NO REFUGE FROM WARMING

SUPPLEMENTARY MATERIALS

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Contents

Save something wild.

Methods: Using the Climate Change Vulnerability Index

The Climate Change Vulnerability Index (Natureserve, undated) requires inputs that measure Direct Exposure to climate change and Sensitivity to climate change, which includes both Indirect Exposure and Species Sensitivity. The Index combines data on exposure to climate change (in this case changes in moisture and temperature) with information about species sensitivity to climate change resulting from extrinsic factors caused by indirect exposure to changes related to climate change (e.g. sea level rise) and species specific factors such as flexibility of habitat and dietary requirements (Figure 1). The index also allows users to include limited information on a species' documented response to recent or ongoing climate change as well as the results of modeling studies. The output of the Index is a score ranging from extremely vulnerable to not vulnerable/ presumed stable/expansion likely. The index identifies the "critical factors" or the elements that make the species assessed vulnerable. The scores and identification of critical factors can be used to develop targeted conservation efforts and further research projects to help manage the species in a climate change future.

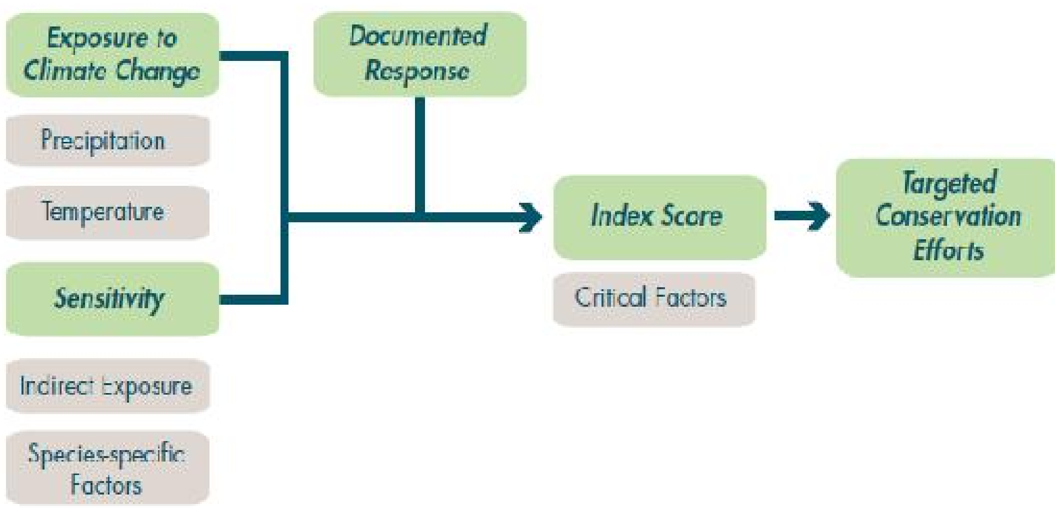

Figure 1: Framework for the NatureServe Climate Change Vulnerability Index. Figure from Glick et al. 2011

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 (Figure 1). These two components are mathematically combined to produce the final vulnerability score. In this way exposure is treated as a modifier of sensitivity. A species with traits that make it highly sensitive to climate change will not have a high vulnerability score if the climate across the region it occurs in remains stable (CCVI Guidelines 2010), while a species with broad tolerances and low sensitivity is unlikely to be vulnerable even if the climate changes drastically across its region.

Adaptive capacity of the species is not explicitly addressed in the index, though several sensitivity factors and indirect climate change factors overlap with factors that might contribute to or detract from the adaptive capacity of the species. For example, one factor assesses whether or not the species has been able to respond to ongoing climate change by changing any aspect of its phenology in a beneficial way. This trait could arguably be considered part of adaptive capacity rather than species sensitivity. Similarly dispersal ability, genetic variation, and distribution as related to natural barriers could all be considered as contributing to the adaptive capacity of the species.

Direct Exposure: Climate Change in the Arctic National Wildlife Refuge

The first factor addressed in the Index is **exposure to climate change.** Exposure information captured in the index includes the magnitude of projected changes in average annual **temperature** and **moisture** across the species' range in the assessment area. To incorporate exposure information the Index guidance suggests using ClimateWizard for developing future climate projections. ClimateWizard, a project of the Nature Conservancy, University of Washington and the University of Southern Mississippi provides a source of downscaled temperature and precipitation predictions from 17 Global Circulation Models (GCMS) that can be downloaded and incorporated into GIS for analysis (Girvetz et al. 2009). See below for a more detailed discussion of the General Circulation Models used and the downscaling process.

Change in Temperature

Across the Arctic National Wildlife Refuge temperatures are projected to increase over the next 50 years. These changes range from an increase of 4 degrees F in the most southern portion of the refuge to greater than 6 degrees F in the north of the refuge (Figure 2). Temperature changes will lead to a variety of impacts including changes in snowfall and snowcover, changes in vegetation, alteration of the fire regime, and changes in species phenology and species interactions. These more specific changes are not part of the outputs from the ClimateWizard tool and therefore cannot be modeled specifically for our assessment.

Table 1 shows the percent of the assessment area in each of the temperature ranges defined in the index. The rankings in the severity of change column of the table are assigned scores from NatureServe based on the relative range of expected changes in temperature by Mid-Century. Each individual species profile describes the changes projected for that species' range within the Refuge.

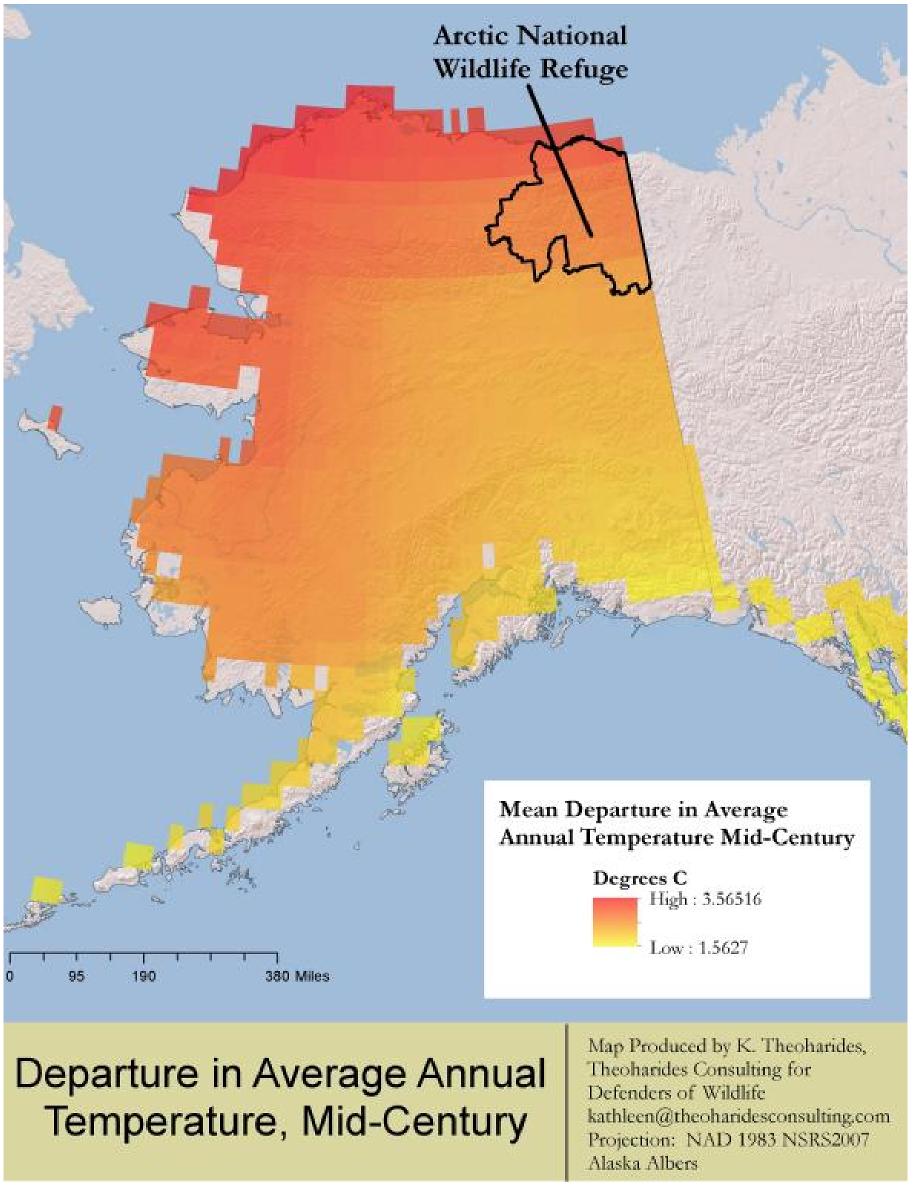

Figure 2: Departure in average annual temperature across the Alaska by Mid-Century.

Table 1: Percent of each category of temperature change in the Arctic Refuge based on ClimateWizard projections. Scope must sum to 100 percent.

Severity of Change	**Temperature Range**	**Scope** (percent of range)
High	>5.5° F (3.1° C) warmer	**7.79%**
Medium High	5.1-5.5° F (2.8-3.1° C) warmer	**57.14%**
Medium Low	4.5-5.0° F (2.5-2.7° C) warmer	**27.27%**
Low	3.9-4.4° F (2.2-2.4° C) warmer	**7.8%**
Insignificant	< 3.9° F (2.2° C) warmer	**0%**
	Total:	**100%**

Change in Moisture

In the lower 48 states the Index version 2.0 includes a Hamon AET:PET moisture metric, rather than changes in precipitation. The Index made this change from the use of precipitation data in the original Index version 1.0 to a more biologically relevant climate variable as species are impacted by available moisture and not precipitation levels directly. The Hamon AET:PET moisture metric used in the Index 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. However, the Hamon AET-PET index employed in the CCVI for the lower 48 states is not available in Alaska so we instead used the percent departure in the historical ratio of Actual Evapotranspiration (AET) to Potential Evapotranspiration to the mid-century projected ratio to indicate how moisture is changing in Alaska. This ratio is available through the ClimateWizard Custom Analysis Tool. Potential Evapotranspiration is defined as the amount of evaporation that would occur if a sufficient water source were available. The actual evapotranspiration (AET) is considered the net result of atmospheric demand for moisture from a surface and the ability of the surface to supply moisture, and PET is a measure of the demand side for moisture. Surface and air temperatures, insolation, and wind all affect this ratio. A loss of moisture over time is indicated by a negative percent departure in the ratio, while a moisture gain is indicated by a positive change (See Table 2). Across the Arctic Refuge moisture change will not be significant as indicated by the AET:PET ratio and may in fact be slightly positive (Figure 3). Changes in the ratio ranged from an increase of .08827 to an increase of .02040. For some caveats about the projected moisture change in the Arctic National Wildlife Refuge, see below.

Table 2: Difference in the ratio of annual AET:PET by mid-century.

Severity	**Moisture range**	**Scope** (percent of range)
Very High	< -0.119	0%
High	-0.097 - -0.119	0%
Medium High	-0.074 - -0.096	0%
Medium Low	-0.051 - -0.073	0%
Low	-0.028 - -0.050	0%
Insignificant	>-0.028	100%
	Total:	100%

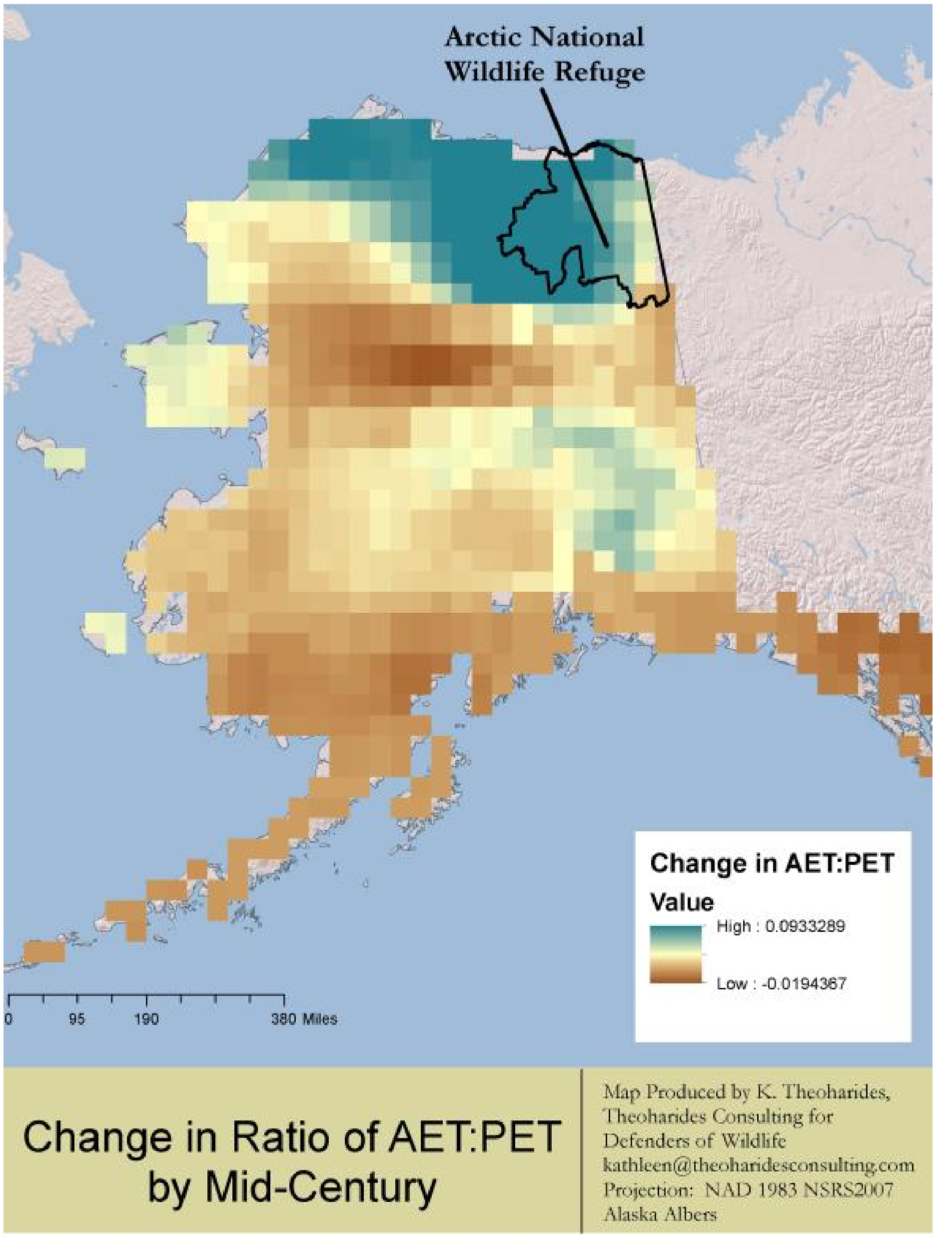

Figure 3: Change in the ratio of AET:PET by mid-century. Change across the refuge was slightly positive, but considered insignificant based on the NatureServe scoring.

Sensitivity to Climate Change

The Index assesses sensitivity by scoring species against 20 factors divided into two categories: **indirect exposure to climate change** (extrinsic sensitivity) **and species-specific sensitivity** (intrinsic sensitivity). Extrinsic sensitivity is sometimes considered adaptive capacity, but in this case the Index treats it as a component of sensitivity.

Species receive a score for each factor ranging from greatly increasing to having no effect on, to decreasing the species' vulnerability. If information is not available the factor can be skipped; the Index can calculate an overall score with as few as 13 of 20 factors. The creators of the Index recommend estimating scores for as many factors as possible and capturing uncertainty and a lack of data by selecting multiple scores for each factor. For detailed descriptions of each factor, please reference the NatureServe Climate Change Vulnerability Index guidance document. Explanations of how each sensitivity factor was treated in our analysis, including any assumptions made, are provided below. We also include details on the background materials used to score each species.

Indirect Exposure to Climate Change

Many species will be affected not only by direct changes in temperature and precipitation, but also by more indirect effects of climate change, such as exposure to sea level rise, and barriers to dispersal and movement. Below are a list of the factors considered in the "Indirect Exposure to Climate Change" category and a brief description of how I treated these.

Sea Level Rise

NatureServe suggests using the scenario of 0.5 to 1m of sea level rise for the assessment. Sea level rise is only an issue for species with ranges that are all or partially within a region that may be subject to the effects of 0.5 to 1m sea level rise and the influences of storm surges in the next 50 years. For example, species whose range within the assessment area occurs 90% of the time in areas subject to sea level rise (e.g. low-lying islands or the coastal zone) will have greatly increased vulnerability due to sea level rise. For our analysis we used imagery available from the Center for Remote Sensing of Ice Sheets (www.cresis.ku.edu/data/sea-level-rise-maps), which provides imagery of the impacts of sea level rise in Alaska and other regions of the world based on different sea level rise scenarios (Figure 4). Most species in our assessment range were not affected by sea level rise because their ranges were not coastal. However, a few species, including the polar bear and the arctic fox, do range in coastal areas and thus they were scored accordingly. Of note: the index does not access whether or not sea level rise will pose a problem for the species, it simply addresses whether the species' current range will be impacted by sea level rise. A species like the polar bear that may be able to move further inland to den and then hunt on top of ice may not in fact be impacted by sea level rise, so scoring here is questionable.

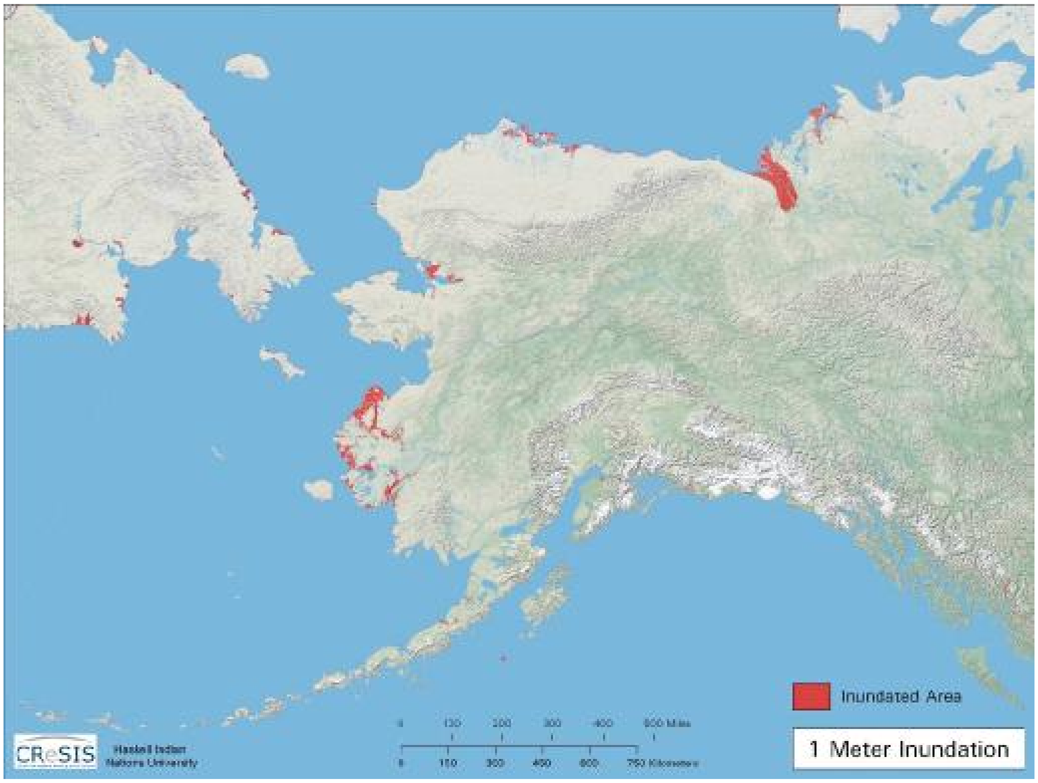

Figure 4: Inundated area of land under a scenario of 1 meter of inundation from sea level rise.

Natural Barriers

The index considers natural barriers to be topographic, geographic or ecological barriers that limit a species' ability to move in response to climate change. The index defines barriers as "features or areas that completely or almost completely prevent movement or dispersal of species" (Young et al. 2010). The inherent assumption is that species will be more vulnerable if they are prevented from moving in response to climate change. Species in the Arctic National Wildlife Refuge are keenly impacted by barriers to northward movement in the form of the Beaufort Sea and arctic sea ice. Most of the species assessed are at the northern edge of their range in our assessment area due to the simple fact that they run out of land and suitable habitat to the north. While some species may be able to move east into Canada in order to go further north and respond to shifting tundra habitat and warming temperatures, the ocean coupled with the mountainous terrain presents many natural barriers to the species assessed. Species that make their home in the tundra may be particularly vulnerable because of projected shrub and boreal vegetation encroachment to the south, coupled with meeting a hard barrier of ice and ocean as well as rising sea levels to the north. For species not expected to see significant habitat shift in next 50 years (e.g. species who live in boreal habitat), or species whose range does not extend to the northern edge of the refuge the impact of barrier was usually scored as neutral.

Anthropogenic Barriers

Anthropogenic barriers are treated the same as natural barriers except that they result from human land use such as areas of intensive urban or agricultural development, waters subject to chemical pollution, or dams that block fish movement. NatureServe suggests assessing the intensity of land use in the assessment area and in the direction of expected species movements using the Wildland-Urban Interface of the Silvis Lab (University of Wisconsin-Madison and the USDA Forest Service). This dataset is not available in Alaska, so we used the National Land Cover Dataset (NLCD) for 2001 from the Multi-Resolution Land Characteristics Consortium (http://www.mrlc.gov/). NLCD 2001 data maps standardized land cover components in the following categories:

- Open water
- Perennial snow/ice
- Developed, open space
- Developed, low intensity
- Developed, medium intensity
- Developed, high intensity
- Barren land
- Deciduous forest
- Evergreen forest
- Mixed forest
- Dwarf scrub
- Shrub/scrub
- Grassland/Herbaceous
- Sedge/Herbaceous
- Moss
- Pasture Hay
- Cultivated crops
- Woody wetlands
- Emergent herbaceous wetlands

We downloaded the NLCD data and brought it into a GIS environment to analyze landcover across the assessment area and in a 60-mile buffer on the east and west of the refuge, which represents the expected direction of species movement. Significant developed and agricultural lands were not located within the refuge or in the buffer around it so this factor was scored as NEUTRAL for all species. If significant oil and gas development were to be allowed in the refuge or to take place in the buffer area in the future, anthropogenic barriers could become a problem for some species.

Land Use Changes Designed to Mitigate Climate Change Impacts

The index also addresses the effects of actions that are taken by human communities to mitigate or adapt to climate change on species in the assessment area. For example, a high future wind or solar power development in an assessment area may negatively impact certain species like bats or desert tortoises. The Index suggests that areas with a high likelihood of wind or solar power development based on maps of resource potential or other knowledge should be scored to reflect this risk to species that could be impacted The National Renewable Energy Laboratory (NREL.gov) provides maps of energy potential for different types of renewable energy including wind and solar. Similarly, actions taken to adapt to rising seas by building fortifications such as sea walls and dykes may be detrimental to species that use wetlands and beaches. This factor is not intended to capture habitat loss from on-going human activities, such as oil and gas development, deforestation or high intensity agriculture. Because we are assessing a National Wildlife Refuge we made the assumption that activities related to mitigation or adaptation are unlikely to occur on a large enough scale within the Refuge to impact the species we assessed. Shoreline fortifications in response to sea level rise may occur in the area of Kaktovik in the 92,000 acres of land owned by the Kaktovik Inupiat Corporation which falls within refuge boundaries. However, the species assessed are not likely to be adversely impacted by shoreline fortifications and it is unlikely that these fortifications would occur across a large enough area to have a significant impact. Another threat in some areas is aforestation as a mitigation strategy. While aforestation may take place in some southern refuges, we made the assumption that a large-scale tree planting program in the High Arctic would not be a high priority, especially given concerns over the loss of tundra habitat.

Species-Specific Sensitivity

To assess species intrinsic sensitivity to climate change the Index asks the user to enter information about the species dispersal and movement ability, its temperature and moisture regime, dependence on disturbance events, relationship with ice or snow-cover habitats, physical specificity to geological features, interactions with other species, and phonological responses to changes in climate. In order to characterize species sensitivity to climate change based on life history data and species ecology we completed a literature review for each species. This review involved extensive searching of scientific databases for peer-reviewed studies as well as the use of species databases such as the NatureServe Explorer which provides access to summarized species information based on already compiled data and literature review. Because many of these factors may be unknown for certain species the index allows the user to only enter data on 13 of the 20 sensitivity factors. The more information provided, the better the accuracy of the score.

The factors below are described in further detail in the Index guidelines provided by NatureServe.
C1. Dispersal and Movements: This factor assesses the species ability to disperse and move across the landscape, based on the assumption that species that have high dispersal capacity may be less vulnerable because they have the capacity to move in response to habitat shifts caused by climate change. Species were scored here according to the Index guidelines. No assumptions were made beyond the directed scoring procedure described in the index guidelines (see p. 21 of guidelines document). Information on dispersal distances was collected from literature review and use of online databases.

C2: Predicted Sensitivity to Temperature and Moisture Changes: This factor scores each species based on the conditions of temperature and moisture that the species can exist under successfully. Species with more narrow abiotic tolerances or requirements, such as species who live in vernal pools or cold alpine environments may be more vulnerable to habitat loss from climate change than species with more widespread distributions" (Young et al. 2010).

a. Temperature: This factor has two components, historical thermal niche and physiological thermal niche.

Historical thermal niche (exposure to past variations in temperature): The index quantifies large-scale variation in temperature that a species has experienced in the last 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" (Young et al. 2010). To assess this factor we used past climate data from the ClimateWizard (available at the 4km2 scale) to make a map in GIS of the difference between the highest mean monthly temperature (July) and the lowest mean monthly temperature (January). We extracted this map of differences using the boundaries of the Arctic Refuge and completed a calculation using raster calculator that provided the difference in temperature across every $4km^2$ grid cell in the park between the average annual high and low. We compared this range to the range of temperature variation given in the NatureServe guidelines to score the factor.

It should be noted that scoring for the factor is based on comparisons in temperature variation to the lower 48 states and may not be relevant in Alaska. Also of concern is the fact that this variable is only considered across the range of the species within the assessment area, rather than across the species' entire distribution. Because the assessment area in this study was small and is an area of relatively stable seasonal temperature variability, historical thermal niche was scored as a factor increasing vulnerability for every species considered in this analysis. For species like the coyote or shrew that have a large range extending into the southern U.S. looking only at temperature variation within the assessment area would seem to falsely amplify the importance of this factor in determining the species vulnerability. However, we believe that inclusion of physiological thermal niche (see below) in the analysis helps to mitigate this potential problem by allowing separate consideration of the species' thermal tolerances across the breadth of its range.

Physiological thermal niche: The physiological thermal niche factor is scored based on how restricted a species is to relatively cool or cold habitats *within the assessment area* that are likely to be vulnerable to loss in extent as a result of climate change. This could include species that occur in the assessment area's northernmost areas, highest elevation zones, or coldest waters" (Young et al. 2010). The Index is not asking about the species distribution relative to other species anywhere in the world, but rather to other species *within the assessment area.* So it is really a question of the relative thermal habitat requirements of the species. If it is distributed widely across the assessment area and does not appear to require a certain cool, or colder than average habitat type within the assessment area than it may be less vulnerable than a species who is limited to alpine pockets with very cold temperatures. For our assessment species that were limited to arctic tundra, alpine areas, or the northern-most portions of the refuge were considered the most sensitive to changes in temperature (that is this factor would Greatly Increase their vulnerability to climate change). Species with wide ranges throughout Canada and the lower 48 states and species that make their primary habitat in boreal forests or other forest types were considered less vulnerable or not at all vulnerable under this factor (Neutral). Species that rely on snow and ice are scored later in the assessment. The Index guidance notes that temperature and hydrologic regime are often difficult to separate and suggest that if temperature is the overriding factor it should be scored here. This is the assumption we worked with.

<u>b. Precipitation:</u> As with temperature, this factor has two components, historical hydrological niche and physiological hydrological niche.

<u>Historical hydrological niche:</u> The index quantifies large-scale variation in temperature that a species has experienced in the last 50 years using mean annual variation in precipitation the species has experienced across the assessment area. The guidance instructs the user to overlay the species range on the Climate Wizard mean annual precipitation map and subtract the lowest pixel value from the highest pixel value to assess this factor, using the extremes *within the assessment area.* Again, it should be noted that scoring for the factor is based on comparisons in temperature variation to the lower 48 states and may not be as relevant in Alaska. Also of concern is the fact that this variable is only considered across the range of the species within the assessment area, rather than across the species' entire distribution. For species like the coyote with large ranges covering a variety of moisture regimes, examining variation within the assessment area seems to falsely amplify the importance of this factor in determining the species vulnerability.

<u>Physiological hydrological niche:</u> Scores for this factor are based on species requirements for a very specific precipitation or hydrologic regime, such as strongly seasonal patterns of precipitation or specific wetland or aquatic habitats such as seeps or vernal pools that may be highly vulnerable to loss across the assessment area. The dependence on these habitats can be permanent or seasonal (Young et al. 2010). In order for this factor to greatly increase or increase a species' sensitivity to climate change the species must be dependent on a very narrowly defined regime. Species that live near wetlands, riparian areas or other "moist areas" were not considered to be strongly tied to a specific hydrologic regime. Examples of species that may be quite sensitive to this factor are species dependent on ephemeral pools.

This factor also asks the assessor to consider the direction of expected climate change in their ranking. Since the Arctic Refuge assessment area is not expected to see significant changes in moisture based on our ClimateWizard projections this factor was often less important. One item of note: Species that are dependent on snow falling as dry snow rather than heavy wet snow or ice were given a score of increase under this factor. These include species like muskoxen that depend on snow that is light and dry to allow them access for grazing in the winter. This appears to be the best place to score a change in the characteristics of precipitation.

c. Dependence on a specific disturbance regime: This factor was scored using the following guidance (for specific scoring see guidance doc). "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" (Young et al. 2010).

Fires were one of the main disturbances we considered under this category as studies suggest fire activity will increase in Alaska often leading to changes in age structure and species dominance in boreal forest (Rupp 2008). Other disturbances affecting species in our assessment included increased parasite and pest outbreaks and increased flooding. Some changes in disturbance regime may actually benefit species and the index is constructed to reflect this.

d. Dependence on ice, ice-edge, or snow cover habitats: This factor assesses a species' dependence on habitats associated with ice or snow across its range in the assessment area. A score of "greatly increase" is for species that are highly dependent (more than 80% of occurrences in range) on snow or ice habitat, such as the polar bear. Many of our species use the snow for burrowing, hiding from predators or hunting. These species were scored as "increase" or "somewhat increase", depending on how strongly they were tied to snow use for these activities. Similarly, species that molt in the winter and take on a white coat were considered to fit into the "increase" category as lack of snow would make them highly visible to predators. Changes in snow condition (i.e. icing over, wetter snow, etc) were considered under the physiological hydrological niche category.

C3: Restriction to uncommon geological features or derivatives: This factor was scored exactly as according to the guidance document for the index. Information on restriction to uncommon geologic features was collected from literature review and use of online databases.

C4: Reliance on interspecific interactions

a. Dependence on other species to generate habitat: Scored as described in guidance document.

b. Dietary versatility: Scored as described in guidance. If species that make up the diet of the species being assessed were considered vulnerable to climate change we used this information as well (e.g. lemmings are an important prey item for arctic fox and are considered extremely vulnerable to climate change).

c. Pollinator versatility: plants only, not considered in our assessment.

d. Dependence on other species for propagule dispersal: mainly for plants, insects and species with immobile progeny; not a factor in our assessment

e. Forms part of an interspecific interaction not covered by 4a-d: Scored as described in guidance. Not a major factor for most of our species. It is important to note that competitive relationships (or other negative interactions) are not considered under this heading. All species interactions described are positive and changes in competitive interactions are not considered anywhere in the index.

C5: Genetic factors

a. Measured genetic variation: Scored as described in guidance document.

b. Occurrence of bottlenecks in recent evolutionary history: Scored as described in guidance document.

C6: Phenological response to changing seasonal temperature and precipitation dynamics: Scored as described in guidance document. This factor assesses the degree to which a species has been able to respond to ongoing climate change through phenological changes (such as the timing of breeding or end of hibernation). This factor was of limited use for our assessment because much of the available data on phenology was not from studies in the assessment area as required by the index. It also does not make sense that this factor was considered in this section rather than section D on observed or modeled responses to climate change. It might be more useful if the index included a sensitivity trait to account for species with life histories that make them particularly susceptible from a phenology standpoint (i.e. species that hibernate, species that time their breeding cycles with emergence of other species, species that molt).

Overall Scoring

The following excerpt from the creators of the index describes how the scoring for the tool works.

Excerpt from:

Young, B. E., K. R. Hall, E. Byers, K. Gravuer, G. Hammerson, A. Redder, and K. Szabo. 2010. A natural history approach to rapid assessment of plant and animal vulnerability to climate change. In *Conserving Wildlife Populations in a Changing Climate*, edited by J. Brodie, E. Post, and D. Doak. University of Chicago Press, Chicago, IL.

To calculate an overall score, the index first combines information on exposure and sensitivity to produce a numerical sum, calculated by adding subscores for each of the extrinsic and intrinsic species sensitivity factors. Factors scored to “somewhat increase,” “increase,” and “greatly increase” sensitivity to climate change receive a values of 1.0, 2.0, and 3.0, respectively. Those scored to “somewhat decrease” and “decrease” sensitivity receive values of -1.0 and -2.0, respectively. Factors for which there are no data or that are scored as “neutral” to vulnerability receive a value of zero. If a factor is scored in multiple levels (e.g., both “somewhat increase” and “increase”), the index uses an average of the values for these levels.

The value for each factor is weighted by exposure to calculate a subscore for the factor. Climate influences vulnerability factors in different ways. For most factors, the exposure weighting is a climate stress value that combines data on projected change in both temperature and precipitation. In these cases, the weighting factor is the product of weightings for temperature (0.5, 1.0, 1.5, or 2.0 depending on whether the temperature across the range of the species is predicted to increase by less than zero, one, two, or greater than two standard deviations of the average temperature increase for the conterminous United States) and precipitation (0.5, 1.0, 1.5, or 2.0 depending on whether the precipitation across the range of the species is predicted to increase or decrease by less than zero, one, two, or greater than two standard deviations of the average precipitation change for the conterminous United States). Other weightings are either fixed at 1.0 in the case of sea level rise (which occurs independent of local climate), tied solely to temperature for historical and physiological thermal niche (thus ranging from 0.5-2.0 as described above), or the average of four times the precipitation and one time the temperature weighting (roughly accounting for how temperature interacts with precipitation) for historical and physiological hydrological niche.

General Circulation Models and Downscaling

To build a downscaled climate model the ClimateWizard requires the user to select a General Circulation Model or ensemble models (Table 3) and a future emissions scenario. General Circulation Models (GCMs) simulate the complex interactions of the atmosphere, oceans, land surface and ice. The models work by balancing (or nearly balancing) incoming energy in the form of short wave electromagnetic radiation with outgoing energy in the form of long wave electromagnetic radiation; any imbalance will result in a change in the average temperature of the earth (www.climatewizard.org).

Table 3: Global Circulation Models available for downscaling through ClimateWizard. Table from www.climatewizard.org

BCCR-BCM2.0	Norway	Bjerknes Centre for Climate Research
CGCM3.1(T47)	Canada	Canadian Centre for Climate Modelling & Analysis
CNRM-CM3	France	Météo-France / Centre National de Recherches Météorologiques
CSIRO-Mk3.0	Australia	CSIRO Atmospheric Research
GFDL-CM2.0	USA	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory
GFDL-CM2.1	USA	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory
GISS-ER	USA	NASA / Goddard Institute for Space Studies
INM-CM3.0	Russia	Institute for Numerical Mathematics
IPSL-CM4	France	Institut Pierre Simon Laplace
MIROC3.2(medres)	Japan	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)
ECHO-G	Germany / Korea	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data group.
ECHAM5/MPI-OM	Germany	Max Planck Institute for Meteorology
MRI-CGCM2.3.2	Japan	Meteorological Research Institute
CCSM3	USA	National Center for Atmospheric Research
PCM	USA	National Center for Atmospheric Research
UKMO-HadCM3	UK	Hadley Centre for Climate Prediction and Research / Met Office

GCMs are driven by emission scenarios or assumptions about how population, energy use and technology are likely to change and develop in the future and the resulting emissions of greenhouse gases. Emission scenarios are essentially storylines that describe what the future *might* look like taking different social, economic, cultural, technological, and other human-based factors into account. Emission scenarios are used as inputs into these models to simulate changes in temperature, precipitation and other climate variables.

In order to make meaningful predictions about how temperature and moisture will change across a particular region, these global models need to be downscaled. ClimateWizard allows the user to downscale any or all of its GCMs using the method described below:

> The following was taken from *Maurer, E. P., L. Brekke, T. Pruitt, and P. B. Duffy (2007), Fine-resolution climate projections enhance regional climate change impact studies, Eos Trans. AGU, 88(47), 504* and describes the data presented in the ClimateWizard:
>
> A statistical technique was used to generate gridded fields of precipitation and surface air temperature over the conterminous United States and portions of Canada and Mexico. The method involves (1) a quantile mapping approach that corrects for GCM biases, based on observations of 1950–1999; and (2) interpolation of monthly bias-corrected GCM anomalies onto a fine-scale grid of historical climate data, producing a monthly time series at each 1/8-degree grid cell. The method has been used extensively for hydrologic impact studies (including many with ensembles of GCMs) and in a variety of climate change impact studies on systems as diverse as wine grape cultivation, habitat migration, and air quality.
>
> The downscaled data are freely available for download at the Green Data Oasis, a large data store at LLNL for sharing scientific data (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/).
>
> Users can specify particular models, emissions scenarios, time periods, geographical areas, and raw data or summary statistics. All data are archived in a standard netCDF format, a self-describing machine-independent format for sharing gridded scientific data. The full text of this article can be found in the electronic supplement to this EOS issue (http://www.agu.org/eos_elec/).

DEVELOPING A FUTURE CLIMATE CHANGE SCENARIO USING CLIMATEWIZARD

The user interface on ClimateWizard is shown in Figure 5 below. In order to build a scenario of future climate change the user must select key inputs into the climate model and then download the data in a GIS compatible format. The user is asked to select an analysis area or spatial extent of the data, the time period (mid-century, end of century or past 50 years), type of map, measurement (precipitation or temperature) and the key inputs into the future climate model (emission scenario and general circulation model).

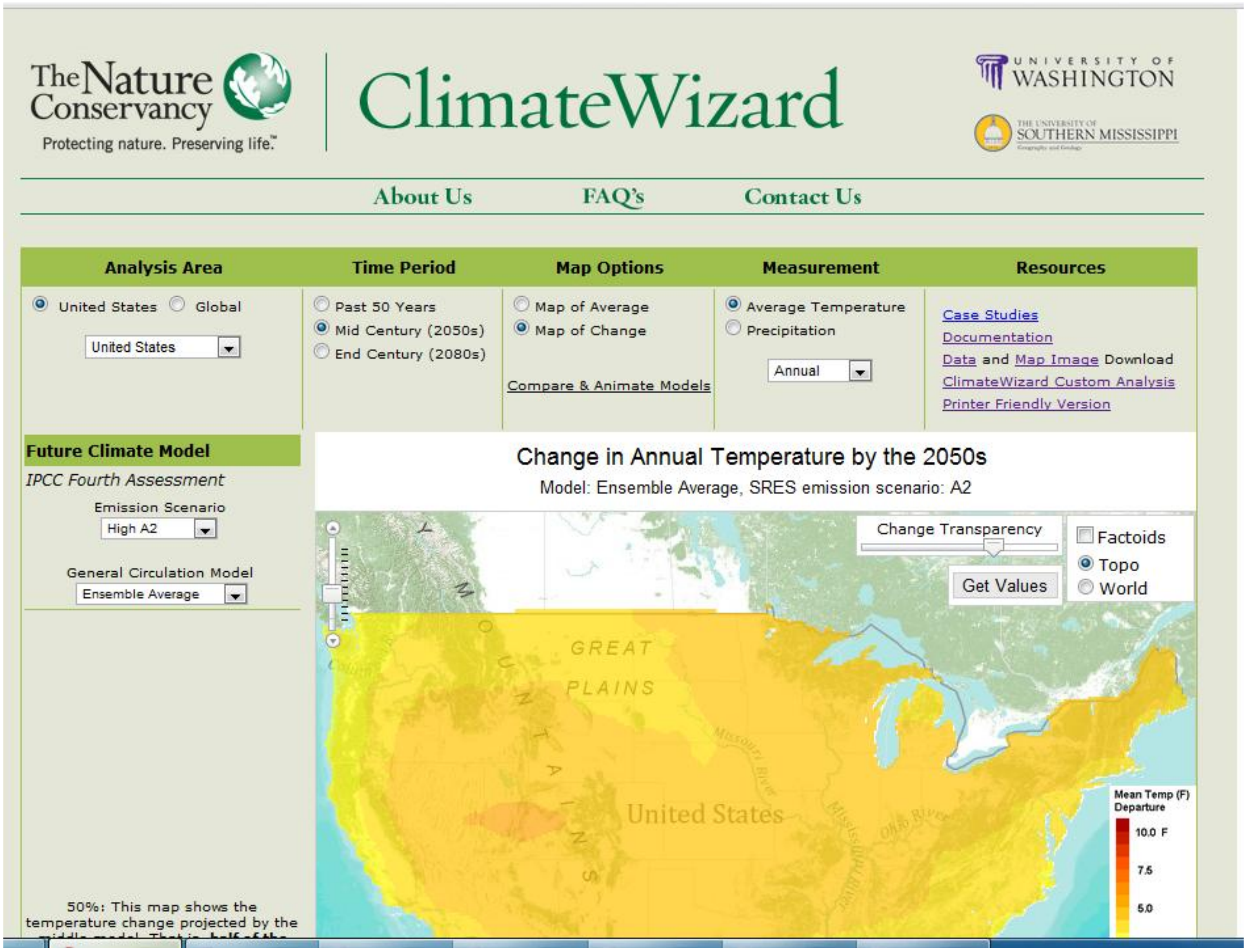

Figure 5: ClimateWizard user interface. The tool asks the user to select the analysis area, the time period, the type of map, measurement and the future climate model inputs (www.climatewizard.org).

For our analysis in Alaska we used a global climate model that combined an average ensemble model of all 17 available GCMs and a "High" A2 emissions scenario to produce both temperature and moisture data (Table 4). Because we used moisture data and not just standard precipitation data we needed to use the ClimateWizard Custom Analysis Tool (www.climatewizard.org/custom) which provides access to more types of data analysis and projections. All projections were made for the middle of the century as directed by the NatureServe CCVI guidance document.

Table 4: Data inputs used for climate projections in the Arctic Refuge

	Temperature	**Moisture**
General Circulation Model	Ensemble Average	Ensemble Average
Emission Scenario	High A2	High A2
Time period	Mid-Century	Mid-Century
Data produced	Average annual change in temperature as ASCII file for input in ArcGIS environment	Percent departure from historical ratio of AET: PET downloaded as ASCII map for input into ArcGIS
Spatial resolution	50km2	50km2

Data Processing

All data was processed in an ESRI ArcGIS 10.0 environment and a full list of steps is provided in Table 6 below along with a brief narrative. This information will not be particularly relevant to non-GIS users.

In order to use the climate exposure data produced with the ClimateWizard tool, we downloaded both temperature and moisture data for the state of Alaska based on the Climate Model described above. The data is downloaded in ASCII (American Standard Code for Information Exchange) format. ASCII is a character encoding scheme based on an ordering of the English alphabet. ASCII files can be imported into a GIS environment and converted into grids or raster data. We brought both the temperature and moisture ASCII files into a GIS environment by using the ArcGIS toolbox to convert the ASCII files to grid files. Grid files display the data as pixels containing different values. We also imported a shapefile of the Alaska National Wildlife Refuge boundaries into the GIS and standardized the projections of all files to NAD_1983_NSRS2007_Alaska_Albers.

Once we created grids of temperature and moisture change I had to change these grids from grids with floating point pixels to integer pixels so that their attribute information could be viewed. In order to preserve the accuracy of the data (integer grids cannot store decimals) we first multiplied the temperature and moisture data by 100 and then converted each grid to an integer file using the raster calculator. We used the Extract by Mask tool with the boundaries of the Arctic Refuge set as the mask to produce maps of change across our assessment area, the Alaska National Wildlife Refuge. This process extracts only data from areas inside the assessment area so that calculations can be made only in the area in question.

The Index requires that the user enter the portion of the species range over the assessment area that falls into the following temperature exposure categories: <3.9 degrees F, 3.9 – 4.4 degrees F, 4.5 – 5.0 degrees F, 5.1 – 5.5. degrees F and > 5.5 degrees F. To calculate the portion of each species range that falls into the above temperature exposure categories, we needed to assess the change of temperature across the species range in the Arctic Refuge. This required an additional extraction of temperature and moisture data using species range data as an additional mask. Species ranges were downloaded in GIS format (as vector files) from the NatureServe Explorer's Digital Distribution Maps of Mammals of the Western Hemisphere (http://www.natureserve.org/getData/animalData.jsp). Once downloaded, we standardized the projections of these files to NAD_1983_NSRS2007_Alaska_Albers. These maps are used as a mask to extract the temperature and moisture data in order to obtain information about the degree of climate change a species will be exposed to in the assessment area.

We extracted temperature and moisture data for each species and exported the attribute tables as dbf files. We then opened the exported dbf files in Excel and calculated the percentage of each species' range that fell into the exposure categories for temperature and moisture, described above. The calculation is done by using the Counts field in the attribute data to sum the number of pixels that fall within a certain category. Each sum is divided by the total of all pixels covering the assessment area and multiplied by 100 to give a percent of assessment area in each category. Results were entered into the CCVI Section A.

Table 6: GIS processing steps and output files created during analysis.

Data Inputs into GIS	**Processing Steps and Output Files**
Average Annual Temperature Departure, Mid-Century	1. Download ASCII file for average annual temperature change in Alaska from ClimateWizard 2. Convert ASCII file to faster grid using ArcToolbox à Conversion Tools à ASCII to Raster (chose float for output data type) = GRID1 (Floating Point) Temperature Change in Alaska 3. Define projection of file to WGS 1983 as specified in ClimateWizard 4. Re-project file to NAD_1983_NSRS2007_Alaska_Albers 5. In ArcToolbox à Map Algebra à Raster Calculator multiply the grid by 100 and convert from a float to an integer using the INT function. = GRID2 (Integer) Temperature change in Alaska 6. Use the following to extract the grid cell information across the assessment area: In ArcToolbox à Spatial Analyst à Extraction à Extract by Mask. Enter the boundary file for Alaska National Wildlife Refuge as the “input raster or feature mask” and GRID2 as the input raster. = GRID3 (Integer) Temperature change in the Arctic Refuge 7. Add species range data for species of interest and ensure file is correctly projected following procedure below. 8. Use the following to extract the grid cell information across the species range in assessment area: In ArcToolbox à Spatial Analyst à Extraction à Extract by Mask. Enter the species range file as the “input raster or feature mask,” and GRID3 as the input raster. =GRID4(Integer) Temperature change across species range in the Arctic Refuge 9. Open the attribute table for the new grid created from extraction and export this attribute table as a .dbf file. 10. Open the .dbf file in Microsoft excel and calculate the sum and percentage of the area within each category given in Section A: Temperature Change of the CCVI using the Count field from the grid file.
Moisture Data	1. Download ASCII file for the average difference in AET:PET in Alaska from ClimateWizard 2. Convert ASCII file to faster grid using ArcToolbox à Conversion Tools à ASCII to Raster (chose float for output data type) = GRID1 (Floating Point) Moisture Change in Alaska 3. Define projection of file to WGS 1983 as specified in ClimateWizard 4. Re-project file to NAD_1983_NSRS2007_Alaska_Albers 5. In ArcToolbox à Map Algebra à Raster Calculator multiply the grid by 100 and convert from a float to an integer using the INT function.

	= GRID2 (Integer) Moisture change in Alaska 6. Use the following to extract the grid cell information across the assessment area: In ArcToolbox à Spatial Analyst à Extraction à Extract by Mask. Enter the boundary file for Alaska National Wildlife Refuge as the "input raster or feature mask" and GRID2 as the input raster. = GRID3 (Integer) Moisture change in the Arctic Refuge 7. Add species range data for species of interest and ensure file is correctly projected following procedure below. 8. Use the following to extract the grid cell information across the species range in assessment area: In ArcToolbox à Spatial Analyst à Extraction à Extract by Mask. Enter the species range file as the "input raster or feature mask," and GRID3 as the input raster. =GRID4(Integer) Moisture change across species range in the Arctic Refuge 9. Open the attribute table for the new grid created from extraction and export this attribute table as a .dbf file. 1. Open the .dbf file in Microsoft excel and calculate the sum and percentage of the area within each category given in Section A: Temperature Change of the CCVI using the Count field from the grid file.
Alaska National Wildlife Refuge Boundary	1. Add shapefile to map 2. Change projection to NAD_1983_NSRS2007_Alaska_Albers 3. Use as analysis mask as described above
Species Range Boundaries	1. Download species range maps from NatureServe 2. Add shapefiles to map 3. Define projection to GCS North American 1983 4. Convert projection to NAD_1983_NSRS2007_Alaska_Albers 5. Use as analysis mask as described above

Climate Change Vulnerability Index: Caveats Regarding Exposure, Sensitivity, and Certainty

The Index is limited in the data it uses to develop a scenario of future climate change the species will be exposed to. For example, it does not include biologically relevant climate changes such as changes in snow cover, monthly temperature changes, changes in degree days or changes in precipitation during certain critical periods. While recognizing that this weakness makes the index more accessible, it is also important to note that studies with more detailed climate change scenarios will likely lead to more thoroughly developed vulnerability assessments. In order to assess the sensitivity factors and include other information about how the climate might change and how these changes may impact the species we assessed, we relied on published study results and summary reports. We include a brief description of these results in the development of the climate change scenario below.

<u>From the Arctic Climate Impacts Assessment (2005):</u>

- The duration of the snow-free period at high northern latitudes increased by 5 to 6 days per decade and the week of the last observed snow cover in spring advanced by 3 to 5 days per decade between 1972 and 2000.
- The treeline is very likely to advance, perhaps rapidly, into tundra areas of northern Eurasia, Canada, and Alaska, as it did during the early Holocene, reducing the extent of tundra and contributing to the pressure upon species that makes their extinction possible.
- Forests are likely to replace a significant portion of the tundra and this will affect the composition of species and habitat availability for tundra species. Increasing forest cover will also lead to a decrease in albedo which will increase positive feedback in climate system. Forest development is likely to also alter local climate by increasing temperature.
- Species that today have more southerly distributions are very likely to extend their ranges north, displacing Arctic species.
- Permafrost is very likely to decay and thermokarst develop, leading to erosion and degradation of Arctic peatlands. Unlike the early Holocene, when lower relative sea level allowed a belt of tundra to persist around at least some parts of the Arctic Basin when treelines advanced to the present coast, sea level is very likely to rise in the future, further restricting the area of tundra and other treeless Arctic ecosystems.
- Taxa most likely to expand into tundra are boreal taxa that currently exist in river valleys and could spread into the uplands, or animal groups such as wood-boring beetles that are presently excluded due to a lack of food resources. Some animals are Arctic specialists and could possibly face extinction. Those plant and animal species that have their centers of distribution in the high or middle Arctic are most likely to show reduced abundance in their current locations should projected warming occur.

<u>From the "Preliminary Report on Projected Vegetation and Fire Regime Response to Future Climate Change in Alaska"</u> (Rupp 2008):

- Model simulations suggest an increase in cumulative area burned through 2099 and a general increase in fire activity in response to warming temperatures and less available moisture.
- Likely shift in boreal vegetation from a spruce dominated landscape to more deciduous vegetation in the next 50 years.
- Increased deciduous dominance on the landscape is likely to result in a change in patch dynamics and age structure in forests with large regions of mature, unburned spruce being replaced by a more patchy distribution of deciduous forests and younger spruce.

From "Evaluating observed and projected future climate changes for the Arctic using the Köppen-Trewartha climate classification" (Feng et al. 2011) (http://newsroom.unl.edu/announce/todayatunl/240/1862):

- By the end of the century, the annual average surface temperature in Arctic regions is projected to increase by 5.6 to 9.5 degrees Fahrenheit, depending on the greenhouse gas emission scenarios.
- The warming, however, is not evenly distributed across the Arctic. The strongest warming in the winter (by 13 degrees Fahrenheit) will occur along the Arctic coast regions, with moderate warming (by 4 to 6 degrees Fahrenheit) along the North Atlantic rim.

- The projected redistributions of climate types differ regionally; in northern Europe and Alaska, the warming may cause more rapid expansion of temperate climate types than in other places.

- Tundra in Alaska and northern Canada would be reduced and replaced by boreal forests and shrubs by 2059. Within another 40 years, the tundra would be restricted to the northern coast and islands of the Arctic Ocean.
- The melting of snow and ice in Greenland following the warming will reduce the permanent ice cover, giving its territory up to tundra.

"Certainty" within the context of the CCVI refers to whether or not the Monte Carlo simulations performed by the algorithm fall into the same category most or all of the time. In this analysis, most of the species ended up in the same vulnerability category in every run of the simulation, thus rating a "very high" certainty value. Where certainty was "low" due to splits in the model runs between different vulnerability categories, we have indicated such in the text and provided an assessment of which factors seemed to cause the variation between simulations.

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