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Original Article

Comparison of Climate Change Vulnerability Assessments for Wildlife

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ABSTRACT The need for wildlife climate change vulnerability and sensitivity assessments has increased over the past decade. Use of these assessments by wildlife and land managers has increased due to concern for potential effects of climate change on species and landscapes. Although many approaches exist for assessing sensitivity and vulnerability to climate change, little is known about the similarity of results between methods. We compared outputs of 3 widely available assessments for the western United States: the NatureServe Climate Change Vulnerability Index, the U.S. Forest Service System for Assessing the Vulnerability of Species, and the Climate Change Sensitivity Database. We performed a broad categorical comparison and examined correlations across rankings to compare assessment outputs. We found little agreement in species rankings between pairs of assessments. There is no apparent pattern within, or between, taxa or habitat associations that could explain this poor correlation. Disparities likely result from differences in question format, choice of data input, or how vulnerability or sensitivity is calculated. Consideration of vulnerability quantification is needed, particularly regarding species sensitivity and adaptive capacity, because of limited understanding of species and community responses to climate exposure. Our results indicate it is extremely important to be aware of the specific goal and the quality, quantity, and variety of data used in each individual assessment in order to adequately use these assessments as tools for management planning. With the increasing need to include climate change scenarios in management actions and decisions, we suggest that increased cooperation among assessment developers could greatly aid in eliminating this discrepancy.

KEY WORDS adaptive capacity, assessment, climate change, climate exposure, model accuracy, NatureServe, sensitivity, vulnerability.

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

The Intergovernmental Panel on Climate Change (Schneider et al. 2007:782) defines vulnerability as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate extremes." Climate change vulnerability is recognized as a function of exposure to changes in climate, the sensitivity of species or systems, and the adaptive capacity of species or systems, to address those changes (Turner et al. 2003, Schneider et al. 2007, Williams et al. 2008, Lawler 2009, Glick et al. 2011). Exposure and sensitivity together represent the potential impact of climate change on a particular species, or system. Sensitivity and adaptive capacity are arguably very similar and often consider closely related variables. Sensitivity represents a measure of the innate characteristics that place a species, or system, at risk of change. Conversely, adaptive capacity measures the degree to which a species, or system, is able to ameliorate that change via behavioral adaptation or genetic evolution.

Vulnerability assessments quantitatively, or qualitatively, combine measures of exposure, sensitivity, and adaptive capacity to evaluate climate change impacts on species and systems. These assessments are designed to compile large volumes of data about climate exposure and species sensitivity and adaptive capacity, making them a useful repository of different sources of knowledge for individual species and systems. These diverse data form the foundation from which vulnerability is evaluated. Data that inform the degree of climate exposure for an individual species include projected change in temperature or hydrologic regime, change in disturbance regime, or change in habitats or habitat features (Glick et al. 2011). These factors typically

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involve changes beyond the species' control. Depending upon the structure of the assessment, species' sensitivity traits range from physiological, behavioral, or ecological traits of the species, such as tolerance to temperature or hydrological regimes, dependence upon certain habitats or habitat characteristics, degree of specialization, reproductive ability, or phenological dependencies (Glick et al. 2011). These may be used to amplify or depress the exposure component. Finally, measures of behavioral or genetic adaptive capacity such as behavioral or genetic plasticity, dispersal ability within the landscape, or evolutionary potential are included to represent the potential of an individual species to counteract the potential impacts of climate change (Glick et al. 2011). Both species and system-based assessments use a variety of techniques to combine these measures to identify conservation and management targets (e.g., Bagne et al. 2011, Lin and Morefield 2011, Young et al. 2011, CCSD 2012, Gardalli et al. 2012).

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

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

To our knowledge, no systematic comparison of the results of different approaches to assessing vulnerability to climate change has been undertaken. Many agencies and local conservation groups have already incorporated results from these various assessments into climate change management reports and policies within the eastern United States (e.g., Young et al. 2009, Bagne and Finch 2010, Dubois et al. 2011, Schlesinger et al. 2011, Brinke and Jones 2012). Given that no 2 assessment approaches available to date use the same combination of variables, or frame their questions in the same way, it is possible that these approaches produce different results for the same species. Here, we compare the outputs of climate-related vulnerability assessments used in the western United States. It will be important to understand whether different assessment procedures produce conflicting outputs prior to using these tools to develop new species-management approaches.

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

METHODS

We chose to compare the previously mentioned assessments on the basis of ease of access, applicability to diverse management objectives and groups of species, frequent use by managers and scientists, and broad diversity of species evaluated by each. These 3 assessments can be compared because they can overlap in the geographic area under consideration. Each assessment approaches the quantification, or categorization, of species vulnerability (NatureServe Climate Change Vulnerability Index and System for Assessing the Vulnerability of Species), or sensitivity (Climate Change Sensitivity Database), using different methodologies, allowing us to compare differing approaches and scoring. We included a sensitivity assessment in our comparisons to understand whether a full vulnerability assessment is needed, or whether the same information can be gathered with less effort. We searched databases and case studies to populate a list of species with available data that were ranked by at least 2 of the 3 assessments. This produced 3 overlapping species lists, one for each pair of assessments (NatureServe Climate Change Vulnerability Index vs. Climate Change Sensitivity Database, NatureServe Climate Change Vulnerability Index vs. System for Assessing the Vulnerability of Species, and Climate Change Sensitivity Database vs. System for Assessing the Vulnerability of Species).

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

NatureServe Climate Change Vulnerability Index

The NatureServe Climate Change Vulnerability Index was developed to provide scientists and managers with a relatively rapid method for grouping species by drivers of vulnerability to climate change. It also aims to increase the efficiency of identifying management concerns and planning for at-risk

Table 1. Comparison of the major categorical input requirements and range of outputs (qualitative or quantitative) for the NatureServe Climate Change Vulnerability Index (NSCCVI), U.S. Forest Service System for Assessing the Vulnerability of Species (SAVS) and the Climate Change Sensitivity Database (CCSD). Table also provides information on the location of case studies to-date and the presence or absence of a measure of uncertainty for each assessment.

		Output				
Assessment title	**Major inputs**	**Low**	**High**	**Uncertainty score?**	**Geographic areas covered or considered**	**Author**
System for Assessing the Vulnerability of Species (SAVS)	Habitat Physiology Phenology Biotic interactions	−20 to 0 (resilience)	0 to +20 (vulnerability)	Yes	Southern Arizona and New Mexico[a]	U.S. Forest Service (Bagne et al. 2011)
NatureServe Climate Change Vulnerability Index v2.1 (NSCCVI)	Downscaled change in temperature (Climate Wizard 2050s) Moisture availability (Hamon AET:PET, Climate Wizard 2050s) Current species distribution Physiological, phenological species traits Knowledge of natural and anthropogenic barriers Documented adaptation responses	Increase likely Presumed stable	Moderately vulnerable Highly vulnerable Extremely vulnerable Insufficient evidence	No	Nevada and the Great Basin	NatureServe (Young et al. 2011)
Climate Change Sensitivity Database (CCSD)	Generalist versus specialist Physiology Life history traits Habitat sensitivities Dispersal ability Disturbance regime Ecological interactions	Low sensitivity	Medium sensitivity High sensitivity	Yes	Pacific Northwest U.S.	University of Washington/ The Nature Conservancy (CCSD 2012)

[a] Rio Grande Bosque, NM; Fort Huachuca, AZ; Barry M. Goldwater Range, AZ; Sky Islands, AZ (USA).

species (Young et al. 2011). The index is designed for use across North America north of Mexico and is most effective at the scale of national parks and wildlife refuges, or of states.

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

Vulnerability is calculated by numerically summing values for exposure, sensitivity, and adaptive capacity and then awarding a categorical score based on threshold values (Young et al. 2011). The index places species into 1 of 6 categories ranging from Increase Likely (abundance and/or range expansion within assessed area) to Extremely Vulnerable (abundance and/or range extremely likely to substantially decrease or disappear), or Insufficient Information (inadequate to calculate index score; Table 1 [Young et al. 2011]). Calculation is performed within a Microsoft Excel (Microsoft Corp., Redmond, WA) spreadsheet, which includes descriptions of all required data and discussion of each question. An additional spreadsheet records the answers to all questions for each species for ease of comparison across species for management consideration. Confidence scores are awarded based on Monte Carlo simulation where multiple answers are indicated for individual questions.

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

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

U.S. Forest Service System for Assessing the Vulnerability of Species

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

The assessment is made of 22 questions designed to represent the intersection between predicted climate change and the predicted response of the species while ultimately addressing potential management actions. Questions are divided into 4 categories according to potential management applications (Habitat, Physiology, Phenology, and Biotic Interactions) rather than by exposure, sensitivity, and adaptive capacity metrics. Habitat questions address the potential impact of climate on breeding and non-breeding areas. This section requires knowledge of climate projections, vegetation types, and predicted impacts to vegetation types. Physiology primarily addresses species' sensitivity traits to changes in climate exposure. Phenology questions consider timing of important life-history events and how they relate to changes in climate. Finally, the biotic interactions section addresses changes in interspecific interactions that could result from a changing climate. The user is responsible for defining which climate models and projections are considered, as well as consideration of data for each species. Two to four responses are possible for each question related to whether a particular effect of climate change will result in an overall positive (increased resilience), or negative (increased vulnerability) response by the species.

The System for Assessing the Vulnerability of Species scores species on a scale from -20 (resilient) to $+20$ (vulnerable) based on user responses (Table 1). Each of the 4 categories is summed and standardized on a -5 to $+5$ scale. These categorical scores are summed to obtain the vulnerability score. Scores can subsequently be used to rank species, or groups of species, according to management goals. A basic measure of uncertainty is calculated from user responses to each question on whether there is adequate, or inadequate, information to accurately respond.

Climate Change Sensitivity Database

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

Numerical and categorical sensitivity scores are assigned to each species based on 7 input categories (Generalist or Specialist, Physiology, Life History, Habitat, Dispersal Ability, Disturbance Regimes, Ecology, Non-climatic factors, Other factors). The Generalist or Specialist category evaluates the specificity of a species' relationship to habitat and other resources. The Phenology category addresses species' physiological sensitivities to changes in temperature, precipitation, pH, and salinity. The Life History category provides a measure of the species' reproductive strategy along the r to K continuum. The section on Sensitive Habitats provides a list of habitats that have been pre-determined to be highly sensitive to climatic changes. Species relying on any of these habitats are determined to be highly sensitive to climate change. Dispersal ability is based on a measure of the maximum annual dispersal distance and the prevalence and effectiveness of barriers to dispersal. Dispersal distance is measured in kilometers and is based on the maximum average likely distance that an individual could move to establish a new population (CCSD 2012). A list of dispersal barriers is provided along with a ranking ranging from "none" to "many." The section on Disturbance Regimes documents the degree to which the species is dependent on the nature of various disturbances, both natural and anthropogenic. The Ecological Relationships category considers the potential sensitivity to climate change of the relationships the species has with its environment, including foraging, habitat, competition, abiotic, and other relationships. The Non-climatic Factors category encompasses all non-climatic threats such as habitat loss, pollution, and invasive species (among others) that may further amplify climate-change sensitivity. Finally, the category for Other Sensitivities allows the user to include any other factors relating to sensitivity that may impact the species and to provide a weight for this measure relative to the other measures of the database (CCSD 2012).

Each section asks the user to rank (1 low to 7 high) whether a particular species' trait lends itself to lower or higher sensitivity. Users are encouraged to answer more detailed questions and provide citations, but these do not factor into the overall scoring. As with the previous 2 assessments, the Climate Change Sensitivity Database provides a measure of uncertainty calculated along with the final sensitivity score. Uncertainty is defined by the user for each category on a scale of 1–5.

Assessment Comparison

We produced a list of 95 species evaluated jointly by ≥ 2 of the assessment approaches. These species covered a wide taxonomic and geographic range (Appendix A available online at www.onlinelibrary.wiley.com). We included 89 species from the NatureServe Climate Change Vulnerability Index, 69 species from the Climate Change Sensitivity Database, and 40 species from the System for Assessing the Vulnerability of Species. Only 8 species were common to all 3 assessments. The NatureServe Climate Change Vulnerability Index and Climate Change Sensitivity Database evaluated 61 species in common, the System for Assessing the Vulnerability of Species and the NatureServe Climate Change Vulnerability Index evaluated 34 species in common, and the System for Assessing the Vulnerability of Species and Climate Change Sensitivity Database evaluated 14 species in common. Using these 3 overlapping lists of species, we evaluated the similarity of pairs of assessment outputs using 2 methods.

First, we divided outputs into either "low" ranking or "high" ranking. We established the dividing point between low and high based on descriptive information available from each assessment (Table 1). Outputs were high if they ranked or scored species as having any vulnerability or sensitivity. Outputs were low if they ranked or scored species as having no or low vulnerability or sensitivity (Table 1). "Low" qualified as a negative score in the System for Assessing the Vulnerability of Species, a rank of Low in the Climate Change Sensitivity Database, or a rank of Increasing or Presumed Stable in the NatureServe Climate Change Vulnerability Index. All other rankings or scores were considered "high." We calculated the percent of species that fell within the low or high categories for both assessments in each pair. If assessment results were similar, the percent of species with high or low vulnerability should be, likewise, similar. Differences in either the percent of species with low or high rankings, or the composition of species within those categories could indicate that assessments lack similarity in methodology or scoring technique. Individual species' "low" and "high" rankings for each pair of assessments are available online at www.onlinelibrary.wiley.com (Appendix B).

Second, we used Spearman's ranked correlation coefficient to compare outputs of each pair of assessments. We calculated values for ρ and P in R 2.14.0 using the *r*corr( ) function of the Hmisc (ver. 3.9–3) package. Our null hypothesis was that ρ did not differ from 0, indicating a lack of correlation between the ranked results of paired assessments. Our alternative hypothesis was that ρ differed significantly from 0 ($\alpha = 0.05$), indicating correlation between the ranked results of paired assessments. We used the Climate Change Sensitivity Database numerical scores for this analysis to more accurately represent the ranking order.

Although the assessments evaluate many of the same species, the geographic areas evaluated by each assessment may not correspond with each other. For this reason, we decided to separately evaluate 6 species using all 3 approaches within the same geographical context. One researcher performed all of the assessments. Where possible similar questions were answered using the same information to maintain as much similarity in data input as possible between assessments. We used Microsoft Excel to assess the degree of correlation between results.

We expected that the NatureServe Climate Change Vulnerability Index and System for Assessing the Vulnerability of Species would have higher correlation than either would have with the Climate Change Sensitivity Database. Both the NatureServe Climate Change Vulnerability Index and System for Assessing the Vulnerability of Species calculate overall vulnerability by incorporating measures of climate exposure and species sensitivity (potential climate change impact) and adaptive capacity. The Climate Change Sensitivity Database only measures how sensitive species are to climate change—it does not incorporate any predictions of climate exposure, and does not explicitly address adaptive capacity. Therefore, the rankings produced by the Climate Change Sensitivity Database should be less similar to those of the other 2 indices than the rankings of the NatureServe Climate Change Vulnerability Index and the System for Assessing the Vulnerability of Species should be to each other.

RESULTS

The 3 assessments were not well correlated with each other and did not have the same distribution of high and low rankings or scorings between pairs of assessments (Fig. 1). The Climate Change Sensitivity Database produced almost 3.5 times more highly vulnerable ranks than did the NatureServe Climate Change Vulnerability Index (Fig. 1a). Ninety-six percent of species were ranked as high by either the Climate Change Sensitivity Database or the NatureServe Climate Change Vulnerability Index, but only 27% were ranked high by both. Similarly, >5 times as many species scored high in the System for Assessing the Vulnerability of Species as ranked high in the NatureServe Climate Change Vulnerability Index (Fig. 1b). Ninety-four percent of species were ranked high by either the System for Assessing the Vulnerability of Species or NatureServe Climate Change Vulnerability Index, but only 18% were ranked high by both. Greater similarity existed between the Climate Change Sensitivity Database and System for Assessing the Vulnerability of Species, which differed by 14% (Fig. 1c). Ninety-two percent of species were ranked high by either the Climate Change Sensitivity Database or System for Assessing the Vulnerability of Species, and 86% were ranked high by both. Of the 8 species evaluated by all 3 assessments, only the NatureServe Climate Change Vulnerability Index produced low ranks of vulnerability for any species (Fig. 1d).

None of the Spearman's ranked correlation coefficients were statistically significant at the $\alpha = 0.05$ level (Fig. 1). The correlation between the NatureServe Climate Change Vulnerability Index and Climate Change Sensitivity Database was nearly significant with a ρ of 0.25 and P-value of 0.053. This pair also had the greatest number of species evaluated in common and could be said to have very similar scoring structures. Both pair-wise comparisons with the System for Assessing the Vulnerability of Species assessment were not significant (System for Assessing the Vulnerability of Species vs. Climate Change Sensitivity Database: $\rho = 0.40$, $P = 0.156$; System for Assessing the Vulnerability of Species vs. NatureServe Climate Change Vulnerability Index: $\rho = 0.26$, $P = 0.145$). The comparison between the System for Assessing the Vulnerability of Species and Climate Change Sensitivity Database had the highest Spearman's correlation coefficient, but also the smallest sample size.

Similar results were seen between the 6 species evaluated by our team. Correlation was highest between the Climate Change Sensitivity Database and NatureServe Climate Change Vulnerability Index ($r = 0.871$). Correlation between the Climate Change Sensitivity Database and System

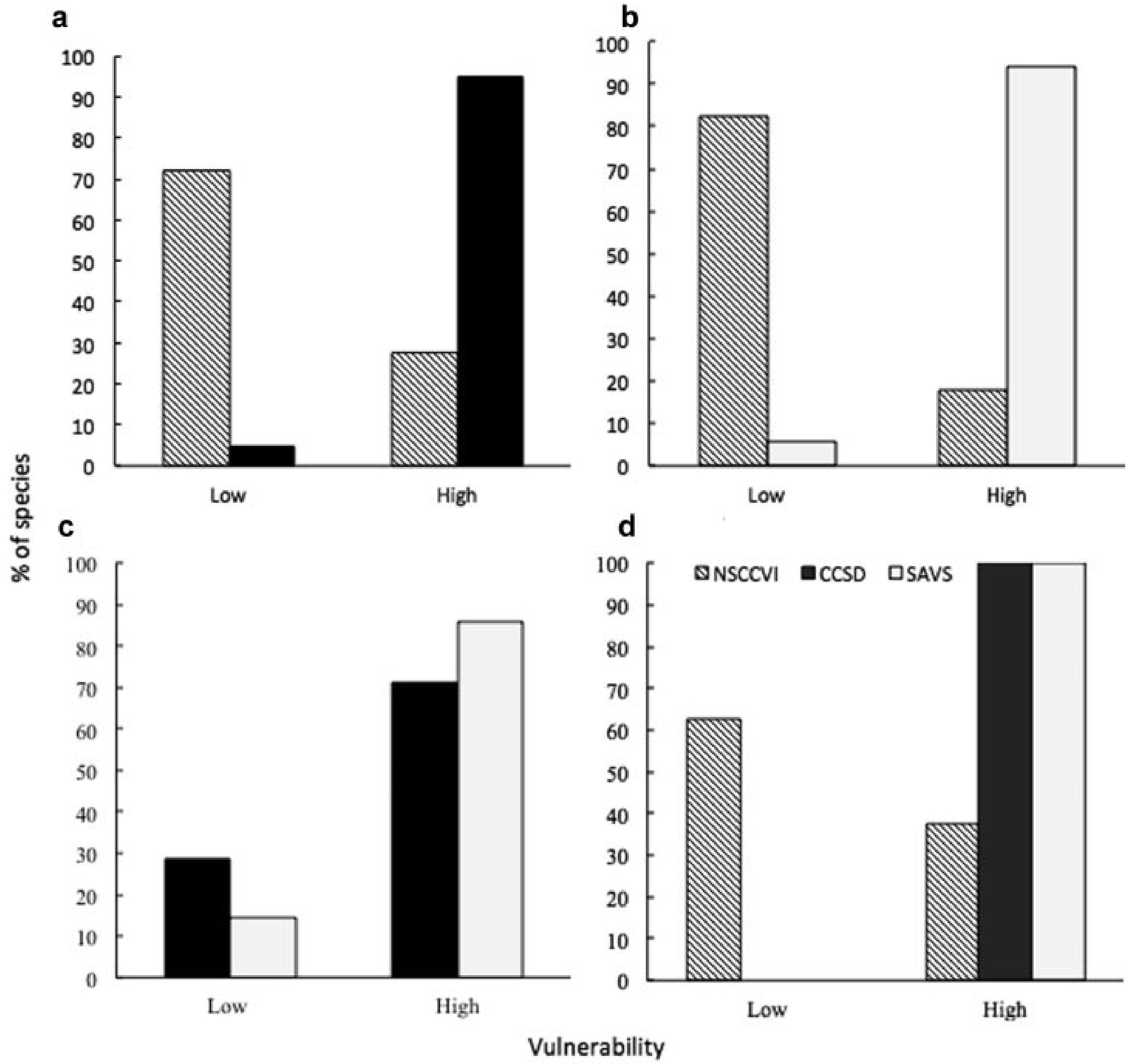

Figure 1. Percentage of species falling under low or high vulnerability/sensitivity in common between (a) NSCCVI (NatureServe Climate Change Vulnerability Index) and CCSD (Climate Change Sensitivity Database), (b) NSCCVI and SAVS (System for Assessing the Vulnerability of Species), (c) CCSD and SAVS, and (d) all three vulnerability assessments as of November 2012 for the Western United States.

for Assessing the Vulnerability of Species and the NatureServe Climate Change Vulnerability Index and System for Assessing the Vulnerability of Species was significantly lower ($r = 0.288$ and $r = 0.222$, respectively). Woodland caribou (*Rangifer tarandus*) ranked most similarly across all 3 assessments (Table 2). In contrast, the American three-toed woodpecker (*Picoides dorsalis*) showed a wide range of rankings (Table 2). Assessment inputs for all species are available online at www.onlinelibrary.wiley.com (Appendix C).

DISCUSSION

Many climate change vulnerability assessments are now being used to identify and inform management actions for species and ecosystems (e.g., Young et al. 2009, Bagne and Finch 2010, Lin and Morefield 2011, Schlesinger et al. 2011, Brinke and Jones 2012). Lack of a common assessment, or a common evaluation technique or outcome, have led to the development of a variety of methodologies for calculating vulnerability. The lack of similarity in outputs of the vulnerability and sensitivity assessments evaluated here speaks to the diversity possible in the formation and application of assessments. There is, as yet, no formal specific definition of how to form a vulnerability assessment because of the large potential number of variables that could be incorporated. For this reason, examination of individual assessment goals, geographical and temporal scale, and choice of input information is critical in order to use each assessment to its full potential.

The only assessment output pairing that appeared similar at the broad-scale analysis was the Climate Change Sensitivity Database and System for Assessing the Vulnerability of Species. Results of the Spearman ranked correlation coefficient indicate that the results of the Climate Change Sensitivity Database and System for Assessing the Vulnerability of Species are not correlated. Although this pairing did show the highest correlation, it also has the smallest sample size. The majority of species also appeared to be ranked

Table 2. Results for 6 species evaluated with vulnerability and sensitivity assessments (as conducted in the western United States) across the Climate Change Sensitivity Database, NatureServe Climate Change Vulnerability Index, and The U.S. Forest Service System for Assessing the Vulnerability of Species.

Assessment	Canadian lynx (*Lynx canadensis*)	Woodland caribou (*Rangifer tarandus caribou*)	Cliff chipmunk (*Tamias dorsalis*)	Lesser goldfinch (*Carduelis psaltria*)	Juniper titmouse (*Baeolophus ridgwayi*)	American three-toed woodpecker (*Picoides dorsalis*)
Climate Change Sensitivity Database	67—high	81—high	34—medium	22—low	39—medium	57—medium
NatureServe Climate Change Vulnerability Index	Moderately vulnerable	Highly vulnerable	Not vulnerable, increase likely	Not vulnerable, presumed stable	Not vulnerable, presumed stable	Highly vulnerable
U.S. Forest Service System for Assessing the Vulnerability of Species[a]	4.55	10.00	4.55	7.27	0.00	1.82

[a] Numerical scores for this assessment range on a scale from −20 (very high resilience) to 20 (very high vulnerability) with 0 indicating neither vulnerability, nor resilience.

similarly between the 2 assessment approaches (Appendix A available online at www.onlinelibrary.wiley.com). However, some difference should be expected between these assessments because the Climate Change Sensitivity Database measures only species sensitivity, whereas the System for Assessing the Vulnerability of Species also includes elements of climate exposure and species' adaptive capacity. Similarly, our own analysis of 6 species showed poor correlation between results of these 2 assessments. More data are needed to better assess the degree of correlation between these assessments.

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

The lack of a strong correlation between the NatureServe Climate Change Vulnerability Index and Climate Change Sensitivity Database outputs is, to some degree, expected because they are assessing different measures (overall vulnerability and species sensitivity, respectively). Similar to the previous 2 pair-wise comparisons, the appearance of a greater percentage of species ranked highly by the Climate Change Sensitivity Database is likely a result of how low and high rankings were defined. The reason for the lack of correlation between the NatureServe Climate Change Vulnerability Index and Climate Change Sensitivity Database may be largely attributed to the inclusion of climate exposure and species' adaptive capacity measures in the NatureServe Climate Change Vulnerability Index. This could also be attributed to lack of overlap in geographic regions because we found higher correlation between these 2 assessments, in our 6-species assessment.

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

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

Perhaps one of the greatest difficulties in attempting a comparison of this nature is the diversity of overlap in geographic areas between assessments for the same species. Almost no species have been evaluated by multiple assessments within the same geographic region. The underlying differences between regional and local habitats and climate impacts can therefore confound comparison across vulnerability assessments. However, in performing our own evaluation of 6 Idaho species, we found that assessment results are not well-correlated. It is clear that each of these assessments has valuable insight to offer concerning sensitivity and vulnerability of wildlife species. Features that are generally addressed by one assessment may be addressed more completely, or from a different perspective, in additional assessments. For this reason we strongly recommend that users evaluate species with multiple assessments to create a more complete picture of vulnerability.

How questions about vulnerability and sensitivity are worded for the user, along with their perception of the species in question, or of climate effects in a particular region, will most certainly influence answer choice when completing each of these assessments. For example, all 3 assessments phrase questions concerning sensitivity of species' physiological thresholds differently. The Climate Change Sensitivity Database asks the user to rank physiological sensitivity (temp, moisture, carbon dioxide, pH, salinity, etc.) where low sensitivity equates with tolerance to change in a wide range of variables (CCSD 2012). The System for Assessing the Vulnerability of Species has 6 questions pertaining to physiology, but only one question that directly enquires whether "limiting physiological conditions [are] expected to change" (Bagne et al. 2011:24). The possible answers to this question focus on temperature and moisture tolerances and whether they are predicted to exceed upper thresholds, remain within current thresholds, or decrease such that lower thresholds are exceeded. Finally, the NatureServe Climate Change Vulnerability Index also focuses on temperature and moisture tolerance, but also enquires about historical conditions (Young et al. 2011). Users are asked to rank the variation in historical temperature and moisture regimes experienced by a given species. Next, the user is asked to rank how restricted a given species is to cool environments, or a specific moisture regime. All 3 assessments enquire about physiological sensitivity, but use varying numbers of questions and phrase their questions differently.

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

Opportunities

Further evaluation of these and other vulnerability assessments with geographic and species overlap comparisons is needed (Davison et al. 2012, Small-Lorenz et al. 2013). Incorporating seasonal variability both in species distribution and natural history could also greatly improve estimates of vulnerability and pinpoint areas and resources of key concern (Small-Lorenz et al. 2013). Increasing the number of species assessed in common would increase sample sizes and allow for greater diversity of comparisons among taxa and habitat associations.

Additionally, a better understanding of the degree to which exposure, sensitivity, and adaptive capacity contribute to overall species vulnerability will improve vulnerability assessments in the future. Although sensitivity is specific to individual species or populations, exposure is contingent upon the geographic area of interest. Therefore, if 2 species are similarly sensitive, but one exists in a region with greater exposure, vulnerability for that species should be greater. Likewise, inclusion of geographical variation in natural and anthropogenic barriers along with evolutionary potential and dispersal abilities would improve measures of adaptive capacity (Davison et al. 2012). Consideration for community level interactions including trophic interactions, competition, and facilitation would also improve predictions for species persistence at the ecosystem and landscape level. Applying vulnerability analyses to on-the-ground management will require spatially dynamic assessments that allow for the variation in structure and function across a landscape and within communities. Incorporating a measure of spatial plasticity to the greater vulnerability score of any particular species could highlight areas of high concern, or refuges and corridors (Davison et al. 2012). These are likely continuing goals, but will greatly assist in development and use of vulnerability assessments.

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

Both state and federal land-management agencies are now looking to climate change vulnerability assessments to inform management decisions. Although these assessments might provide an opportunity for agencies to prioritize species' vulnerabilities to climate change, these vulnerability assessments are currently limited in their applicability until they are applied to landscapes across different seasons

(Small-Lorenz et al. 2013). Incorporating seasonality and temporal variability may help span the gap between assessment results and on-the-ground management actions to address climate-related concerns.

LITERATURE CITED

Bagne, K. E., and D. M. Finch. 2010. An assessment of vulnerability of threatened, endangered, and at-risk species to climate change at the Barry M. Goldwater range, Arizona. U.S. Department of Agriculture Department of Defense Legacy Program Report, Project 09-433. U.S. Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona, USA.

Bagne, K. E., M. M. Friggens, and D. M. Finch. 2011. A system for assessing vulnerability of species (SAVS) to climate change. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-257, Fort Collins, Colorado, USA.

Brinke, R. B., and C. Jones. 2012. The vulnerability of provincially rare species (species at risk) to climate change in the Lake Simcoe watershed, Ontario, Canada. Natural Heritage Information Centre, Science and Information Branch, Ontario Ministry of Natural Resources, Peterborough, Canada.

Climate Change Sensitivity Database [CCSD]. 2012. Climate Change Sensitivity Database. <http://climatechangesensitivity.org/>. Accessed 15 Sep 2012.

Davison, J. E., S. Coe, D. Finch, E. Rowland, M. Friggens, and L. J. Graumlich. 2012. Bringing indices of species vulnerability to climate change into geographic space: an assessment across the Coronado National Forest. Biodiversity Conservation 21:189–204.

Dubois, N., A. Caldas, J. Boshoven, and A. Delach. 2011. Integrating climate change vulnerability assessments into adaptation planning: a case study using the NatureServe Climate Change Vulnerability Index to inform conservation planning for species in Florida. Defenders of Wildlife, Washington, D.C., USA.

Gardalli, T., N. E. Seavy, R. T. DiGaudia, and L. A. Comrack. 2012. A climate change vulnerability assessment of California's at-risk birds. PLoS ONE 7:e29507.

Girvetz, E. H., C. Zganjar, G. T. Raber, E. P. Maurer, P. Kareiva, and J. J. Lawler. 2009. Applied climate-change analysis: the Climate Wizard tool. PLoS ONE 4:e8320–e8339.

Glick, P., B. A. Stein, and N. A. Edelson, editors. 2011. Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C., USA.

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

Lawler, J. J. 2009. Climate change adaptation strategies for resource management and conservation planning. The Year in Ecology and Conservation Biology 1162:79–98.

Lin, B. B., and P. E. Morefield. 2011. The vulnerability cube: a multi-dimensional framework for assessing relative vulnerability. Environmental Management 48:631–643.

McCarthy, P., B. Neely, and A. W. Thomas. 2010. Climate change vulnerability assessments, lessons learned from practical experience: practitioner's responses to frequently asked questions. Climate Change Vulnerability Assessment Workshop, The Nature Conservancy, Boulder, Colorado, USA.

Schlesinger, M. D., J. D. Corser, K. A. Perkins, and E. L. White. 2011. Vulnerability of at-risk species to climate change in New York. New York Natural Heritage Program, Albany, USA.

Schneider, S. H., S. Semenov, A. Patwardhan, I. Burton, C. H. D. Magadza, M. Oppenheimer, A. B. Pittock, A. Rahman, J. B. Smith, A. Suarez, and F. Yamin. 2007. Assessing key vulnerabilities and the risk from climate change. Pages 799–810 *in* M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, editors. Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, England, United Kingdom.

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

Turner, B. L., R. E. Kasperson, P. A. Matson, J. J. McCarthy, R. W. Corell, L. Christensen, N. Eckley, J. X. Kasperson, A. Luers, M. L. Martello, C. Polsky, A. Pulsipher, and A. Schiller. 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences of the United States of America 100:8074–8079.

U.S. Fish and Wildlife Service. 2010. Rising to the urgent challenge: strategic plan for responding to accelerating climate change. <http://www.fws.gov/home/climatechange/strategy.html>. Accessed 25 Oct 2012.

Williams, S. E., L. P. Shoo, J. L. Isaac, A. A. Hoffmann, and G. Langham. 2008. Towards an integrated framework for assessing the vulnerability of species to climate change. PLoS Biology 12:2621–2626.

Young, B. E., E. Byers, K. Gravuer, K. R. Hall, G. A. Hammerson, and A. Redder. 2011. Guidelines for Using the NatureServe Climate Change Vulnerability Index. NatureServe, Arlington, Virginia, USA.

Young, B. E., E. Byers, K. Gravuer, K. R. Hall, G. A. Hammerson, A. Redder, K. Szabo, and J. E. Newmark. 2009. Using the NatureServe Climate Change Vulnerability Index: a Nevada case study. NatureServe, Arlington, Virginia, USA.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

Appendix A: Scores and ranks of individual species as assigned by NatureServe Climate Change Vulnerability Index (NSCCVI), Forest Service System for Assessing the Vulnerability of Species (SAVS), and the Climate Change Sensitivity Database (CCSD).

Appendix B: List of species in ranked by each pair of vulnerability assessments (NatureServe Climate Change Vulnerability Index [NSCCVI], Forest Service System for Assessing the Vulnerability of Species [SAVS], and Climate Change Sensitivity Database [CCSD]).

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