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Research article

Capturing subregional variability in regional-scale climate change vulnerability assessments of natural resources

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A B S T R A C T

Natural resource vulnerability to climate change can depend on the climatology and ecological conditions at a particular site. Here we present a conceptual framework for incorporating spatial variability in natural resource vulnerability to climate change in a regional-scale assessment. The framework was implemented in the first regional-scale vulnerability assessment conducted by the US Forest Service. During this assessment, five subregional workshops were held to capture variability in vulnerability and to develop adaptation tactics. At each workshop, participants answered a questionnaire to: 1) identify species, resources, or other information missing from the regional assessment, and 2) describe subregional vulnerability to climate change. Workshop participants divided into six resource groups; here we focus on wildlife resources. Participants identified information missing from the regional assessment and multiple instances of subregional variability in climate change vulnerability. We provide recommendations for improving the process of capturing subregional variability in a regional vulnerability assessment. We propose a revised conceptual framework structured around pathways of climate influence, each with separate rankings for exposure, sensitivity, and adaptive capacity. These revisions allow for a quantitative ranking of species, pathways, exposure, sensitivity, and adaptive capacity across subregions. Rankings can be used to direct the development and implementation of future regional research and monitoring programs. The revised conceptual framework is equally applicable as a stand-alone model for assessing climate change vulnerability and as a nested model within a regional assessment for capturing subregional variability in vulnerability.

1. Introduction

Global mean annual temperature has increased by 0.8 °C since 1880 (Walsh et al., 2014), and future warming is almost certain (IPCC, 2013). Although historical precipitation trends vary spatially (IPCC, 2013), declines in regional streamflows have been well documented (Fu et al., 2010; Luce and Holden, 2009; Rood et al., 2005). Understanding how these temperature and precipitation changes will affect natural resources, and developing management plans that address these changes, is a primary focus of federal natural resource agencies in the United States (National Park Service, 2010; USDA Forest Service, 2008). Developing such management plans requires projecting future climate conditions and understanding how climate can influence natural resources. Climate change vulnerability assessments (CCVAs) provide a framework for achieving this understanding.

For the United States Forest Service (USFS), CCVAs fulfill several purposes. They provide a framework for synthesizing projections of future climate conditions, assessing known sensitivities of species or resources to direct and indirect effects of climate change, developing potential management strategies and tactics for adapting to climate change, and monitoring the outcomes of those actions (Peterson et al., 2011). CCVAs can also help ensure that stated agency or organizational goals can continue to be met under changing climate conditions (Julius et al., 2008), and that they fulfill

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federally mandated requirements to address climate change impacts within the agency (USDA Forest Service, 2008).

Across the United States, the USFS has to date conducted multiple CCVAs (EcoAdapt, 2014; Halofsky et al., 2011; Raymond et al., 2014; Swanston et al., 2011). These assessments focused on relatively small regions and included one to four National Forests or National Parks (e.g., Olympic National Forest and Olympic National Park, WA (Halofsky et al., 2011); northern Wisconsin (Swanston et al., 2011); the Nez Perce-Clearwater National Forest, ID (EcoAdapt, 2014); and the North Cascades Range, WA (Raymond et al., 2014)).

An alternative to multiple CCVAs, each focused on a small area, is a regional CCVA, which can include multiple land management agencies and cover many management units. Conducting regional-scale CCVAs offers several advantages. A regional CCVA may provide a better match to the scale of species distributions and the scale at which ecological processes (e.g. dispersal) operate. Another advantage is the increased potential for collaboration across administrative boundaries, which rarely have ecological relevance. Collaborating across boundaries allows the development of local management options that are coordinated over a larger region (Joyce et al., 2008; Littell et al., 2010). For example, from a local perspective a species undergoing a range shift may look like extirpation, but from a regional perspective such change can be seen as a range expansion and an opportunity for collaboration (Stephenson and Millar, 2012). Finally, organizing and conducting one regional CCVA may be more efficient than conducting multiple smaller CCVAs.

Regional CCVAs can provide a starting point for developing a portfolio of management strategies coordinated across ecological and administrative boundaries. Comparing and contrasting climate change vulnerability across subregions can aid in developing adaptive monitoring and research programs (Lindenmayer and Likens, 2009) based on hypotheses describing those vulnerabilities (Nichols and Williams, 2006). Thus, regional CCVAs offer significant advantages for large land management agencies such as the USFS.

However, there are important challenges of selecting appropriate species or resources and capturing subregional variability in vulnerability in regional CCVAs that are not present in CCVAs of smaller regions. Because of their extent, regional CCVAs can span a range of environments and habitats, include more species and populations, and involve potentially differing management objectives and priorities. These issues may lead to concerns about the quality and usefulness of regional CCVAs, yet to date no research has evaluated ways to address these concerns. We are unaware of an assessment that attempted to cover a large, climatically and ecologically diverse area, provide a summary of natural resource vulnerability across the region as a whole, and incorporate variability in natural resource vulnerability with subregions.

In this paper, we present a framework for capturing subregional variability in climate change vulnerability in a regional CCVA. First, we describe the framework as implemented in the first regional CCVA conducted by the USFS and partner agencies and organizations. Second, we summarize the results of implementing the framework for wildlife resources, evaluate the evidence for subregional variability in vulnerability to climate change, and evaluate the ability of our framework to characterize subregional variability. Finally, we recommend how the process can be improved. Although we focus on wildlife vulnerability, we provide examples of how this approach can be applied to other natural resources as well.

2. Methods

2.1. The regional CCVA

The Northern Rockies Adaptation Partnership (NRAP) was the first regional CCVA led by the USFS (http://adaptationpartners.org/nrap). The two primary objectives of NRAP were to synthesize the best available scientific information to assess climate change vulnerability, and develop adaption options. The NRAP geographic area covers 15 national forests and three national parks in the USFS Northern Region, which includes the northern panhandle portion of Idaho, all of Montana, portions of North and South Dakota, and the Greater Yellowstone Area of Montana, Wyoming, and Idaho (Fig. 1). Because this region encompasses a wide range of climatological, topographic, and ecological variability, five subregions were delineated: West, Central, East, Greater Yellowstone Area (GYA), and Grassland (Fig. 1).

The process of conducting the NRAP CCVA (Fig. 2) included a combination of regional leadership and local science-management partnerships. This process has been successfully implemented in several previous CCVAs (Halofsky et al., 2011; Littell et al., 2012; Raymond et al., 2013, 2014), without the inclusion of subregions. A regional level leadership team organized the assessment and compiled a first draft. The assessment covered eight resource categories (water resources, fisheries, wildlife, forested vegetation, non-forested vegetation, ecological disturbance, recreation, and ecosystem services), plus a section describing projected future climate conditions. Regional-level scientists and managers selected specific resources to be covered and compiled a draft vulnerability assessment based on literature review. Workshops were held in October–November 2014 with scientists and managers in each of the five subregions to 1) capture subregional information and variability in vulnerability to climate change not addressed in the draft vulnerability assessment, and 2) develop adaptation strategies (general) and tactics (on-the-ground actions) for responding to projected effects of climate change. The regional leadership team reviewed and synthesized the information gathered from the workshops, then provided subregional participants the opportunity to review the assessment before final publication.

2.2. Framework for capturing subregional variability

We based our framework on the conceptual model of vulnerability to climate change described by the Intergovernmental Panel on Climate Change (IPCC, 2007) and recommended for application in natural resource CCVAs (Glick et al., 2011). In this model, the degree of change (exposure) and response to those changes (sensitivity) define potential impact. Impact together with the ability to alleviate or accommodate those impacts (adaptive capacity) defines vulnerability. We sought to capture subregional variability in vulnerability based on the expert opinions of subregional-level managers and scientists attending the workshops. The framework consisted of questions (Appendix A) to capture: 1) species, resources, or other information missing from the assessment (Questions 1 & 2); 2) subregional variability in sensitivity (Questions 3 & 5), exposure (Question 4), and adaptive capacity (Question 5), and; 3) additional information needed to either assess vulnerability or develop adaptation options (Question 6). In the results and discussion below, we focus on results from the wildlife resources groups.

3. Results and discussion

Across the five subregional workshops, there were four to nine participants in the wildlife resource group, excluding the discussion leader and note taker. The wildlife chapter lead author was the discussion leader at four of the five workshops, and the note taker was consistent at three of the five. In total, participants discussed 19 wildlife species (Table 1).

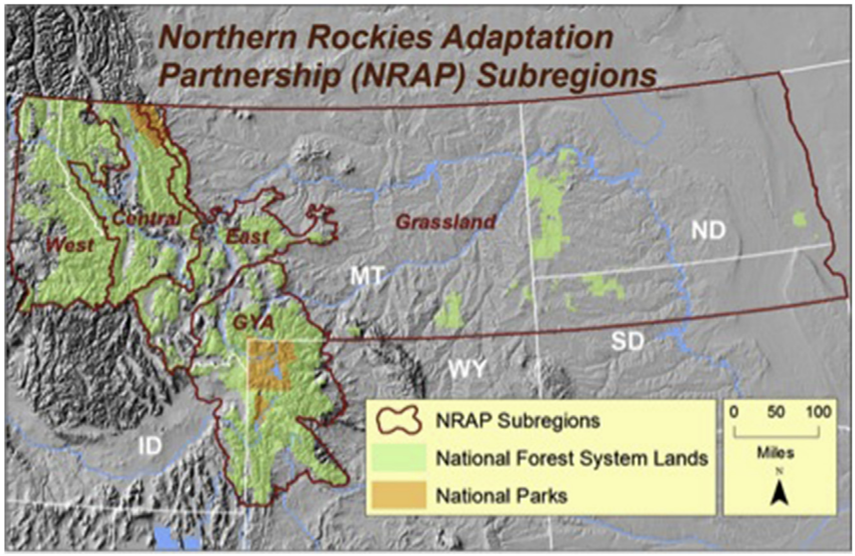

Fig. 1. Regional and subregional boundaries of the Northern Rockies Adaptation Partnership. Figure credit: Robert Norheim, USDA Forest Service.

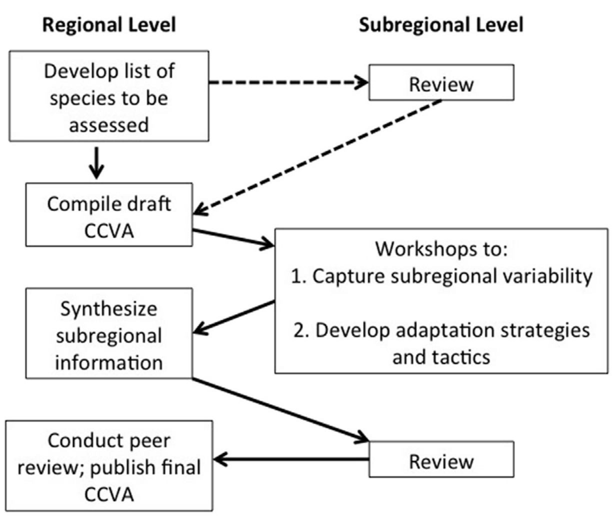

Fig. 2. Conceptual diagram illustrating the process of conducting a regional climate change vulnerability assessment. Solid arrows indicate workflows that occurred during the Northern Rockies Adaptation Partnership. Dashed arrows indicate workflows we recommend for future assessments. Regional personnel conducted tasks on the left, and tasks on the right occurred in subregions.

3.1. Information missing from the initial draft of the regional CCVA

At every workshop, wildlife resource participants recommended adding species that were important in their subregion but not included in the draft assessment (Table 1). Whether to include a suggested new species was decided based on consensus of the workshop participants in each subregion. Added species tended to be those that were seen as sensitive to some aspect of climate and for which participants saw viable management options. In some subregions, species included in the regional assessment were not discussed, even though present in the subregion, because participants saw no viable management options, because that species had been discussed at a previous workshop, or because they were seen as lower priority in that subregion.

3.2. Subregional variability in vulnerability

Because species were added at all workshops, there was not a common set of species to evaluate across all subregions. Additionally, participants did not always complete the entire questionnaire. Therefore, we were unable to rank species vulnerability across subregions.

Synthesis of workshop discussions revealed that participants tended to organize their thoughts according to what we termed “pathways of climate influence” (see below). Participants discussed how these pathways could interact with population characteristics (e.g., location in the species' environmental niche, population genetics, and population size; i.e. adaptive capacity) to ultimately affect the future state of a population (vulnerability). We found that a conceptual framework based on pathways of climate change (Fig. 3) was a useful way of assimilating participant responses and characterizing subregional variability. Initially, it was sometimes difficult to categorize a response as belonging to sensitivity, exposure, or adaptive capacity. However, when we reviewed responses in terms of climate influence pathways, defining exposure, sensitivity, and adaptive capacity was more intuitive.

3.2.1. Pathways of climate influence

We identified two broad categories of climate influence pathways: direct and indirect (Fig. 3). Direct pathways operate through species' physiological tolerance of temperature or moisture. Participants noted there was often little known about direct pathways. More commonly discussed in workshops were indirect pathways, in which climate conditions affect a component of a species' environment, which in turn affects that species. Each pathway had its own exposure, sensitivity, and adaptive capacity components. The relative importance of pathways, as determined by the number of times a pathway was discussed in a subregion, divided by the sum of times all pathways were discussed, differed across subregions (Fig. 4). A summary of specific discussions in NRAP about pathways of climate influence and affects on vulnerability, with examples from each subregion, is provided in Appendix B.

During our synthesis, we realized it was critical to clearly define each of the components of vulnerability within a pathway. We defined exposure as the changes an organism will face, through direct or indirect effects of climate change and sensitivity as the

Table 1
Species covered in the draft Northern Rockies Adaptation Partnership vulnerability assessment and discussed at subregional workshops. Note that not being discussed does not indicate absence from a subregion.

Habitat	Species	Regional draft	West[a]	Central[a]	East[a]	GYA[a]	Grassland[a]
Dry forest							
	Pygmy nuthatch (*Sitta pygmaea*)	X		X	X	X	
	Flammulated owl (*Otus flammeolus*)	X		X		X	
Riparian-wetland							
	Townsend's big-eared bat (*Corynorhinus townsendii*)			X	X	X	
	American beaver (*Castor Canadensis*)			X	X	X	
	Harlequin duck (*Histrionicus histrionicus*)			X		X	
	Northern bog lemming (*Synaptomys borealis*)					X	
	Moose: *Alces alces*					X	
	Boreal toad: *Bufo boreas*			X		X	
	Columbia spotted frog: *Rana luteiventris*			X		X	
Aspen							
	Cavity nesters			X	X	X	
	Ruffed grouse (*Bonasa umbellus*)					X	
Sagebrush grasslands							
	Greater sage-grouse (*Centrocercus urophasianus*)	X				X	X
	Pygmy rabbit (*Brachylagus idahoensis*)				X		
	Brewer's sparrow (*Spizella breweri*)					X	
	Pronghorn (*Antilocapra Americana*)					X	
Mountain grasslands							
	Mountain quail (*Oreortyx pictus*)		X				
Mesic old-growth forest							
	Fisher (*Martes pennant*)	X		X		X	
Snow-dependent species							
	American pika (*Ochotona princeps*)	X				X	
	Canada lynx (*Lynx Canadensis*)	X		X		X	
	Wolverine (*Gulo gulo*)	X		X		X	

[a] See Fig. 1 for subregional boundaries.

response to those changes (Glick et al., 2011). Adaptive capacity had two primary components, organismal and organizational. Organismal adaptive capacity included factors that were unlikely to vary across subregions, such as animal size and mobility, as well as factors that were more likely to vary across subregions, which participants termed current wildlife population characteristics. These characteristics included the position the population occupies in its environmental niche (e.g., at optimal conditions, or at marginal conditions), population size, and genetics structure. For example, species exist in different parts of their niches in each subregion: some are in the middle, but some are on the climatic

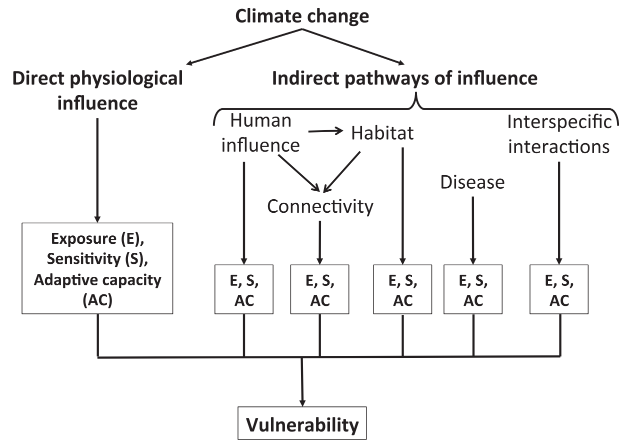

Fig. 3. Conceptual framework for assessing vulnerability to climate change that is based on pathways of climate influence. Each pathway is composed of its own exposure, sensitivity, and adaptive capacity components. Example, not exhaustive, indirect pathways are shown.

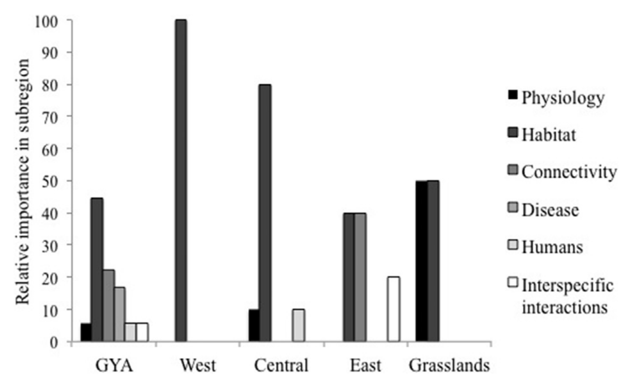

Fig. 4. Relative importance of climate influence pathways across subregions for the Northern Rockies Adaptation Partnership climate change vulnerability assessment. Importance was calculated by dividing the number of times a pathway was discussed by the total number of times all pathways were discussed. See Fig. 1 for subregional boundaries.

boundaries of their niche. Thus, similar exposure to physical climate change can lead to changes in habitat in one subregion but not another. Participants also discussed the influences of organizational adaptive capacity. Managers felt they had more options for implementing adaptation tactics when there were collaboratives, which included non-federal agency partners, in place. Greater capacity for implementing adaptation tactics influenced the perceived vulnerability in subregions.

3.3. Information needs

In most subregions, participants discussed the general lack of understanding of the specific mechanisms of direct climate sensitivity for many wildlife species and agreed that a better understanding was essential for both assessing vulnerability and developing adaptation options. Participants also identified multiple indirect pathways they saw as particularly important but not well understood. The lack of understanding of climate influences on disease occurrence and transmission was discussed in three of the five subregions. The influences of changes in water supply, habitat distribution, vegetation phenology, community composition, species interactions, and human development on connectivity and dispersal ability were identified as poorly understood processes in at least one subregion, but again, essential for assessing vulnerability and developing adaptation options. Finally, the need for coordinated monitoring of important wildlife resources was identified in three of the subregions.

4. Discussion

4.1. Framework evaluation

The questionnaire allowed us to address our three objectives of elucidating information missing in the draft CCVA, describing variability in vulnerability across subregions, and identifying information needed to better assess vulnerabilities and develop adaptation tactics. However, aspects of the questionnaire design limited its usefulness by not allowing for a quantitative comparison of vulnerability across subregions.

A primary result of working through the questionnaire was the identification of multiple species important in subregions that were not included in the regional draft assessment (Table 1). Vulnerability assessments for each of these additional species were included in the final NRAP assessment, making the product a more useful resource for users in all subregions.

Although the questionnaire allowed for open discussions, as originally intended, it limited our ability to make quantitative comparisons of species importance and vulnerability across subregions. A common set of species was not evaluated in all subregions. Therefore, a lack of recorded information did not necessarily indicate a lack of importance. Species were excluded from discussion because 1) they were added at subsequent workshops, 2) participants decided to discuss only those species for which they could identify viable management actions, or 3) they had been discussed in a previous workshop.

The structure of the questionnaire by exposure, sensitivity, and adaptive capacity did not fit well with participants' thinking about vulnerability. There were multiple instances of ambiguity and confusion among the meaning of the terms exposure, sensitivity, and adaptive capacity. Only after casting responses in terms of pathways of climate change were we able to categorize responses into exposure, sensitivity, and adaptive capacity and make quantitative comparison across subregions.

4.2. Recommendations

We developed a set of recommendations for improving the process of capturing subregional variability in wildlife vulnerability to climate change. We believe these recommendations will provide a better balance between open discussion and consistent, quantitative measures of subregional variability in climate change vulnerability.

4.2.1. Developing the species list

We recommend an initial list of species to be covered in the assessment be sent to the subregions for review well in advance of the workshops. Species can be selected for assessment because 1) there is prior information on climate sensitivities (Raymond et al., 2014), 2) they represent critical habitat types (Decker and Fink, 2014), 3) they are rare, endangered, hunted or otherwise important to people, or 4) there are viable management alternatives. These reasons may vary by subregion. Providing participants with an opportunity to comment on the species included before the workshops will ensure all subregions have the opportunity to discuss the same set of species and will allow more time for discussing subregional vulnerabilities during the workshops.

4.2.2. Revised conceptual framework for capturing subregional variability

Information from workshop discussions was more easily structured in terms of potential pathways of climate influence on habitats and species, rather than solely in terms of exposure, sensitivity, and adaptive capacity. We therefore developed a revised conceptual framework for capturing subregional variability that is structured around potential pathways of climate influence (Fig. 3). Each pathway allows for separate estimates of exposure, sensitivity, and adaptive capacity. Fig. 3 depicts the most common pathways discussed in the NRAP workshops, but is not a comprehensive list. Depending on the species, a single pathway may be comprised of multiple additional pathways.

We recommend the regional leadership team provide workshop participants with as complete a list of potential pathways as possible. Deciding on a final species list well in advance of the workshops (our first recommendation) would make this task easier. However, pathways will likely be added during workshops. We suggest including those in subsequent workshops, and if possible, having previous participants rank them as well. If that is not feasible, the regional leadership team could complete those rankings. To allow for quantitative comparisons across subregions, participants should be asked to complete a questionnaire for each species in the assessment and to record if a species is not present or a pathway is not applicable in that subregion. We provide a revised questionnaire example in Appendix C.

This structure allows for a quantitative ranking of species vulnerability across subregions. Separately ranking exposure, sensitivity, and adaptive capacity allows for a synthesis and ranking of the components of vulnerability across subregions. The species, pathway, and component rankings could then be mapped to provide a visual depiction of vulnerability across the region.

The revised framework can be applied to natural resources other than wildlife. For example, changes in temperature and precipitation can alter tree species composition, thereby changing competitive interactions. An assessment of ecosystem services may include a pathway of climate influences on economics. Specific pathways will vary by resource area and according to the ecological, climatological, social, and economic characteristics of the region.

The information we gathered depended on our choice of assessment process, the participants attending the workshop, and the questionnaire we used. Changes in any of these could yield different results. However, this is true for other approaches as well. For example, when Lankford et al. (2014) compared the Climate Sensitivity Database (http://climatechangesensitivity.org), the NatureServe Climate Change Vulnerability Index (http://www.natureserve.org/conservation-tools/climate-change-vulnerability-index), and the System for Assessing Vulnerability of Species (SAVS) to climate change (Bagne et al., 2011), they found little agreement in vulnerability rankings across assessments. Given the uncertainties highlighted at subregional workshops, these differences are not surprising. Importantly, the framework we developed differed from these indices in that its primary purpose was not to produce a single vulnerability metric, but rather to provide a structured approach for assessing vulnerability.

4.2.3. Future work

Our assessment did not seek to capture social vulnerability to climate change effects on natural resources. Participants readily detected subregional differences in natural resource vulnerabilities, and the importance of corresponding ecosystem services also varies subregionally. We therefore suggest that a useful next step will be to use the estimates of natural resource vulnerability from the NRAP process as estimates of exposure in an assessment of social vulnerability (Marshall et al., 2013).

In one assessment of social vulnerability, adaptive capacity had a strong influence on vulnerability (Marshall et al., 2013). We noted the difference in perception and influences of organismal versus organizational adaptive capacity within the NRAP vulnerability assessment. Further work evaluating the definitions and influences of forms of adaptive capacity would provide additional clarification to the assessment process.

5. Conclusions

Regional CCVAs provide an opportunity to elicit and synthesize our understanding of climate change vulnerability across diverse subregions. However, when a regional CCVA encompasses a broad range of climatological and ecological variability, it may be difficult to produce a useful assessment unless subregional variability is considered. We found multiple instances of subregional variability in vulnerability to climate change across the NRAP region. Our experience in NRAP workshops suggests that a conceptual framework structured around pathways of climate influence and population characteristics, with separate evaluations of exposure, sensitivity, and adaptive capacity within each pathway, is an intuitive way to capture subregional variability in a CCVA workshop. This framework is equally applicable as a stand-alone model for assessing climate change vulnerability and as a nested model within a regional assessment for capturing subregional variability in vulnerability.

The revised conceptual framework can be used as a foundation for designing future research and monitoring programs (Nichols and Williams, 2006), directly addressing the ubiquitous need for a better understanding of climate influences on natural resources. Focal species must be selected for research and monitoring, and the rankings of our revised framework would provide for an objective means of making those selections. Identifying and contrasting the importance of pathways of climate influence across subregions can suggest potential mechanisms of climate influence. Hypotheses can be developed to account for these mechanisms and management actions monitored to test those hypotheses. Based on the results of those tests, decisions can be made to continue with management actions, or develop new actions or hypotheses, creating an adaptive monitoring program (Lindenmayer and Likens, 2009). The assessment of adaptive capacity across the region can inform initial decisions of where to conduct research or management.

Capturing the subregional variability in vulnerability to climate change within a regional CCVA will make the product more useful to managers and scientists across the region. The process of conducting regional CCVAs will improve with repetition and with people sharing their experiences of what did and did not work well.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2015.12.017.

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