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Tools and Technology

Using The Climate Change Vulnerability Index to Inform Adaptation Planning: Lessons, Innovations, and Next Steps

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ABSTRACT New tools and approaches are becoming available for wildlife conservation managers to help support climate adaptation activities, but few studies have documented how practitioners have applied these tools and perceive their utility. We surveyed the literature and users of the NatureServe Climate Change Vulnerability Index (CCVI), a tool that is widely used in North America to assess species' vulnerability to climate change, to characterize 1) how the tool has been used; 2) the objectives addressed by projects using the tool; 3) novel approaches that might be useful to other users; 4) how the results contributed to climate change adaptation planning; and 5) needed improvements recognized by users of the tool. Responses from 25 CCVI users, representing state agencies and natural heritage programs, conservation organizations, and universities, combined with published reports from 20 CCVI assessments, indicated that the CCVI has been applied to large numbers of species from diverse taxonomic groups. Results from these assessments have been used to communicate about climate change vulnerability, select species to be prioritized for management, inform management decisions, identify monitoring needs, and inform land-acquisition decisions. Users of the CCVI have developed novel ways to address uncertainty in climate and species natural-history data, involve stakeholders, evaluate migratory species, address specific management questions, and combine outputs with the results of parallel spatial analyses. To address user needs, future iterations of the tool should address climate exposure in the full life cycle of migratory species; better examine species dependent on specific vegetation microhabitats; and improve treatment of the effects of climate on diseases, parasites, and natural enemies.

KEY WORDS adaptation planning, assessment, climate change, vulnerability.

Although scientists have long known that greenhouse gas emissions and shifts in land use brought about by an industrialized society are inexorably changing climates and affecting ecosystems (IPCC 1990), much of the theory and practice on how to modify natural resource management to address this threat is more recent. Practitioners widely agree that an early step is to assess species and ecosystems of interest for their vulnerability to the impacts of climate change (Lawler et al. 2010, Cross et al. 2012). Assessments identify the climate-mediated processes that management activities need to influence through adaptation planning. Several theoretical frameworks for vulnerability assessment are available (Füssel and Klein 2006, IPCC 2007, Williams et al. 2008), as are best practice guidelines for managers (AFWA 2009, Glick et al. 2011, Rowland et al. 2011). The methods that have been used to conduct climate change vulnerability assessment include spatial analyses of climate projections, bioclimatic models, expert-based consultation approaches, and trait-based indexes of vulnerability (Thomas et al. 2004, Enquist and Gori 2008, Galbraith and O'Leary 2011, Young et al. 2012, Foden et al. 2013).

Among the different methods, trait-based approaches are those that use species' biological characteristics as predictors of extinction risk due to climate change, often in combination with estimates of exposure (Williams et al. 2008, Bagne et al. 2011, Foden et al. 2013). The use of generalized natural-history characteristics allows trait-based approaches to be applied to numerous taxa, facilitating comparisons of vulnerability in support of priority-setting exercises. One trait-based tool that has been developed to assess species vulnerability in North America is the Climate Change Vulnerability Index (CCVI; Young et al. 2012). The CCVI contains scoring elements that collectively reflect factors known to influence climate change vulnerability and uses this information to place species into broad categories of vulnerability. The tool is designed to help resource managers screen relatively large numbers of species from diverse taxonomic groups in order to identify the species most vulnerable to climate change and the factors leading to that vulnerability (Young et al. 2012). Since its first release in 2010, the CCVI has become a popular tool used by

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government, non-profit, and academic environmental programs. A recent survey revealed that the CCVI is now the most common method being used by state agencies to assess the impacts of climate change on wildlife as part of federally mandated revisions to their state wildlife action plans (AFWA 2012).

As the field of climate change vulnerability assessment matures, it is important to analyze the methods themselves to determine how successfully they are satisfying the needs of their target audiences. Any tool receiving wide use is susceptible to inadvertent misuse by well-meaning practitioners (Loiselle et al. 2003). Broad usage also increases opportunities for the development of innovations and novel approaches by the user community. Information provided by such an analysis can contribute to future improvements to the tool itself and form the basis of best practice guidelines and the dissemination of creative applications. Here we describe the results of a survey of the CCVI user community to learn about their experiences using the CCVI, the context in which the CCVI was used, and how the results contributed to climate change adaptation planning and implementation. The survey results also provide lessons in how to apply the tool, as well as novel ways the CCVI can support different vulnerability assessment objectives. Most of the findings are applicable broadly to climate change vulnerability assessment independent of the specific method used.

THE CLIMATE CHANGE VULNERABILITY INDEX

The CCVI is a tool programmed in MS Excel 2010 that integrates information about projected temperature and moisture changes, landscape context, natural history traits related to climate sensitivity and adaptive capacity, and documented and modeled responses to climate change. The tool supports assessments of any aquatic or terrestrial plant or animal within a specified geographic area. A scoring mechanism uses the magnitude of projected climate change to weight sub-scores of how each landscape and natural history factor influences vulnerability to climate change. The results place each species in a category of vulnerability (extremely vulnerable, highly vulnerable, moderately vulnerable, not vulnerable–presumed stable, or not vulnerable–increase likely). Uncertainty in how a particular factor influences vulnerability is registered by selecting multiple response categories. Once scoring is complete, the tool runs a Monte Carlo simulation to explore graphically how uncertainty in scoring individual factors might create uncertainty in the overall score for the species. The tool then uses the proportion of Monte Carlo runs that match the overall score to produce a measure of confidence in species information. Results for assessments of multiple species are stored in a spreadsheet that allows color-coded comparisons of species' sub-scores across individual factors. A companion document provides guidelines on how to fill out the required fields and incorporate the results in a management context (Young et al. 2011*a*). Young et al. (2012) present a more detailed explanation of the factors and scoring mechanism, and the tool is available at http://www.natureserve.org/climatechange.

METHODS

To characterize applications of the CCVI, we employed an online survey of users conducted June–September 2013. The survey consisted of 26 questions addressing the purpose of the assessment, parameters of the assessment (nos. of species assessed, taxonomic, and geographic coverage), who carried out the assessment, the intended audience, relevance to management plans, strengths and weaknesses of the tool itself, strengths and weaknesses of tool outputs, whether the tool was modified, and the extent to which assessment results have been incorporated into adaptation planning activities (see online Supporting Information for question text). To limit the time investment needed to complete the survey, most questions presented participants with multiple answers to choose from, with the option to write in additional responses and explanations. Questions about strengths and weaknesses invited open-ended responses. We quantified answers to multiple-choice questions by tallying the frequency with which each choice was selected. A specialist in public survey design reviewed draft questions to clarify intent and reduce potential bias in response. The Wildlife Conservation Society Institutional Review Board determined that the research was exempt from review for use of human subjects based on federal regulations, section(s) 45 CFR 46.101(b)(2).

We compiled a list of CCVI users to invite to complete the survey. This list included anyone who had contacted one of the authors since 2010 about a project using the CCVI and leaders of CCVI projects that the authors were aware of through presentations at conferences or publications of results. The list also included participants in Notre Dame's Collaboratory for Adaptation to Climate Change (http://adapt.nd.edu) who use an online version of the CCVI. We consulted with the Association of Fish and Wildlife Agencies for additional names of assessment leaders from state agencies they had identified in their own survey (AFWA 2012) as having used the CCVI. We edited the list to include only one person per project to avoid duplication of responses. When different taxonomic groups were assessed independently by separate agencies for a state-level assessment, we invited the leaders of each assessment to complete the survey. We sent personalized e-mails to the final list of 46 users inviting them to complete the survey (Fig. 1), following up with a reminder e-mail 1 month later. Finally, we searched the literature for reports describing CCVI assessment results to supplement ideas and views expressed by survey respondents.

RESULTS

Assessment Context

Representatives of 25 assessments completed the survey, or a response rate of 54%. We received responses from across North America representing a diverse set of institutional affiliations, including natural heritage programs (36%), non-

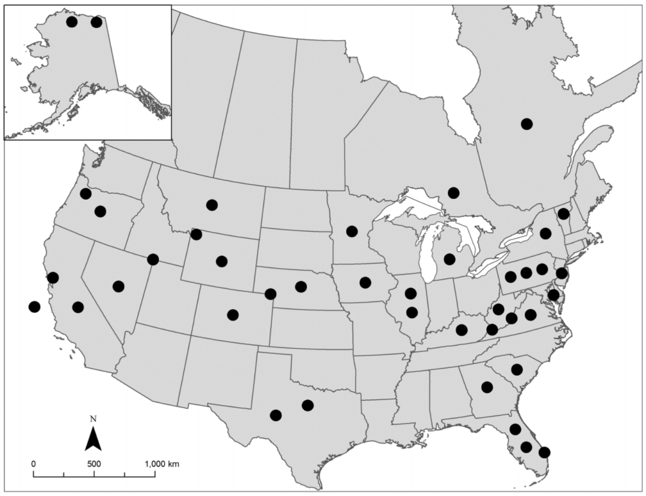

Figure 1. Locations of projects (representing state agencies and natural heritage programs, conservation organizations, and universities) invited to complete a June–September 2013 survey of Climate Change Vulnerability Index users in the United States and Canada. Dots represent approximate centers of each project's assessment area. All invitees, rather than respondents, are indicated to preserve anonymity.

profits (28%), state agencies that are not heritage programs (12%), a federal agency (4%), a university (4%), a natural history museum (4%), and a joint natural heritage program and state agency effort (4%). In addition, we found reports of 20 distinct CCVI assessments in the literature (Table 1).

Climate Change Vulnerability Index assessments fulfilled numerous objectives, even within individual projects. The most commonly cited purposes for carrying out assessments were to generate broad understanding about climate change (76%) and to address species management decisions (72%). Identifying information gaps (40%) and prioritizing science needs (40%) were also frequently cited objectives. Fewer respondents cited the need to update an existing plan (36%) or develop a new plan (16%) as reasons for carrying out the assessment. Of those citing updating or developing a new plan as motivation, 10 of the 12 plans were state wildlife action plans. Other plans were similarly broad, such as the Arctic National Wildlife Refuge Comprehensive Conservation Plan, but one focused on a single species (Pacific Lamprey Conservation Initiative).

All respondents targeted their assessments at managers or scientists directly involved in species management decisions. Additional audiences were decision-makers involved in natural resource policy (52%), the general public (28%), and the institution carrying out the assessment itself (8%).

Table 1. Completed Climate Change Vulnerability Index assessments in the United States and Canada from 2010–2013 with available reports, compiled from a web search and first-hand knowledge of the authors. Not all projects were represented by survey respondents.

Geographic scope	Taxa assessed	Purpose	Reference
Arctic National Wildlife Refuge	Mammals	Understand vulnerability	Delach et al. 2011
Arctic Alaska	Birds	Understand vulnerability	Liebezeit et al. 2012
California	Rare plants	Understand vulnerability	Anacker et al. 2011, Anacker et al. 2013
Colorado	Plants	SWAP[a] update	CO Natural Heritage Program for Rare Plant Conservation Initiative 2011
Colorado–Gunnison Basin	Vertebrates, invertebrates, and plants	Understand vulnerability	Neely et al. 2011
Florida	Vertebrates and invertebrates	SWAP update and inform adaptation planning	Dubois et al. 2011
Great Plains	Grassland birds	Inform adaptation planning	Zack et al. 2010
Illinois	Vertebrates and invertebrates	SWAP update	Walk et al. 2011
Michigan	Vertebrates, invertebrates, and plants	SWAP update	Hoving et al. 2013
Nevada	Vertebrates and invertebrates	SWAP update	Szabo 2012, Young et al. (2011*b*)
New York	Vertebrates and invertebrates	SWAP update	Schlesinger et al. 2011
Ontario–Lake Simcoe Watershed	Vertebrates and plants	Inform adaptation planning	Brinker and Jones 2012
Oregon–Willamette Valley	Vertebrates, invertebrates, and plants	SWAP update	Steele et al. 2011
Oregon–West Eugene	Wetland vertebrates, invertebrates and plants	Inform adaptation planning	Kaye et al. 2012
Pennsylvania	Vertebrates, invertebrates, and plants	Understand vulnerability	Furedi et al. 2011
Pennsylvania	Plants	Understand vulnerability	Morton and Speedy 2012
Virginia	Vertebrates, invertebrates, and plants	SWAP update	Chazal 2010
West Virginia	Vertebrates, invertebrates, and plants	Understand vulnerability	Byers and Norris 2011
Western United States	Plants	Prioritize seed collection	Treher et al. 2012
Military Installations – California, Washington, Georgia	Vertebrates (3)	Understand vulnerability	Sperry and Hayden 2011

[a] State Wildlife Action Plan.

The respondents used the CCVI to assess substantial numbers of species. Over two-thirds of the projects assessed >50 species, with 7 assessing >250 species. The species assessed were drawn from a wide range of terrestrial and aquatic taxonomic groups, with vascular plants and vertebrates being the most common (Fig. 2). The spatial extent of the majority (64%) of assessments was a state or province. Other geographies included wildlife refuges, watersheds, ecoregions, and a portion of a species range. The respondents were able to compile sufficient information to meet the CCVI's minimum data requirements for most species assessed. Overall, 86% reported being able to find sufficient data to score ≥90% of species on their lists.

Typically the CCVI was the only vulnerability assessment method considered (56%, or 14 assessments). In 8 cases, other methods were considered before deciding to use the CCVI, and in 3 other cases, the CCVI was used in conjunction with species distribution models or scenario-based spatial analysis. A variety of models were employed for actually carrying out the assessments. Usually staff at the institutional lead for the project conducted the CCVI assessments themselves (48%). In another 48% of the cases, outside experts were engaged to either review staff assessments, provide information that staff used to fill out assessments, or supplement staff efforts to complete CCVI assessments. The number of individuals that were involved in some way with the assessments varied from 1 to >50, with a mode of 5–9 people. Eight respondents (32%) reported modifying the tool to serve their needs. Modifications included adjusting the scoring algorithm, adjusting the exposure categories, hiding the overall score from expert assessors to avoid bias, and revising specific factors to address aspects of natural history that were missing from the criteria.

Conducting the Assessment

All respondents identified at least 1 strength and 1 weakness of the tool. The majority (>50%) perceived the ease of use of the tool as a key strength, referencing the detailed guidelines (Young et al. 2011*a*) and familiarity with the MS Excel platform. The second-most commonly cited strength was its ability to screen the vulnerability of multiple species across a range of taxa. Many appreciated the ability to apply a consistent and repeatable framework that combines exposure and sensitivity using a diverse set of life-history traits.

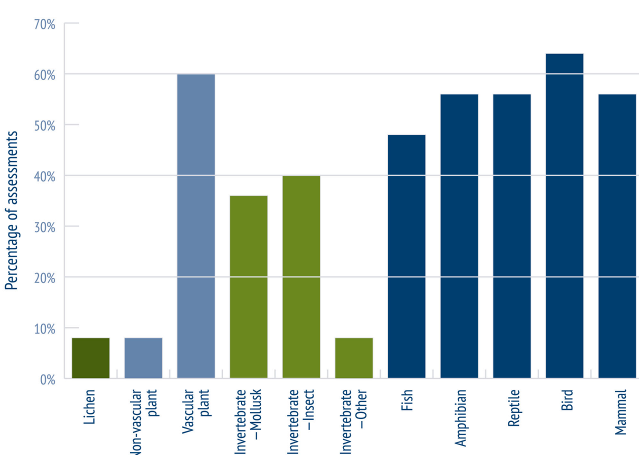

Figure 2. Representation of taxonomic groups in the 25 Climate Change Vulnerability Index assessments carried out by respondents (representing state agencies and natural heritage programs, conservation organizations, and universities) to a June–September 2013 survey of Climate Change Vulnerability Index users in the United States and Canada. Colors distinguish major taxonomic divisions (dark green = lichens; light blue = plants; light green = invertebrates; dark blue = vertebrates).

The cited weaknesses of the CCVI tool can be grouped into 3 main categories: limitations on data availability, needed improvements, and content and analysis shortcomings. A number of comments on data limitations related to a lack of satisfactory information available for both the exposure and sensitivity components. Respondents mentioned both quality (e.g., coarse resolution of climate model output, lack of information about microclimate) and availability (e.g., limited knowledge about the genetic diversity of many species) and their effects on uncertainty associated with the results. A few respondents (20% of those citing weaknesses) expressed disappointment in some technical aspects of the tool. For example, the tool cannot batch-calculate the vulnerability of multiple species at once. The bulk of the critiques, however, were related to its content and analytical capabilities. Many called out a lack of consideration for indirect effects of climate change (e.g., changes in disease and parasitism, changes in habitat dynamics) and the difficulty of use for certain taxonomic groups (e.g., aquatic species, migratory species, and plants). Some also highlighted the tool's superficial analysis of exposure, which considers projected annual temperature and moisture changes as opposed to climate changes during specific seasons that might be more meaningful biologically. While many respondents found the written guidelines helpful, a primary suggestion for improvement was to provide a greater number of species-specific examples to aid the interpretation of some of the sensitivity and indirect climate factors.

Interpreting the Results

Tool users described a variety of strengths of the CCVI in interpreting and sharing the vulnerability results, some of which parallel those for conducting the assessment. Again, there were positive comments about the common framework that the CCVI offers for multiple species and the resulting ease in comparison and integration with the outputs of other assessments. Many found the overall vulnerability score, relative rankings, and vulnerability categories straightforward to interpret and communicate to diverse audiences such as scientists, managers, and decision-makers. Several users noted the importance of the characterization of confidence, both in conjunction with the vulnerability results table and through the Monte Carlo simulations. Users felt that the ability to compare confidence among species helped to strengthen interpretation, especially when examining the influence of specific factors underlying vulnerability. Multiple respondents appreciated the color-coded results table that facilitated the recognition of the key sensitivity and indirect climate factors contributing to vulnerability.

In contrast, the standardized framework that some users favored was viewed as a limitation by others in interpreting or communicating the results. Some users found the outputs complicated to interpret or wished that the CCVI outputs were better able to capture additional (derived) exposure variables that more directly affect vulnerability of individual species. In other cases, users noted instances where the scores failed to capture perceived vulnerabilities. Roughly 25% of respondents felt that the confidence levels associated with results did not adequately capture the multiple sources of uncertainty that can potentially influence vulnerability across different species, particularly for species occurring in habitats that are likely to be affected by climate change in complex ways as well as for highly mobile and migratory species.

Another fairly common critique was the perception that the categories of vulnerability were arbitrary and misleading, which in at least one case led to challenges in communicating results when many species had the same overall score. A few respondents found it particularly hard to interpret species scored as 'neutral' with respect to vulnerability for multiple factors, and one user suggested changing the 'presumed stable' and 'increase likely' categories to 'climate neutral' and 'likely to benefit.' However, the most commonly cited (approx. 33%) challenge to interpreting the results was the lack of information about the underlying scoring algorithm. As one respondent stated, "It took a while to understand the details of how the algorithm was generating scores and explain that clearly to participants not intimate with the tool." Another simply made note of the "black box" and "undocumented nature of calculations." Other suggested challenges cited in terms of interpreting the results of assessments included potential scale issues when interpreting results for broadly versus narrowly distributed species relative to the assessment area and the limited data summary options currently offered by the tool.

Applying the Results

Most respondents (76%) indicated that the results of the assessment were being used in some way. The most commonly cited use (65%) was as a general resource to understand and communicate climate change vulnerability. A number of respondents indicated that the results of the assessment were being used to inform the selection of species to be prioritized for management (44%), as well as to inform management decisions (40%) and monitoring efforts (36%) for species that are currently under management. Two respondents (8%) indicated that the results of the assessment were being used to inform land-acquisition decisions.

Approximately half (56%) of the respondents reported that the assessment results were being used for some aspect of species climate change adaptation planning or other management activities. Of these respondents, the overall CCVI score and the table of factors and sub-scores were considered the most useful outputs of the tool. The Monte Carlo simulation and uncertainty assignments were considered somewhat less useful. The overall CCVI score was most often cited as being used to set or evaluate priorities (67%), whereas the table of factors and sub-scores was typically used to develop management strategies or inform specific management decisions (83%).

To inform climate change adaptation planning and other management activities, CCVI users expressed satisfaction in being able to differentiate highly vulnerable from less vulnerable species using the overall scores. Some users noted difficulties in using the vulnerability scores to set priorities, particularly when many species had the same score, or when there were questions as to whether the scores adequately captured the species' vulnerabilities and the associated uncertainty. Other outputs, such as the table of factors and sub-scores, were considered helpful for identifying research and monitoring needs, as well as guiding the development of appropriate adaptation strategies. However, one user noted that it was difficult to prioritize strategies without considering climate change vulnerability in the context of other threats. One respondent indicated that issues related to uncertainty and a perceived lack of a connection between climate exposure and vulnerability score affected the willingness of participants engaged in the assessment to make decisions based on the outputs.

DISCUSSION

The survey responses demonstrate that the CCVI is serving to build climate change understanding and support adaptation planning for resource managers and scientists across North America. The CCVI has been used to achieve a number of objectives, including educating and communicating about climate change, informing species management, and identifying monitoring needs and data gaps. However, as with any tool, the CCVI cannot be all things to all users. Users identified a number of challenges to both assessing species' vulnerability to climate change and the application of results to adaptation planning. Others described innovative ways they have overcome similar challenges to achieve results that inform adaptation planning. These user experiences document lessons pertinent not only to future users of the tool but to other climate change vulnerability assessment approaches as well. Here we discuss how CCVI results have been used in adaptation planning, limitations and innovations of the tool, and future improvements needed (see Supporting Information for additional considerations for CCVI users).

Role in Adaptation Planning

A major motivating factor for carrying out a climate change vulnerability assessment is to inform adaptation planning and make decisions about management strategies for implementation (Cross et al. 2012, Groves et al. 2012). The results of our survey indicate that many CCVI assessments are successfully being used in this way – to help prioritize species and identify specific vulnerabilities that adaptation strategies might target. The vulnerability scores inform conservation priorities, such as the lists of species of greatest conservation need included in state wildlife action plans. Information about the factors contributing to vulnerability has been used to influence species management and conservation. These 2 applications point to how the CCVI can serve multiple purposes in adaptation planning efforts, providing inputs to both top-down and bottom-up approaches to species-level assessment (*sensu* Hansen and

Hoffman 2010). Using the CCVI vulnerability ranks to prioritize species for subsequent planning represents a top-down perspective. On the other hand, bottom-up assessments start with a set of conservation or management priorities in place (using, for example, criteria such as conservation status, recreational value, or cultural significance) and identify how projected climate change will impact particular species to identify potential management options. In these applications, the sources of vulnerability (typically species' sensitivities to climate change) identified by the CCVI are of greater importance than relative vulnerability. In practice, a combination of both a top-down and bottom-up approach may be used. In some cases parallel assessments of habitats or vegetation communities have taken place. Neely et al. (2011) conducted assessments of ecosystems alongside their CCVI assessments in Gunnison Basin, Colorado, USA, to explore correlations between the climate change vulnerability of both species and habitats and develop mutually beneficial strategies.

Limitations and Innovations

Although CCVI users cited the consistent framework applicable across taxa as a strength, they also cited a lack of specificity, missing sensitivity, and other issues as limitations. Respondents to our survey noted cases in which species they anticipated to be vulnerable to climate change, such as wetland-dependent species, yielded lower-than-expected vulnerability scores. On the one hand, preconceived assumptions about climate change vulnerability may be incorrect. For example, because the CCVI uses the magnitude of climate exposure to weight sensitivity factors, species' overall vulnerability will likely be low in cases of low-magnitude climate exposure even for somewhat sensitive species. Similarly, species for which most of the sensitivity factors score low (even if a single one is high) will likely result in a low overall vulnerability assessment (e.g., Liebezeit et al. 2012). These sometimes unanticipated results highlight the importance of understanding the underlying assumptions imbedded in the CCVI when interpreting resulting scores (Füssel and Klein 2006, Williams et al. 2008).

These and other observations captured in the surveys and associated vulnerability assessment reports reflect an underlying trade-off between designing a tool that facilitates standardization across diverse and at times poorly known taxa and a more flexible but data-intensive tool that can be customized for specific target species. One benefit of the wide application of the CCVI is the variety of innovative ways it has been used to support assessments despite perceived limitations. Here we discuss some examples that may help other users who face similar challenges and review suggestions for future tool development.

Evaluating distinct life stages and populations.—Several respondents noted difficulty in applying the CCVI to migratory species because they felt the tool did not fully capture the range of factors affecting species vulnerability across different life stages. These observations parallel recent criticisms that vulnerability indices, such as the CCVI, do not adequately incorporate climate-related risks occurring outside of the user-defined assessment area (e.g., Small-Lorenz et al. 2013). Migratory species may be exposed to different magnitudes of climate change or be associated with different factors influencing sensitivity (e.g., different disturbance regimes, species interactions) during different stages of their annual cycle. As a result, climate exposure and sensitivity in any part of the annual cycle may affect species vulnerability, and exposure in one stage of the annual cycle may carry over to influence the species in a subsequent stage (Tøttrup et al. 2012). Consequently, considering the vulnerability of species based only on exposure and sensitivity factors during the breeding season is unlikely to capture the true vulnerability of many migratory species (Small-Lorenz et al. 2013). One way to address this issue is to approach assessments of migratory species by assessing different stages separately and using the highest vulnerability score to characterize the species (Liebezeit et al. 2012).

Addressing uncertainty.—Uncertainty is an element of nearly all resource management planning and decision-making, but its sources and impacts on outcomes can vary (Kujala et al. 2013). Components of uncertainty associated with any vulnerability assessment include climate models, emissions scenarios, and species-specific responses to changing climates. Data for input to the CCVI are evidently readily available, as shown by survey respondents reporting a low portion of assessments that resulted in an insufficient evidence score. Despite this, user perspectives on uncertainty in CCVI outputs ranged from views focused on how perceived uncertainties impeded the application of the results to those placing high value on documenting the influence of uncertainty on the overall results. The CCVI allows for expressions of uncertainty in how particular sensitivity factors are scored, but it does not explicitly address uncertainty in climate projections except through the recommendation to use climate model ensembles based on a single emissions scenario rather than a single global circulation model.

Although some users have critiqued the CCVI for not taking into account uncertainty from climate projections (Zack et al. 2010, Hoving et al. 2013), a subset of survey respondents reported using a sensitivity analysis to better characterize the uncertainty of their results, in relation to exposure as well as sensitivity inputs. For example, Liebezeit et al. (2012) addressed concern over how the choice of climate model or scenarios could influence results by repeating assessments with multiple climate projections and then conducting a sensitivity analysis to explore effects on vulnerability. Similarly, Steel et al. (2011) assessed the influence of climate model and emissions scenario uncertainty by using 4 global circulation models run under 3 emissions scenarios, representing the bookends of temperature and precipitation change specific to the Willamette Valley, Oregon, USA, while keeping sensitivity scores constant. In another application, the assessors modified the CCVI to allow the display of underlying numerical scores and used the range of numerical scores calculated for each species to graphically depict uncertainty in assessing sensitivity (Dubois et al. 2011). This approach can alleviate concerns regarding the possible influence that 1 or 2 variables can have on the CCVI score (Sperry and Hayden 2011).

However, the general nature of the exposure inputs used in the CCVI, such as annual means instead of seasonal means or maxima that might be more critical measures for particular species, could result in species being more vulnerable to climate change than indicated by their CCVI score. In addition, the CCVI has a limited ability to detect indirect effects of climate change, such as through mutualisms and pollinator and prey diversity, and the effects of projected increases in stochastic events (Sperry and Hayden 2011). A more in-depth analysis into indirect effects of, for example, climate-induced alterations in human land use, changes in disease transmission patterns, and shifts in the population dynamics of natural enemies or invasive species (Bellard et al. 2012), is beyond the scope of a tool designed to rapidly assess large numbers of species.

Future Improvements

The survey results highlight several areas for future improvement to the CCVI, which we summarize here. First, for migratory species the tool should provide a way to incorporate consideration for climate exposure in life-cycle stages that occur outside of the assessment area. One approach would be to overlay the distribution of the species during the season it does not inhabit the assessment area on a climate exposure map to obtain a value for that season's climate exposure and combine this with the exposure value for the assessment area. A challenge is that often the destination of a migratory species is not precisely known. Second, a consideration of the climate sensitivity of plant species that form microhabitats required by other species is needed. Third, the description of the generic interspecific interaction factor should be clarified to allow consideration of the effects of climate on diseases, parasites, and natural enemies on the assessed species. With the rate of climate warming accelerating (IPCC 2013), improving vulnerability assessment tools, such as the CCVI, will be critical to supporting practitioners charged with managing natural resources in this rapidly changing environment.

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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.

I. Survey (questions posed to users of the Climate Change Vulnerability Index).

II. Additional discussion of Climate Change Vulnerability Index use.