changes; consider scoring species associated with such springs as Neutral.
**Similarly, species inhabiting caves fed by groundwater may be less vulnerable to changes in precipitation than species inhabiting caves fed by surface runoff water.

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 highly vulnerable to loss or reduction with climate change AND the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution, abundance, or habitat quality. If this second condition is not met (e.g., species dependent on springs tied to a regional aquifer that would not be expected to change significantly with climate change), the species should be scored as Neutral. Examples for Greatly Increase include certain spring-dependent fishes, ephemeral pool-dependent branchiopods, and 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 highly vulnerable to loss or reduction with climate change AND the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution, abundance, or habitat quality. If this second condition is not met, the species should be scored as Neutral. Examples for Increase include certain amphibians that often breed in vernal pools but also regularly use other aquatic or wetland habitats, and 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. Also included are desert or semidesert plants that frequently occur in but are not restricted to or almost restricted to moisture-accumulating microsites, as well as plants (and animals that depend on these species) for which >50% of populations occur in areas such as sandy soils that are sensitive to changes in precipitation.
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 AND the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution, abundance, or habitat quality. If this second condition is not met, the species should be scored as Neutral. Examples for Somewhat Increase include 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, and 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.
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.
Somewhat Decrease Vulnerability:	Species has very broad moisture regime tolerances OR would benefit by the predicted change in hydrologic regime. Examples include water-limited species that could increase with increasing precipitation or arid-adapted species that could increase in areas with decreasing moisture availability.

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.

Finally, be sure to also consider species that benefit from a lack of disturbance and may suffer due to disturbance increases when scoring this factor. For a map of modeled future fire regime, see Figure 2 in Krawchuk et al. (2009, available: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0005102).

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.
Somewhat Decrease 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 increases the species' distribution, abundance, or habitat quality. For example, if climate change increases the frequency of fires, black-backed woodpeckers may benefit due to increased availability of foraging habitat (burned-over forests that become infested with beetles). Many fire-adapted plants can be scored here if a predicted increase in fire frequency/intensity is anticipated to be beneficial.

Decrease 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 increases the species' distribution, abundance, or habitat quality. For example, in areas predicted to experience increased fire frequency, invasive grasses that have a strong positive response to fire (e.g., ecosystem function-altering) could be scored here.

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

NOTES: This factor pertains to a species' dependence on habitats associated with ice (e.g., sea ice, glaciers) or snow (e.g., long-lasting snow beds, avalanche chutes) throughout the year or seasonally during an essential period of the life cycle. "Range" refers to the range within the assessment area.

Greatly Increase Vulnerability:	Highly dependent (>80% of subpopulations or range) on ice- 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- 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- 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.
Neutral:	Little dependence on ice- or snow-associated habitats (may be highly dependent in up to 10% of the range).

C3) Restriction to Uncommon Geological Features or Derivatives

NOTES: This factor pertains to a species' need for a particular soil/substrate, geology, water chemistry, or specific physical feature (e.g., caves, cliffs, active sand dunes) for reproduction, feeding, growth, or otherwise existing for one or more portions of the life cycle (e.g., normal growth, shelter, reproduction, seedling establishment). 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) 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 microhabitat 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 features is not relevant to the species (e.g., many birds and mammals), choose Somewhat Decrease.

Increase Vulnerability:	**Very highly dependent** upon, i.e., more or less endemic to (> 85% of occurrences found on) a particular highly uncommon geological feature or derivative (e.g., soil, water chemistry). Such features often have their own endemics. Examples include serpentine (broad and strict) endemic plants, plants of calcareous substrates where such substrates are uncommon (e.g., California, southeastern U.S.), plants restricted to one or a few specific rock strata, organisms more or less restricted to inland sand dunes or shale barrens, obligate cave-dwelling organisms, and springsnails restricted to springs with high dissolved CO2. This category could also include fish species that require a highly uncommon substrate particle size for their stream bottoms, such as the Colorado pikeminnow (*Ptychocheilus lucius*) that spawns only on rare cobble bars cleared of debris by strong upstream currents.
Somewhat Increase Vulnerability:	**Moderately to highly dependent** upon a particular 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 geological feature or derivative that is not highly uncommon within the species' range, but is not one of the dominant types. Examples of the latter include species more or less restricted to active coastal sand dunes, cliffs, salt flats (including shorebirds that require sodic soils), inland waters within a particular salinity range, and non-dominant rock types such as occasional igneous rock intrusions within a landscape mostly dominated by sedimentary and/or metamorphic rocks. This category could also include fish species that require a specific substrate particle size for their stream bottoms, if that type of stream bottom is not one of the dominant types within the species' range.
Neutral:	Having a **clear preference** for (> 85% of occurrences found on) a certain geological feature or derivative, where the feature is among the dominant types within the species' range. For example, red spruce prefers acidic, organic soils (not uncommon within its range), although it is occasionally found on other soil types. 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) will probably fall here, upon confirmation that the substrate type is not particularly uncommon within the species' range.
Somewhat Decrease Vulnerability:	**Somewhat flexible but not highly generalized** in dependence upon geological features or derivatives, i.e., found on a subset of the dominant substrate/water chemistry types within its range. Most habitat descriptions that mention more than one type of relatively widespread geological feature should probably go here; however, if all types mentioned are uncommon within the species' range, Somewhat Increase may be appropriate. This category also encompasses species not strongly tied to any specific geological feature or derivative, such as many birds and mammals.
Decrease Vulnerability:	**Highly generalized** relative to dependence upon geological features or derivatives, i.e., the species is described as a generalist and/or a significant proportion of its occurrences have been documented on

	substrates or in waters that represent opposite ends of the spectrum of types within the assessment region (e.g., many occurrences known from both acidic and basic soils or waters, or from both sandy and clay soils). Species such as common yarrow (*Achillea millefolium*) and coyote (*Canis latrans*) should be assigned to this category.

C4) Reliance on 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:
Habitat refers to any habitat (e.g., for reproduction, feeding, hibernation, seedling establishment, etc.) necessary for completion of the life cycle, including habitats used only on a seasonal basis. For plants, creation of 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 C4e.

Greatly Increase Vulnerability:	Required habitat generated primarily by one species, and that species is highly to extremely vulnerable to climate change within the assessment area. The following examples are cases in which species depend on others to generate habitat, although the species generating the habitat is not necessarily highly vulnerable to climate change throughout its range. In harsh environments, the presence of a single ecosystem engineer can create habitat for species for which abiotic conditions would otherwise be unsuitable (e.g., *Spartina alterniflora* in eastern North American salt marshes). There are also examples of "habitat structure specialists" among arthropods: several insect species (e.g., the beetle *Onthophilus giganteus*) are entirely dependent on southeastern pocket gopher (*Geomys pinetis*) tunnels for habitat, and the spider *Masoncus pogonophilus* depends on habitat provided by colony chambers of the Florida harvester ant (*Pogonomyrmex badius*) (Cushing 1997). Kirtland's warbler (*Dendroica kirtlandii*) is dependent on jack pine (*Pinus banksiana*) for its nesting habitat.
Increase Vulnerability:	Required habitat generated primarily by one species, and that species is at most moderately vulnerable to climate change within the assessment area. See examples of species requiring other species to generate habitat under Greatly Increase Vulnerability. If the climate change vulnerability of the habitat-generating species is unknown, check both Greatly Increase and Increase Vulnerability.
Somewhat Increase Vulnerability	Required habitat generated primarily by one or more of not more than a few species. For example, a certain degree of specificity exists between particular cactus species and certain nurse plants; burrowing owls (*Athene cunicularia*) depend on excavations made by relatively few species of burrowing mammals; marbled murrelets (*Brachyramphus marmoratus*) strongly depend on a few species of large trees to provide suitable nesting platforms; certain plant species depend on large grazing animals to generate disturbance required for establishment and early growth.
Neutral:	Required habitat generated by more than a few species, or does not involve species-specific processes.

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.

Increase Vulnerability:	Completely or almost completely (>90%) dependent on one species during any part of the year. For example, Clark's nutcracker (*Nucifraga columbiana*) depends heavily on the seeds of whitebark pine (*Pinus albicaulis*).
Somewhat Increase Vulnerability:	Completely or almost completely (>90%) dependent during any part of the year on a few species from a single guild that may respond similarly to climate change. For example, the larvae of various fritillary butterflies rely heavily on a few species of violets; the great purple hairstreak is dependent on a few mistletoe species.
Neutral:	Diet flexible; not dependent on one or a few species. For example, the diet of the great horned owl (*Bubo virginianus*) is flexible and not strongly dependent on one or a few species (although its diet may be dominated by one or a few species in a particular location).
Somewhat Decrease Vulnerability:	Omnivorous diet including numerous species of both plants and animals.

c) Pollinator versatility (plants only)

NOTES: Quantitative thresholds loosely follow data in Waser et al. (1996).

Increase Vulnerability:	Completely or almost completely dependent on one species for pollination (> 90% of effective pollination accomplished by one 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).
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.

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) OR propagules can be dispersed by more than a few species.

e) Forms part of an interspecific interaction not covered by C4a-d

NOTES: Can be applied to plants or animals. 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. Here an interspecific interaction can include mutualism, parasitism, commensalism, or predator-prey relationship.

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" compared to findings using similar techniques on related taxa.
Somewhat Decrease Vulnerability:	Genetic variation reported as "high" compared to findings using similar techniques on related taxa.

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

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.

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 (Møller 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. This may be assessed using either published multi-species studies such as those cited above or large databases such as that of the U.S. National Phenology Network.

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 which is average compared to other species in similar habitats or taxonomic groups, OR seasonal dynamics within the species' range show no detectable change.
Somewhat Decrease Vulnerability:	Seasonal temperature or precipitation dynamics within the species' range show detectable change, and phenological variables measured for the species show detectable change which is significantly greater than that of other species in similar habitats or taxonomic groups.

Section D, Documented or Modeled Response to Climate Change

Data required for the factors in this section will rarely be available, so none are required to calculate an Index score. Specific instructions for each factor are as follows.

D1) Documented response to recent climate change (e.g., range contraction or phenology mismatch with critical resources)

NOTES: 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 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 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 increasing or decreasing with climate change. Includes species undergoing range shifts without significant change in distributional area or species undergoing changes in phenology but no change in net range size or population size.
Somewhat Decrease Vulnerability:	Distribution or abundance undergoing small but measureable increase (10-30% over 10 years or three generations) believed to be associated with climate change. Distribution changes must be true increases in area, not range shifts.
Decrease Vulnerability:	Distribution or abundance undergoing moderate or major increase (>30% over 10 years or three generations) believed to be associated with climate change. Distribution changes must be true increases in area, not range shifts.

D2) Modeled future (2050) change in range or **population size**

NOTES: This factor can include both distribution models and population models. Models should be developed based on reasonably accurate locality data (error <5 km) 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 no greater than a 20% change relative to current range within the assessment area OR predicted future abundance represents increases or decreases < 20% associated with climate change processes.
Somewhat Decrease Vulnerability:	Predicted future range represents a 20-50% increase relative to current range within the assessment area OR predicted future abundance represents 20-50% increase associated with climate change processes.
Decrease Vulnerability:	Predicted future range represents a > 50% increase relative to current range within the assessment area OR predicted future abundance represents > 50% increase associated with 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.

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, and the minimum number of factors in Sections B and C are completed. The Index scores (Box 6) provide a relative measure of vulnerability to climate change. 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 or characteristics that may cause them to increase.

Box 6. 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.

Not Vulnerable/Presumed Stable: 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.

Not Vulnerable/Increase Likely: Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

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

Measures of Confidence.— To estimate confidence in species information, 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 Index score resulted from the simulation runs, providing a graphical depiction of the confidence in the overall Index 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.

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. In extreme cases, species should be moved to the next higher vulnerability category due to their increased risk from these factors.

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 6 lists some sample suggestions for management actions to address some of these factors.

Species Moving into or out of the Assessment Area.—Receiving an Index score of Not Vulnerable/Presumed Stable 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. The Index flags species with characteristics that might make them likely to move out of or expand in the assessment area in the Notes section immediately below the Index score. 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 6. Possible management actions.

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* between populations to increase genetic diversity

* Note that translocating individuals is a controversial action because of potentially conflicting goals, one of which may be to preserve unique subpopulations and genotypes.

ACKNOWLEDGMENTS

We thank the Faucett Family Foundation, the Duke Energy Corporation, the Nevada Natural Heritage Program, and the Pennsylvania Heritage Program for financial support during the development of this Index. We are also grateful to Kristin Snow for help programming the Index and to an anonymous reviewer for many useful comments including suggestions for the names of the C2 subfactors.

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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.

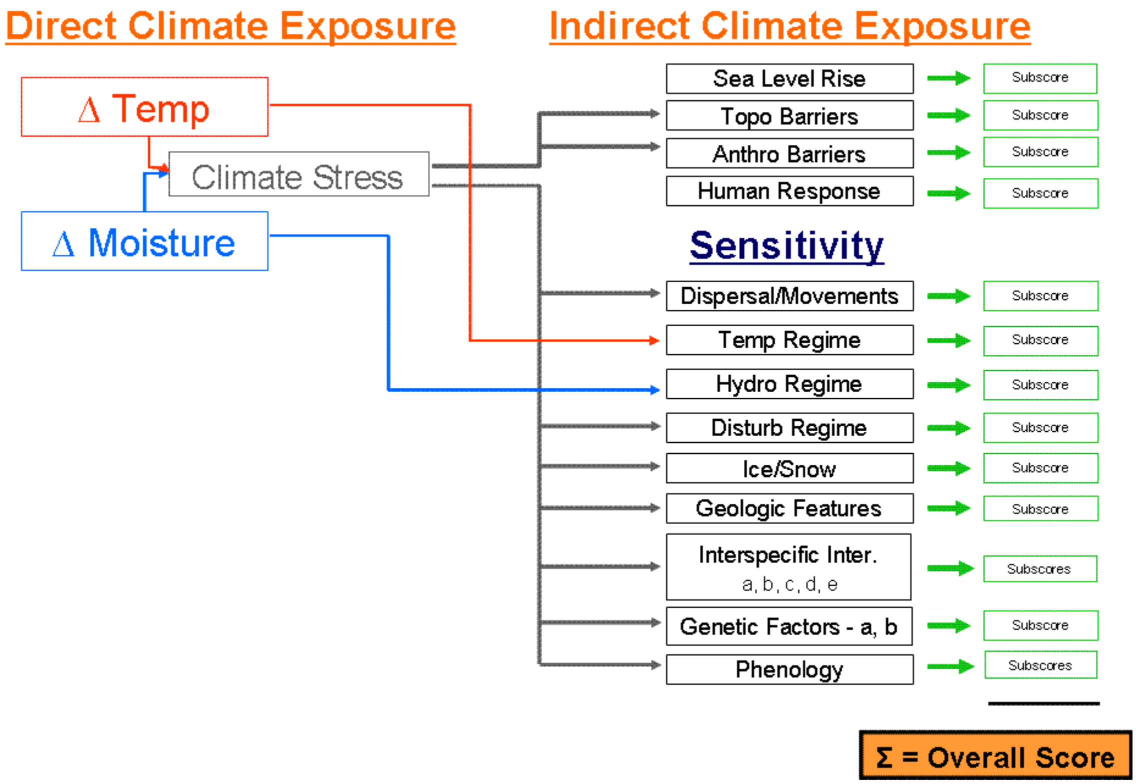

Figure 1. Relation between exposure to local climate change and sensitivity factors.

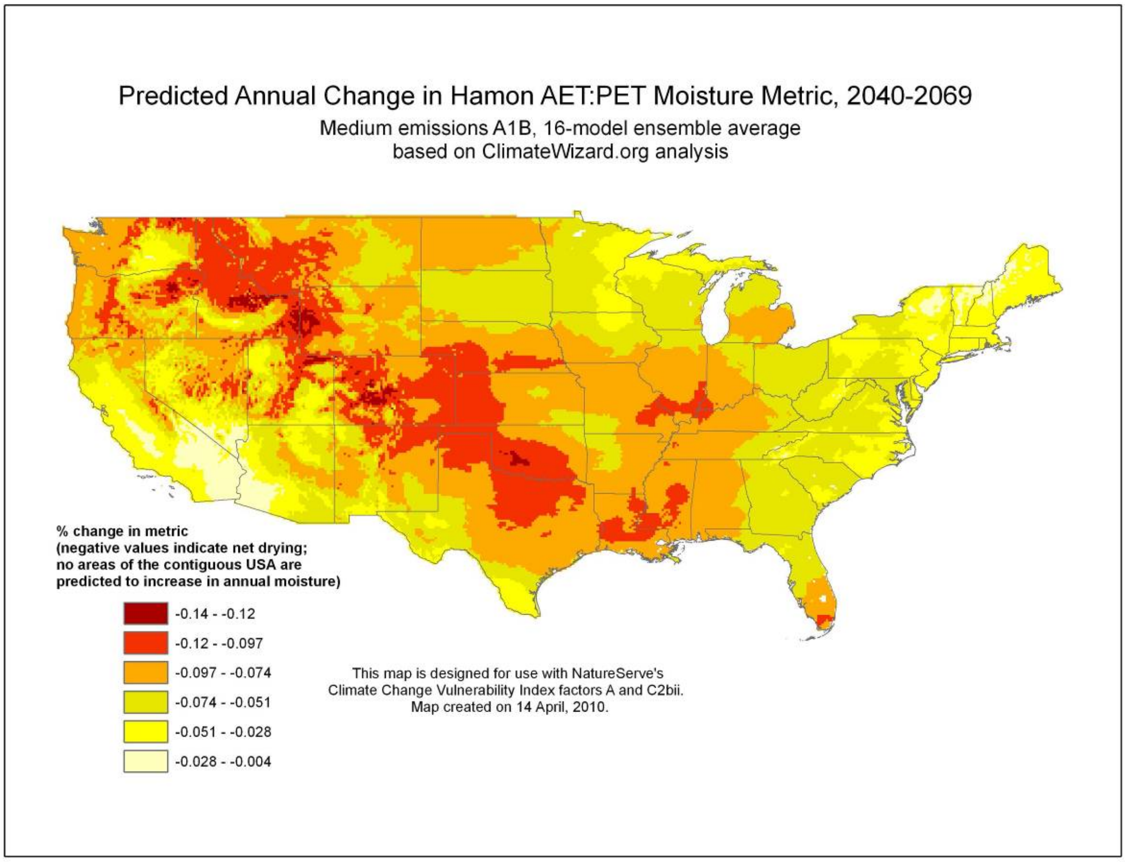

Figure 2a. Predicted change in annual moisture.

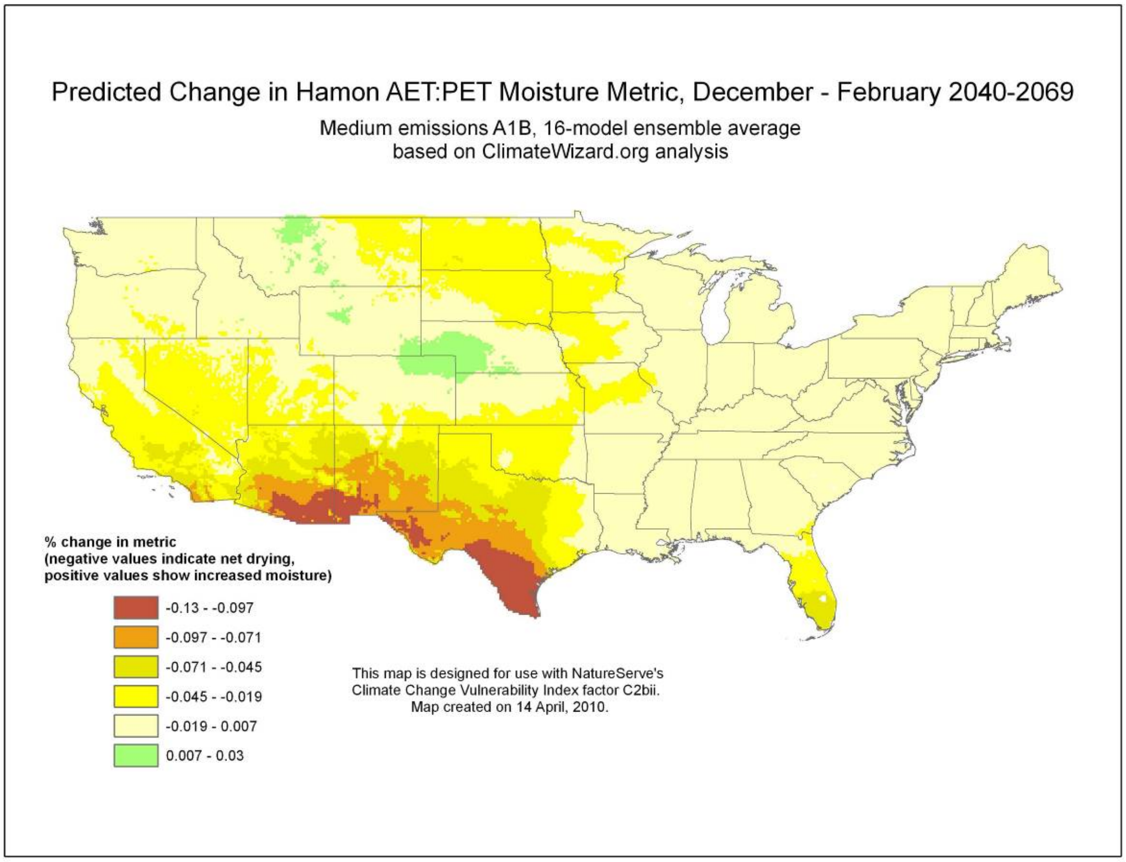

Figure 2b. Predicted change in winter moisture.

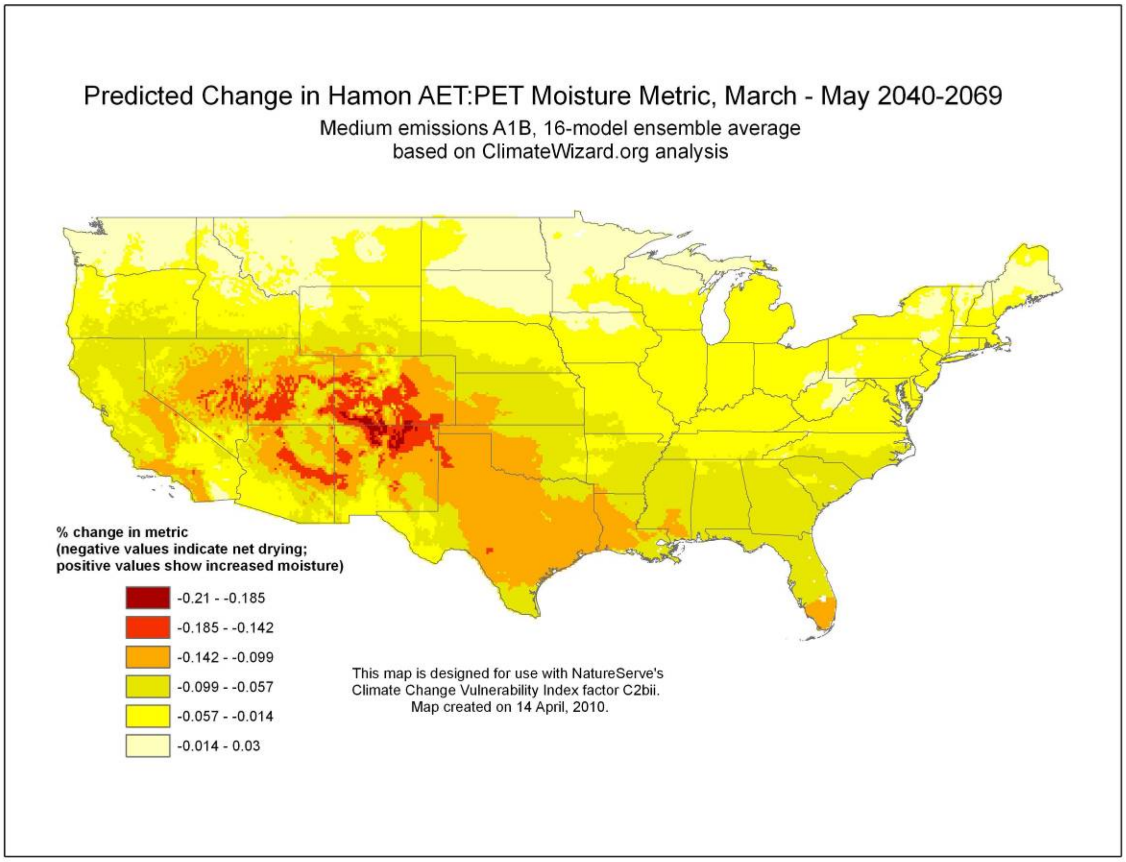

Figure 2c. Predicted change in spring moisture.

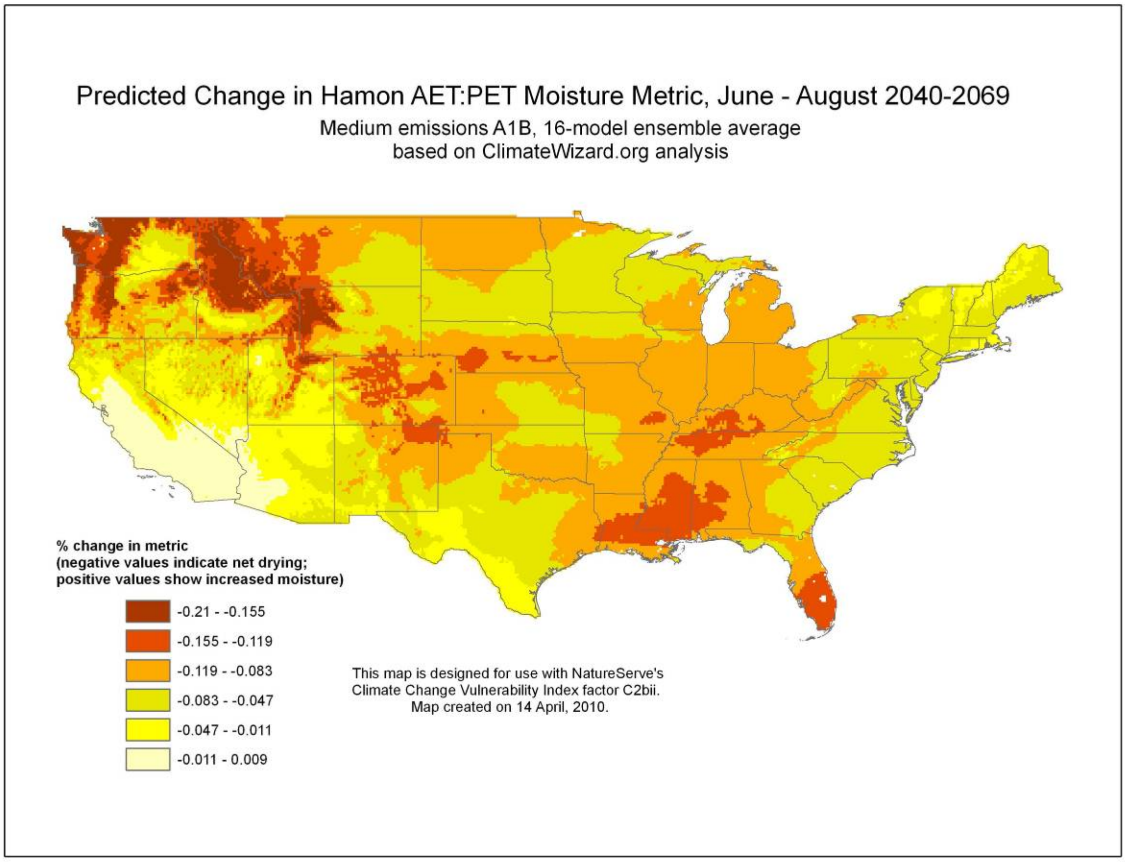

Figure 2d. Predicted change in summer moisture.

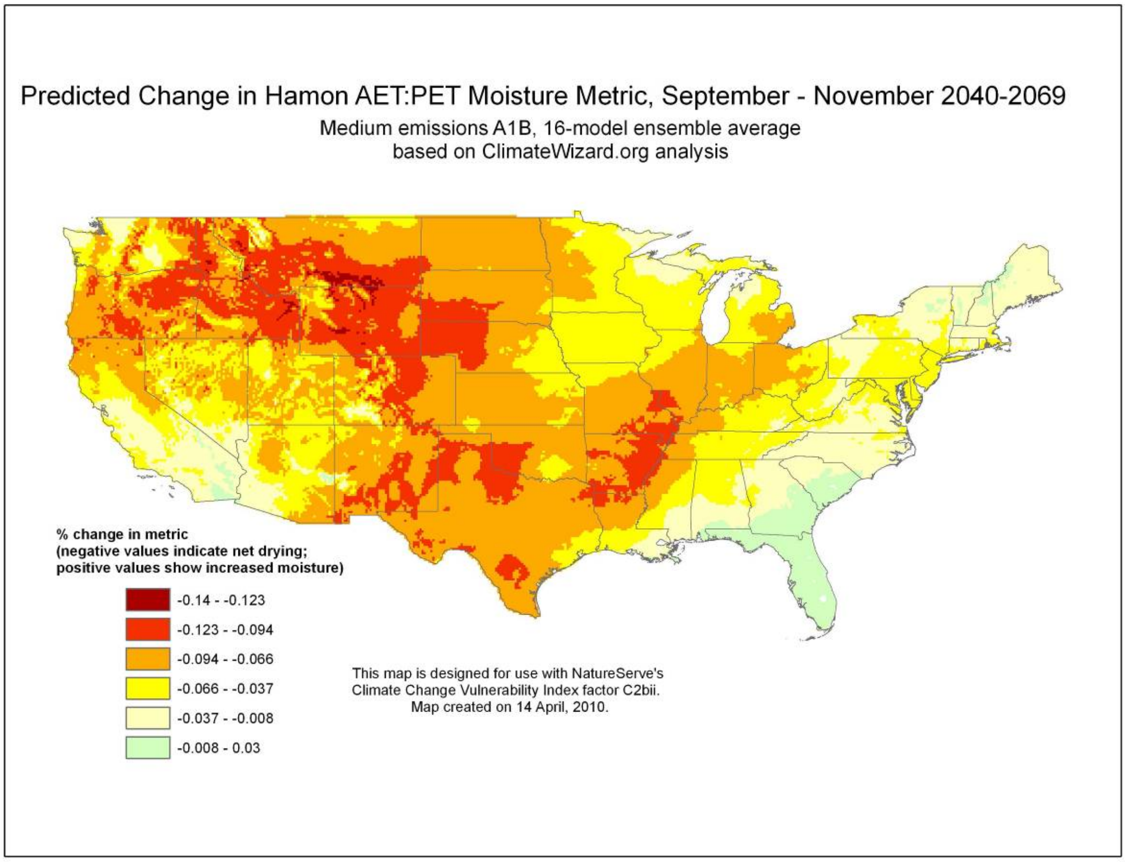

Figure 2e. Predicted change in fall moisture.

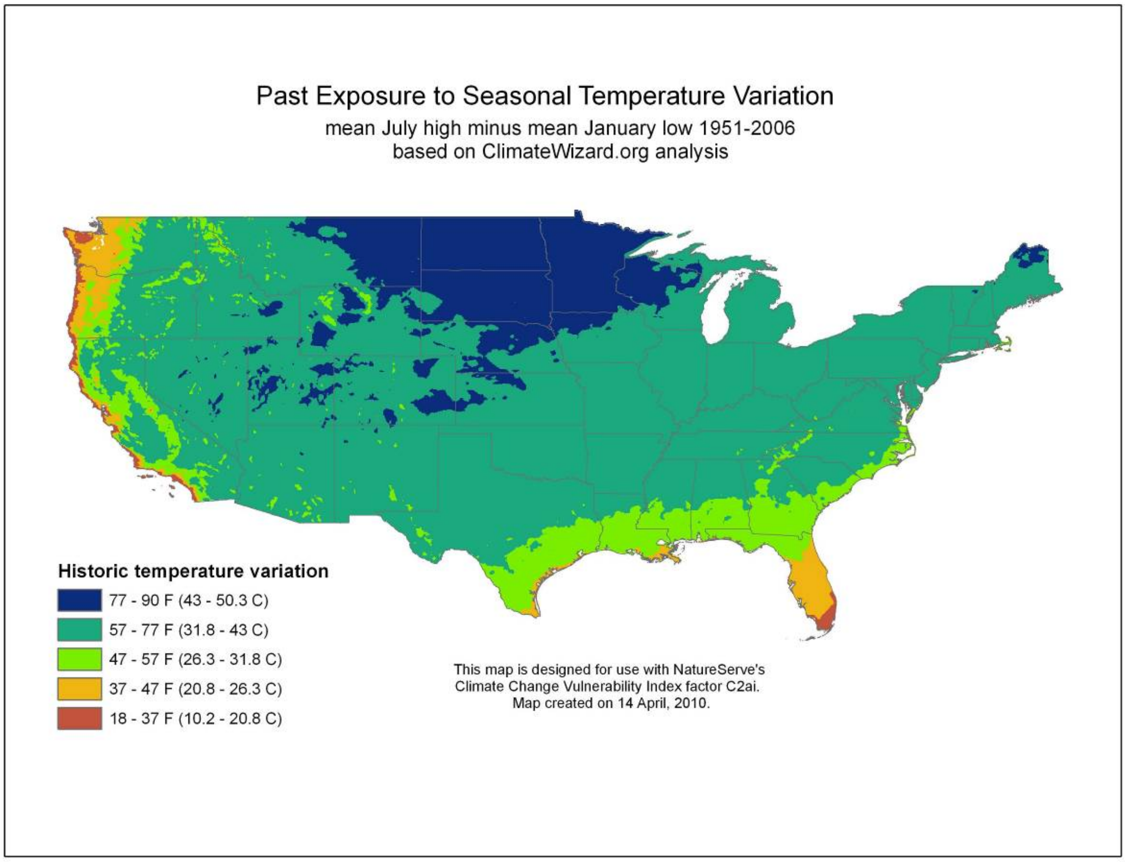

Figure 3. Past exposure to temperature variation for factor C2ai.

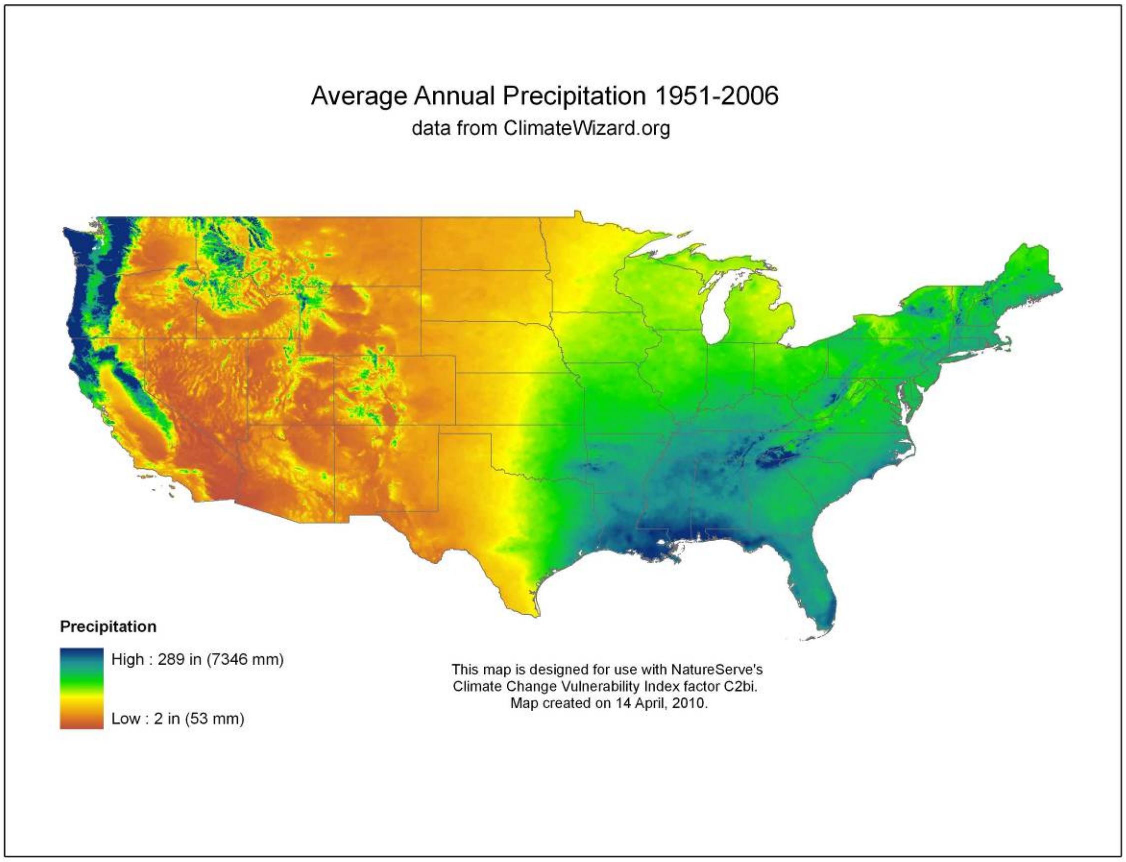

Figure 4. Past exposure to precipitation variation for factor C2bi.

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 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	Presumed Stable	S2	G2
Reptile	*Phrynosoma platyrhinos*	Desert horned lizard	Presumed Stable	S4	G5
Bird	*Quiscalus mexicanus*	Great-tailed grackle	Increase Likely	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; SD, Somewhat Decrease; Dec, Decrease; 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 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	Dec	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	SD	MV
Asclepias eastwoodiana	N	N	SI	N	N	SI	Inc	N	N	N/A	U	PS
Phrynosoma platyrhinos	N	N	N	N	SD	Inc-SI	N	N	N	SI	U	PS
Quiscalus mexicanus	N	SD	Dec	N	N	N	N	N	N	SD	U	IL

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/Convert/Polygon to Raster". Set your output to GRID 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.
2. Calculate the predicted temperature for each cell of your range map: Using the "Spatial analyst" link on your toolbar at the top of the screen, select "Spatial Analyst/Raster Calculation". Set the calculation to "range * temp", using the actual names of the files that appear in the window. 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/Classified/Create Histograms". Create classes as per the Index

thresholds (choose # classes and click "classify"). 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.
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: Using the "Spatial analyst" link on your toolbar at the top of the screen, select "Spatial Analyst/Raster Calculation". Set the calculation to "range * temp var", using the actual names of the files that appear in the window. This multiplies the value for historic temperature variation 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/Classified/Create Histograms". 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: Using the “Spatial analyst” link on your toolbar at the top of the screen, select “Spatial Analyst/Raster Calculation”. Set the calculation to “range * past precip”, using the actual names of the files that appear in the window. 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/Classified/Create Histograms”. Click “Classify” and 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.