Guidelines for Using the Climate Change Vulnerability Index

NatureServe

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OVERVIEW

Motivated by the need for a means to rapidly assess the vulnerability of species to climate change, NatureServe initiated an effort to develop a Climate Change Vulnerability Index. The Index uses a scoring system that considers the magnitude of climate change predicted to occur in a species' range and measures that against species' characteristics relative to four criteria, each supported by published studies: 1) natural habitat and landscape context, 2) human management and land use context, 3) species-specific factors, and 4) documented response to climate change in the published scientific literature. Assessing priority species with this Index can provide valuable input for modifications of state wildlife action plans to address climate change or help land managers evaluate the likely effectiveness of alternative strategies to increase the resilience of species to climate change. This document briefly explains the Index, how to use it, and how to interpret the results.

<u>Box 1. Key characteristics of the Index</u>

* Programmed in an 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
* Identifies factors causing vulnerability
* Complementary to NatureServe Conservation Status Ranks

INTRODUCTION

Need Addressed.—Although scientists have been concerned about climate change for decades, most decision makers have only recently recognized the urgency of the problem. 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 species respond differently to change. Also, climate change vulnerability is a rapidly developing field of inquiry. The results do not always filter to field conservationists rapidly, 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 and limited conservation resources. To handle the complexity posed by this problem, managers need a way to group species based on similar drivers of vulnerability and potential management needs. Doing so would increase the efficiency of planning for climate change adaptation and may help target species for which more in depth work is warranted.

Managing for species that will be shifting their ranges over significant distances will require coordination across state boundaries. Having a tool that can be applied by neighboring states (especially those oriented in a north-south manner) would help to coordinate efforts and understand which species of concern will be moving in or out, and which may be vulnerable across their entire range.

To address these needs, NatureServe has developed the Climate Change Vulnerability Index. This 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). Some factors such as population size, range size, and demographic factors influence both conservation status and vulnerability to climate change. To avoid duplicating these factors, the Vulnerability Index does not consider them. Conservation status ranks are therefore an important consideration in the interpretation of the results.

Target Audience.—The 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 in terrestrial or aquatic plant and animal species. A noteworthy application of the Index is as part of a larger strategy to update a state wildlife action plan to address climate change. 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 the both the Vulnerability Index and other options in the context of their particular needs, geographic scale, and resources available. Below are a few examples of alternative approaches.

In Massachusetts, researchers from the Manomet Bird Observatory have teamed with the state Division of Fisheries and Wildlife to use a habitat approach. They divided the state into 22 habitats and asked experts to assess the vulnerability of each habitat. Some habitats, such as spruce-fir forest, which is cold-adapted and at the southernmost extent of their range in Massachusetts, will almost certainly disappear in the state during this century whereas other will persist. By assigning their species "of greatest conservation need" (as listed in their wildlife action plan) to habitats, they obtained a quick overview of vulnerable species. To learn more, contact Hector Galbraith of Manomet (hg2@hughes.net).

In New Mexico, scientists at The Nature Conservancy began by mapping trends in climate change during the period 1970-2006. Overlaying changes in temperature and precipitation with major habitat types showed that most mid- to high-elevation forests and woodlands are becoming warmer and drier and thus highly vulnerable to climate change. New Mexico's grasslands have experienced more stable conditions and may therefore be less vulnerable. Reports summarizing this work are available at http://nmconservation.org/projects/new_mexico_climate_change/.

HOW THE INDEX WORKS

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 studies of this nature have been conducted on the species.

Exposure to climate change is measured by examining the magnitude of predicted temperature and precipitation change across the range of the species within the assessment area. The Climate Wizard (http://climatewiz.org) provides a convenient source of downscaled climate predictions that can be visualized on screen or downloaded into a GIS for further analysis.

Sensitivity is assessed by scoring species against 21 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 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 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.

Relation between Exposure and Sensitivity.—The Index treats exposure to climate change as a modifier of sensitivity. If the climate across the range of a species will not change much, none of the sensitivity factors will weigh heavily. A large change in climate will amplify the effect of any sensitivity factor that increases vulnerability to climate change. In most cases, temperature and precipitation change will combine to modify sensitivity factors. However, for factors such as sensitivity to temperature change, only predicted temperature change 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 designed to mitigate against climate change, are not influenced by exposure to local climate change. The magnitude of sea level rise will reflect global warming, not climate change in the area where a coastal species occurs. Similarly, land use changes such as the siting of wind towers or the cultivation of crops for biofuel are meant to mitigate against global climate change and not local climate change where they occur.

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

Time and Geographic Scale.—The Index contemplates vulnerability to climate change by the year 2080, a typical cut-off date for predictions made in the International Panel on Climate Change reports (e.g., IPCC 2007). The user can modify this target year as long as the same year is used as the end date for downscaled climate predictions. Future, advanced versions of the Climate Wizard will allow you to request this sort of data based on any user-defined horizon date. If using a time scale significantly different than 2080, the thresholds separating the different index categories may need adjustment to adequately separate species into different vulnerability categories.

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. For wide ranging species, the variation in climate predictions, especially for precipitation, can be large across the area under assessment leading to difficulty in predicting the direction and magnitude of population and range change. In these cases, there may be local population expansions and contractions.

Note that for 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. The result will be less variance in the Index scores across species.

The current version of the index is tailored for use in North America north of Mexico. Use elsewhere may require modification of specific factors. 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.

Indirect Exposure to Climate Change

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

2) *Distribution relative to natural topographic or geographic habitat 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).

3) *Distribution relative to anthropogenic barriers*. Dispersal of a species to areas with favorable climates may be hindered by intervening urban or agricultural areas (Parmesan 1996).

4) *Predicted impact of land use changes designed to mitigate against climate change*. Strategies designed to mitigate against 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 ability*. 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 el. 2007).

2) *Predicted sensitivity to temperature and precipitation changes*. Species requiring specific precipitation 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

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) *Physical Habitat Specificity*. 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 habitat 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 a mutualism not covered by 4a-d

5) *Migrations and Movements (animals only)*. Species with very specific migratory destinations are vulnerable whereas those with broad destinations are less vulnerable to climate change ((Laidre and Heide-Jørgensen 2005, Jiguet et al. 2007).

6) *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

7) *Phenological response to changing seasonal temperature and precipitation regimes*. 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 change in distribution or abundance attributable 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 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 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 ability, temperature/precipitation regime, dependence on disturbance events, relationship with ice or snow-cover habitats, habitat specificity, interactions with other species including diet and pollinator specificity, migrations, 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 ten of the 17 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 use the Climate Wizard data in your own GIS, you can save time by adjusting the classification scale to match the temperature and precipitation 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 three major global circulation models (GCMs). Each GSM 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 and precipitation predictions on the Climate Wizard and Box 3 explains how to download these data into ArcGIS.

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 (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.

<u>Box 2. Using Climate Wizard to obtain Downscaled Climate Prediction Data</u>

1. From the Climate Wizard home page, click Climate Wizard, then climate conditions of the future: United States

2. Select the state you are working in.

3. For Temperature, make sure that the Average Temperature tab (at the top) and Annual button (on the top left) are selected.
4. Under Map Options, choose Map of Difference.
5. Under Emissions Scenario choose Medium.
6. Under General Circulation Model, choose Ensemble, and then Medium in the adjoining drop-down menu.

Box 3. How To Open Climate Wizard Data in ArcGIS

1. Download the appropriate .asc file from the Climate Wizard. Display exactly the data you want to download, then click the Data (GIS format) option from the Download section.
2. Open a new ArcGIS project.
3. In the ArcToolbox, go to Data Management Tools→Raster→Raster Dataset→Copy Raster→Select file for input. Rename with 13 letters or less for output, leave extension blank (this will give you a GRID file, which is easiest to use for math).
4. In the 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 1972.prj

Land Use Data.—To evaluate factor B3, *Distribution relative to anthropogenic barriers*, you will need land cover maps for your region. We recommend the Wildland-Urban Interface data to assess the intensity of land use in the 48 contiguous states of the USA (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 on-line 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 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 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 spreadsheets provide guidance for completing each corresponding section of the Calculator. The same guidance is reproduced here for convenience.

Preliminary Information.—Fill out the header information for the geographic area assessed, species, whether it is a plant or animal, assessor, and notes. Because some factors are specific to either plants or animals, the latter box 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.

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 C-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. 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.

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. Obtain Climate Wizard data as instructed in Box 2. For temperature, either count the number of pixels 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 degrees F warmer
- 4.1-5 degrees F warmer
- 3.1-4 degrees F warmer
- <= 3 degrees F warmer

Then do the same for precipitation, estimating the percentage of the range of the species in each of the following categories:

- >5" drier
- 3.1-5" drier
- 1-3" drier
- No significant change (<1")
- 1-3" wetter
- 3.1-5" wetter
- >5" wetter

If you are using percentages, check to make sure that the percentages entered for each climate factor sum to 100.

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 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.

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 expanse with a rising sea level.

B2) Distribution Relative to Natural Topographic or Geographic Habitat Barriers

NOTES: This factor reflects how a species' physical habitat context may affect its ability to track climate envelope shifts, for example whether the species may be restricted from dispersing to or persisting in new climatically-favorable areas because of topographic or geographic barriers. This factor does not address potential dispersal restriction due to hydrological habitat features, or due to natural or anthropogenic fragmentation of the species' preferred vegetation type(s); these factors are addressed elsewhere. For migratory species, the range restriction can apply to a single period of the annual cycle (for example, the breeding season).

Greatly Increase Vulnerability:	Range 100% restricted to an island/island group, OR range 100% restricted to the alpine life zone (above climatic tree line), the upper montane cloud forest, or the uppermost habitat type [life zone] of a vertically zoned high elevation landform (mountaintop, mesa, massif, etc.)., OR large, strong barrier to dispersal occurs on border of range restricting dispersal in direction of expected shift of favorable climate (such as occurring along the southern border of a Great Lake).
Increase Vulnerability:	Range >75% restricted to an island/island group OR alpine/upper montane cloud forest/uppermost life zone of a mountainous area, OR with naturally limited but potentially viable options for dispersal (such as being significantly limited from dispersing by a large water body), OR requires narrow and geographically restricted (i.e. island-like) topographic features for one or more portions of the life cycle (e.g., normal growth, shelter, reproduction, seedling establishment). Species restricted to "sky islands" at the top of desert mountains should be placed here if they do not qualify under Greatly Increase above. Island-like hydrological features (e.g. springs in arid areas, vernal pools) should not be considered here; these are accounted for elsewhere.
Somewhat Increase Vulnerability:	Range >90% restricted to a peninsula with an orientation that may restrict dispersal in the direction of expected shift of favorable climate. For example, species occuring on a peninsula with a mainland connection to the east, south, or west when favorable climates are expected to shift north.
Neutral:	Range with no topographic or geographic barriers to dispersal.
Somewhat Decrease Vulnerability:	Current range constricted by natural barriers (such as in a valley between two mountain ranges), but larger area of habitat available in direction of expected shift of favorable habitat.

B3) Distribution Relative to Anthropogenic Barriers

NOTES: As climate changes and species seek to move to more suitable areas, anthropogenically altered areas such as urban and intensive agricultural environments are likely to pose significant barriers for many species. A classic example of this phenomenon is the quino checkerspot butterfly (Euphydryas editha quino), a resident of northern Baja California and southern California - warming climates are forcing this butterfly north, but urbanization in San Diego blocks its movement (Parmesan 1996).

Use the published maps or downloadable GIS data for Wildland-Urban Interface to assess intensity of land use in the 48 contiguous states of the USA (Silvis Lab, University of Wisconsin-Madison and the USDA Forest Service North Central Research Station, http://silvis.forest.wisc.edu/library/wuilibrary.asp). For the published Silvis Lab maps, any legend color other than green (vegetated, low housing density) qualifies as intensive land use for this factor. 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. * See below for instructions for downloading Silvis GIS data.

Use a 100 km buffer around the current distribution, emphasizing the direction of anticipated range shift. This distance is based on models of California plants (Loarie et al. 2008), which project species range centroids to shift by an average of up to 151 kilometers in high emission scenarios (A1FI) with dispersal.

Greatly Increase Vulnerability:	Land use > 80% urban and/or other intensive land use with reasonable permanence and unsuit
Increase Vulnerability:	Land use 60-80% urban and/or other intensive land use with reasonable permanence and unsuitability (e.g. intensive agriculture), within species' range + 100 km buffer.
Somewhat Increase Vulnerability:	Land use 40-59% urban and/or other intensive land use with reasonable permanence and unsuitability (e.g. intensive agriculture), within species' range + 100 km buffer.
Neutral:	Land use < 40% urban and/or other intensive land use with reasonable permanence and unsuitability (e.g. intensive agriculture), within species' range + 100 km buffer.
Somewhat Decrease Vulnerability:	Species is well-adapted to the type of intensive land use in its expected direction of range shift, e.g., raccoons in urban areas.

B4) Predicted Impact of Land Use Changes Designed to Mitigate against Climate Change (e.g., plantations for carbon offsets, wind-farms, biofuels production)

NOTES: Strategies designed to mitigate against 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.

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 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 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 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 are may possibly 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 they 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 ten of the 17 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 Ability

NOTES: If species requires other species for propagule dispersal, also complete factor C3e. Categorization for plants based on Vittoz and Engler (2007).

Greatly increase Vulnerability:	Essentially a sessile organism with **no current capacity to disperse more than a few meters** per generation (disperser may be extinct, or dispersal may be limited to vegetative shoots). Many plant species lacking obvious dispersal adaptations or those dispersed ballisticly would fall into this category.
Increase Vulnerability:	Organism **unknown to be able to disperse greater than ~100 m/yr** during dispersal stage of the life cycle OR dispersal possible only along corridors of specialized habitat (such as riparian zones). Many plant species dispersed by ants would fall into this category, as well as plants dispersed by wind with low efficiency (e.g. species with inefficiently-plumed seeds and/or that occur in predominantly in forests).
Somewhat Increase Vulnerability:	Organism **unknown to be able to disperse greater than ~1 km/yr** during dispersal stage of the life cycle. Many plant species dispersed by wind with high efficiency would fall into this category (e.g. species with efficiently-plumed seeds or very small propagules that occur predominantly in open areas).
Neutral:	Organism typically capable of dispersing **at least 1 km/yr** during dispersal stage of the life cycle. If nonmobile, has a range of potential dispersal agents (not all of which need have been documented). Some plant species with obvious dispersal adaptations will likely fall into this category - for example, plant species with fleshy fruits or edible nuts whose most frequent dispersers move distances of this scale.
Somewhat Decrease Vulnerability:	Organism good at dispersing, **typically greater than 1 km** per year during dispersal stage of the life cycle with regular long-distance dispersal events recorded. Some plant species adapted to animal dispersal would likely fall into this category (e.g. seeds that are cached, deposited post-ingestion, or transported on fur whose most frequent dispersers move distances of this scale).
Decrease Vulnerability:	Organism very good at long-distance dispersal, with **frequent long-distance dispersal events (much greater than 1 km)** recorded. May include species dispersed by migratory animals, species known to be dispersed by ocean currents, species prone to intentional or unintentional human dispersal (may be established outside its native range), or an animal species known to disperse long distances via its own locomotory abilities.

C2) Predicted Sensitivity to Temperature and Precipitation Changes

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

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

i) Macro sensitivity (exposure to past temperature variation)

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 state or 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 Seasonal Temperature Variation map 1951-2006 (Figure 2) or calculated using GIS data downloaded from ClimateWiz.org.

For **migratory species**, use the difference between highest and lowest temperatures during the season of occupation. Migrating species will have differing temperature variations in differing portions of their range. Choose the most sensitive part of the migration cycle (e.g., breeding area) for this factor.

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.

Greatly Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **very small (< 37 degrees F)** temperature variation in the past 50 years.
Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **small (37 - 47 degrees F)** temperature variation in the past 50 years.
Somewhat Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **slightly lower than average (47.1 - 57 degrees F)** 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 degree F)** 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 degrees F)** temperature variation in the past 50 years.

ii) Micro sensitivity

NOTES: This factor pertains to a species' tendency to occupy warmer or cooler than average microsites within its typical habitat. It is intended to flag species that occupy small temperature niches highly vulnerable to change. Note that "cooler" microhabitats should not be confused with "moist/wet" habitats, which are treated under C2bii, Precipitation Micro sensitivity.

For wider ranging species that are not dependent on microsites, this factor also reflects whether the portion of the range assessed is on the "leading" or "trailing" edge of a distribution that may be tracking a climate envelope that is moving across the assessment area.

Increase Vulnerability: Completely or almost completely dependent on the coolest of local microsites/microhabitats (e.g. frost pockets). Also, species for which the area assessed represents less than 25% of the range, and this portion of the range is on the trailing edge of a distribution that is tracking a climate envelope away from this area.

Somewhat Increase Vulnerability: Somewhat dependent on the coolest of local microsites/microhabitats OR shows a preference for local microsites/microhabitats toward the cooler end of the spectrum. Also, species for which the assessment area represents less than 50% of the range, and this portion of the range is on the trailing edge of a distribution that is tracking a climate envelope moving away from this area.

Neutral: Settings in which the species typically occurs lack significant microsites/microhabitats OR species does not respond to microsites in its habitat.

Somewhat Decrease Vulnerability: Broad tolerance for a variety of temperature niches and microsites (such as occurring in disparate habitats such as "wetlands and uplands") OR shows a preference for local microsites/microhabitats toward the warmer end of the spectrum. Also, species for which the area assessed represents less than 50% of the range, and this portion of the range is on the leading edge of a distribution that is tracking a climate envelope into this area.

b) Predicted sensitivity to changes in precipitation, based on current/recent past specificity with regard to precipitation, moisture, and hydrological regime

i) Macro sensitivity (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. Overlay the species range on the ClimateWiz mean annual precipitation map 1951-2006, and subtract the lowest pixel value from the highest value to assess this factor.

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

ii) Micro sensitivity

NOTES: This factor pertains to a species' dependence on narrowly defined hydrologic regime, including a strongly seasonal precipitation patterns and/or specific aquatic/wetland habitats that may be highly vulnerable to loss or reduction with climate change (certain springs, vernal pools, seeps, seasonal standing or flowing water, or other aquatic or wetland ecosystems). Dependence may be permanent or seasonal. As a result of geographical differences in modeled future precipitation, 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.

Greatly Increase Vulnerability: Completely or almost completely (>90% of occurrences or range) dependent on a specific aquatic/wetland habitat highly vulnerable to loss or reduction with climate change (certain springs, vernal pools, seeps, seasonal standing or flowing water, etc.) AND the expected direction of precipitation change (wetter or drier) is likely to reduce the species' distribution, abundance, or habitat quality. Examples include certain spring-dependent fishes and ephemeral-pool-dependent branchiopods in areas vulnerable to desiccation as a result of climate change.

Increase Vulnerability: Moderately (50-90%) dependent on a strongly seasonal precipitation regime and/or a specific aqautic/wetland habitat highly vulnerable to loss or reduction with climate change (certain springs, vernal pools, seeps, seasonal standing or flowing water, etc.) AND the expected direction of precipitation change (wetter or drier, seasonal distribution) is likely to reduce the species' distribution, abundance, or habitat quality. Examples 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 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 precipitation regime and/or a specific aqautic/wetland habitat highly vulnerable to loss or reduction with climate change (certain springs, vernal pools, seeps, seasonal standing or flowing water, etc.) AND and the expected direction of precipitation change (wetter or drier, seasonal distribution) is likely to reduce the species' distribution, abundance, or habitat quality. Examples 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: Little or no dependence on a strongly seasonal precipitation regime and/or a specific aqautic/wetland habitat highly vulnerable to loss or reduction with climate change (certain springs, vernal pools, seeps, seasonal standing or flowing water, etc.) OR hydrological requirements not likely to be significantly disrupted in major portion of the range.

Somewhat Decrease Vulnerability: Species with very broad moisture regime tolerances OR species that would benefit by the predicted change in precipitation. Examples include water-limited species that could increase with increasing precipitation or arid-adapted species that could increase in areas with decreasing precipitation.

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. For a map of departure from long-term fire regime, see http://www.fws.gov/invasives/staffTrainingModule/methods/burning/sup_intro2.html.

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.
Somwhat 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 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.
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.

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.

Increase Vulnerability:	Strongly or moderately dependent (>50% 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, polar bear (*Ursus maritimus*) is strongly dependent on sea ice throughout its range; Kittlitz's murrelet (*Brachyramphus brevirostris*) feeding habitat is moderately to strongly associated with tidewater glaciers.
Somwhat 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) Physical Habitat Specificity

NOTES: This factor pertains to the degree of specificity in soil/substrate, geology, or specific physical features (e.g., caves, cliffs, active sand dunes) where a species reproduces, feeds, grows, or otherwise exists. Species with narrow habitat requirements may be 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. These are covered elsewhere in the index.

Increase Vulnerability:	Requires narrow or moderately narrow and generally geographically restricted habitats for one or more portions of the life cycle (e.g., normal growth, shelter, reproduction, seedling establishment). For example, fringe-toed lizards *(Uma* spp.) are tightly resticted to active sand dunes, and various plants are restricted primarily to particular soil types with unusual chemical characteristics (e.g. serpentine endemics).
Somewhat Increase Vulnerability:	Requires somewhat narrow and generally geographically restricted habitats for one or more portions of the life cycle. For example, certain reptiles and plants are generally associated with particular substrates that may restrict their distribution.
Neutral:	Neither particularly specialized nor generalized in physical habitat requirements.
Somewhat Decrease Vulnerability:	Moderately generalized in the physical habitats where it can survive and reproduce. If there is a preferred substrate, it tends to be widely available (e.g. sandy soil).
Decrease Vulnerability:	Highly generalized in the physical habitats where it can survive and reproduce. For example, yarrow (*Achillea millefolium*) maintains viable populations in a wide range of substrates.

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 4e.

Increase Vulnerability:	Required habitat generated primarily by 1 species. For example, 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 (Skelley and Kovarik 2001), and the spider *Masoncus pogonophilus* depends on habitat provided by colony chambers of the Florida harvester ant (*Pogonomyrmex badius*) (Cushing 1997).

Somwhat 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 1 species during any part of the year. For example, Clark's nutcracker (*Nucifraga columbiana*) depends heavily on the seeds of whitebark pine (*Pinus albicaulis*).

Somwhat 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 based on data in Waser et al. (1996).

Increase Vulnerability: Completely or almost completely dependent on 1 species for pollination (> 90% of effective pollination accomplished by 1 species) or, if no observations exist, morphology suggests very significant limitation of potential pollinators (e.g. very long corolla tube).

Somwhat 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; 5 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: Freshwater mussels requiring fish to disperse larvae; a plant requiring a specific animal for dispersal such as whitebark pine and Clark's Nutcrackers.

Increase Vulnerability:	Completely or almost completely (roughly > 90%) dependent on a single species for propagule dispersal.
Somwhat Increase Vulnerability:	Completely or almost completely (roughly > 90%) dependent on a small number of species for propagule dispersal.
Neutral:	Disperses on its own (most animals) OR propagules can be dispersed by more than a few species.

e) Forms part of a mutualism not covered by C4a-d

NOTES: Can be applied to plants or animals. Refers to mutualisms unrelated to to habitat, seedling establishment, diet, pollination, or propagule dispersal. For example, an acacia bush requiring an ant colony for protection against herbivores.

Increase Vulnerability:	Requires mutualism with a single other species for persistence. Many Orchidaceae will be in this category because of their requirement for a specific fungal partner for germination ("The availability of a suitable mycorrhizal fungus is crucial to orchid establishment. Recent studies have shown a surprisingly high level of orchid specificity for their mycorrhizal fungi." Tupac Otero and Flanagan 2006).
Somwhat Increase Vulnerability:	Requires mutualism 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 (e.g. *Botrychium* - mycorrhizae). Many Orchidaceae will be in this category because of their requirement for a specific fungal partner for germination. ("The availability of a suitable mycorrhizal fungus is crucial to orchid establishment. Recent studies have shown a surprisingly high level of orchid specificity for their mycorrhizal fungi." Tupac Otero and Flanagan 2006).
Neutral:	Does not require a mutualism or, if it does, many potential candidates for mutualistic partners are available.

C5) Migrations and Movements (animals only)

Greatly Increase Vulnerability:	Regularly migrates to or through a single distinct and geographically restricted location (including breeding area, wintering area, or migration stopover site) where ecological integrity or environmental conditions for migration may be compromised by climate change.
Increase Vulnerability:	Regularly migrates to or through a few distinct and geographically somewhat restricted locations (including breeding areas, wintering areas, or migration stopover sites) where ecological integrity or environmental conditions for migration may be compromised by climate change.
Somewhat Increase Vulnerability:	Nonmigratory and populations do not regularly make substantial (> 100 km) distributional shifts in response to changing environmental conditions (includes amphibians, denning snakes, and other groups that undergo localized breeding or seasonal migrations of under ~10 km).

Neutral:	Migrates short distances (typically < 200 km) OR contains a mix of migratory and nonmigratory populations OR at the species level has many migratory destinations for reproduction (for example, salmon, sea turtles).
Somewhat Decrease Vulnerability:	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) OR species is basically nonmigratory but populations regularly shift distribution up to hundreds of kilometers in response to changing environmental conditions (e.g., black-backed woodpecker often makes substantial shifts in its distribution in accordance with concentrations of wood-boring insects).
Decrease Vulnerability:	Regularly migrates to one or more broad geographical area(s) encompassing > 100,000 km^2.

C6) 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 C6a is "unknown")*

NOTES: In the absence of rangewide genetic variation information (C6a), 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.

Increase Vulnerability:	Evidence that total population was reduced to ≤ 250 mature individuals and/or that occupied area was reduced by >60% at some point in the past 500 years.
Somewhat Increase Vulnerability:	Evidence that total population was reduced to 251-1000 mature individuals and/or that occupied area was reduced by 40-60% 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 > 40% at

some point in the past 500 years.

C7) 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 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 3 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 or pied flycatchers with winter moth caterpillars, or honey-buzzards 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 Sensitivity for this factor. Similarly, species that respond by changing their phenology (without a related decline in population) should also be scored as Neutral Sensitivity.

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 (2080) 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 <5km) using algorithms that are supported by peer-reviewed literature. Areas of obvious overprediction should be removed from current and predicted future distributions. Projections should be based on "middle of the road" climate scenarios for the year 2080. 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).

Greatly increase vulnerability:	Predicted future range represents > 70% decrease relative to current range OR predicted future abundance represents >70% decrease associated with climate change processes.
Increase Vulnerability:	Predicted future range represents a 40-70% decrease relative to current range OR predicted future abundance represents 40-70% decrease associated with climate change processes.
Somewhat Increase Vulnerability:	Predicted future range represents a 20-40% decrease relative to current range OR predicted future abundance represents 20-40% decrease associated with climate change processes.
Neutral:	Predicted future range represents no greater than a 20% change relative to current range OR predicted future abundance represents increases or decreases < 20% associated with climate change processes.
Somewhat Decrease Vulnerability:	Predicted future range represents a 20-40% increase relative to current range OR predicted future abundance represents 20-40% increase associated with climate change processes.
Decrease Vulnerability:	Predicted future range represents a > 40% increase relative to current range OR predicted future abundance represents > 40% increase associated with climate change processes.

D3) Overlap of modeled future (2080) 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 projected future range AND a large, strong barrier (landform and/or anthropogenic) to the dispersal of the species separates these two ranges.
Increase Vulnerability:	Predicted future range overlaps the current range by 30% or less.
Somewhat Increase Vulnerability:	Predicted future range overlaps the current range by 30-60%.
Neutral:	Predicted future range overlaps the current range by > 60%.

D4) Occurrence of protected areas in modeled future (2080) 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.

Increase Vulnerability:	< 5% of the modeled future distribution is encompassed by one or more protected areas.
Somewhat Increase Vulnerability:	5-30% of the modeled future distribution is encompassed by one or more protected areas.
Neutral:	>30% of the modeled future distribution 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 Section A and the minimum number of factors in Sections B and C are completed. The Index scores (Box 5) 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 successfully separates 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 5. Definitions of Index Scores

Extremely Vulnerable: Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2080.

Highly Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2080.

Moderately Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease by 2080.

Not Vulnerable/Presumed Stable: Abundance and/or range extent within geographical area assessed not likely to change (increase/decrease) by 2080. Actual range boundaries may change.

Not Vulnerable/Increase Likely: Abundance and/or range extent within geographical area assessed likely to increase by 2080.

Insufficient Evidence: There is not a minimum level of information about a species' susceptibility factors to be able to calculate an index score.

Measures of Confidence.— To estimate **confidence in species information**, the Index uses a Monte Carlo simulation to compare how often runs of the Index randomly choosing one of the checked boxes for factors in which more than one box is checked yield the same Index score as when an average of the multiple boxes is used. The simulation runs for 1000 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.

A measure for **confidence in the magnitude of climate change** is under development.

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 vulnerabilities. The simplest approach, therefore, is to sort species based first on their climate change vulnerability, and then within vulnerability categories by their conservation status.

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. Box 6 provides some suggestions for management actions to address some of these factors.

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
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.

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. For these reasons it is a useful to review the list of results with an eye toward species that are at the southern or northern edges of their ranges. 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.

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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.

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

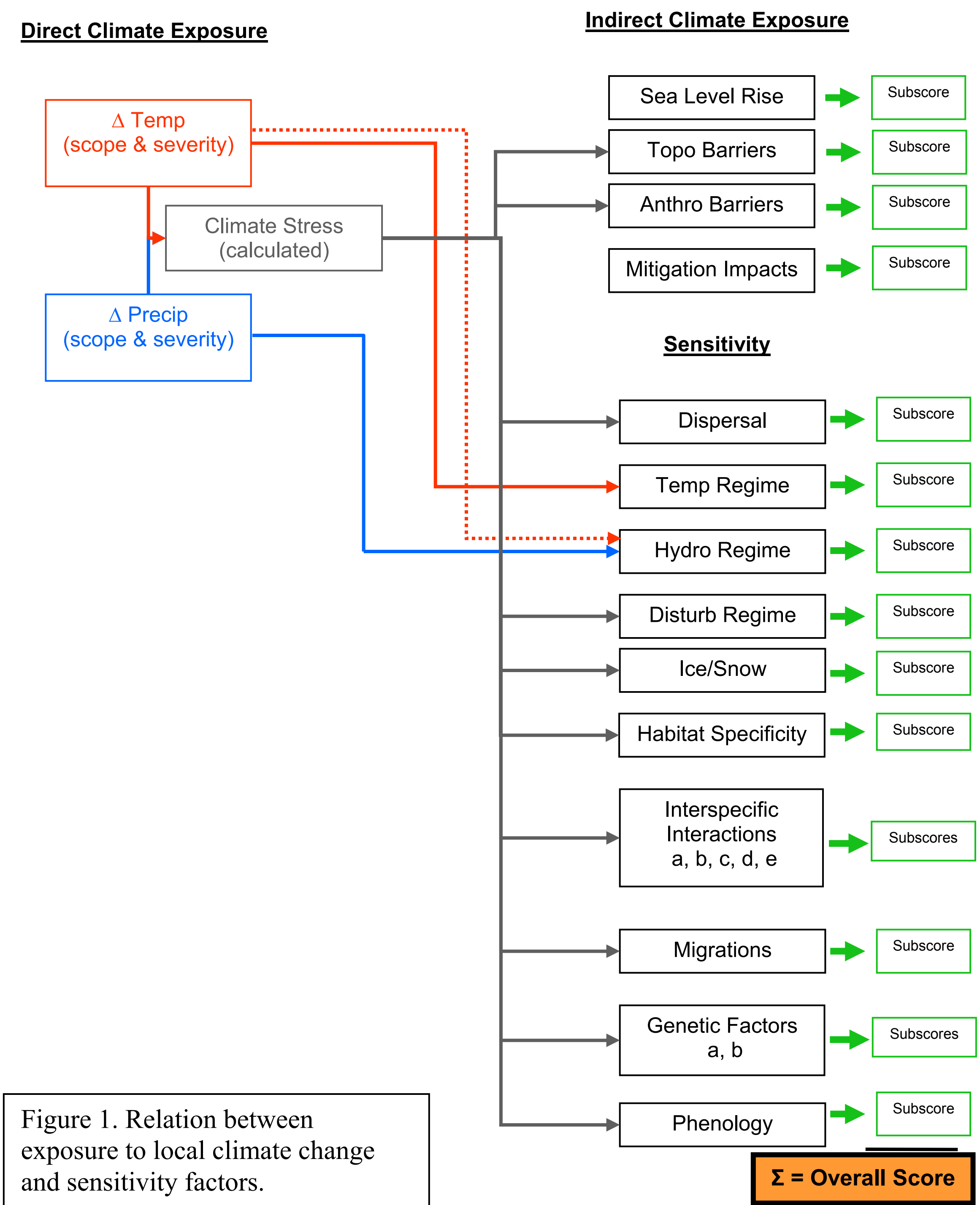

Figure 1. Relation between exposure to local climate change and sensitivity factors.

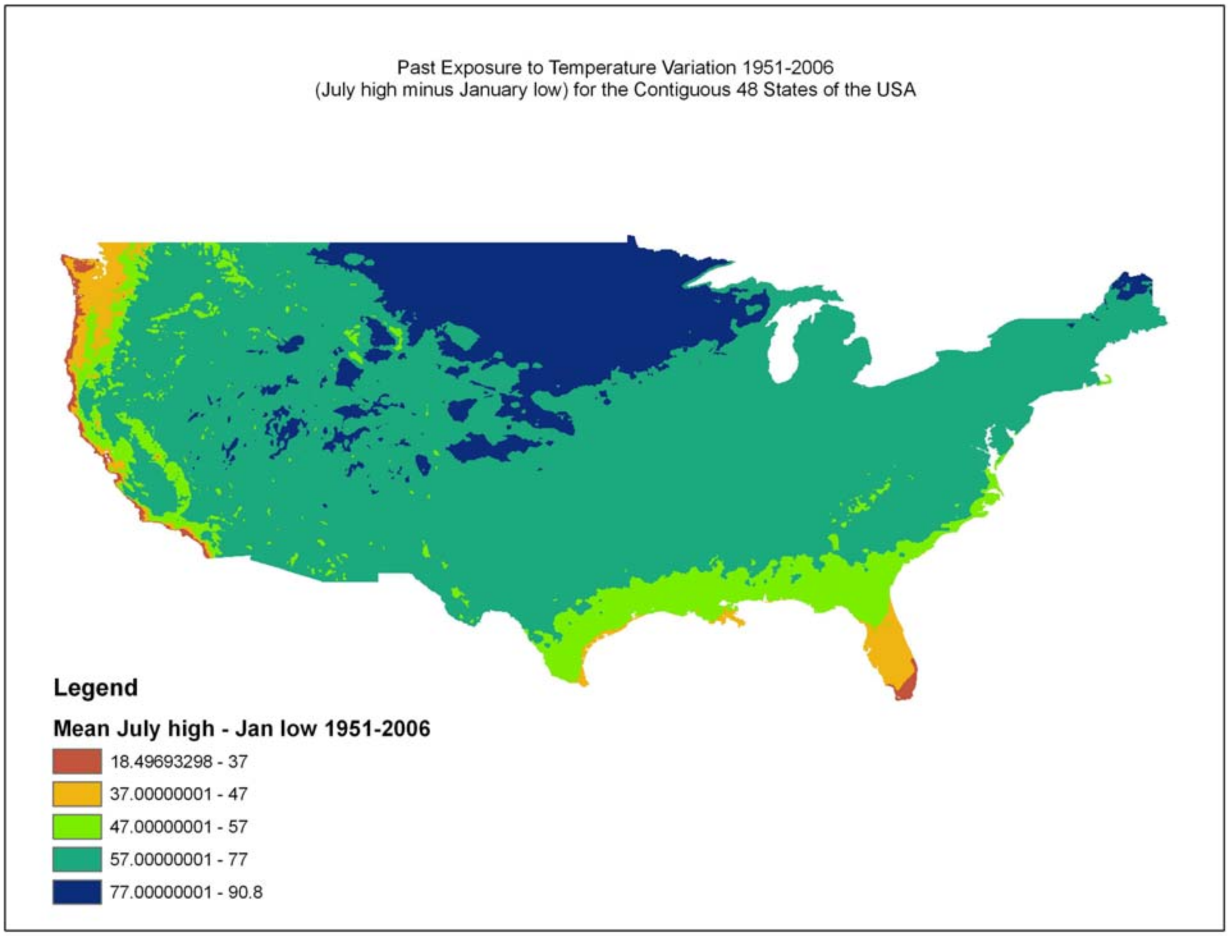

Figure 2. Past exposure to temperature for factor C2ai.