# Improving the Role of Vulnerability Assessments In Decision Support for Effective Climate Adaptation


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***Abstract:*** *Vulnerability assessments (VA) have been proposed as an initial step in a process to develop and implement adaptation management for climate change in forest ecosystems. Scientific understanding of the effects of climate change is an ever-accumulating knowledge base. Synthesizing information from this knowledge base in the context of our understanding of ecosystem responses to natural/historical climate can be challenging. Little attention has focused on how information gathered in the vulnerability assessment phase actively facilitates the implementation of adaptation actions, that is, how and whether VA outputs actually are being used in resource projects. Given that financial and staffing resources remain critical barriers for natural resource managers, the assessment of vulnerability needs to be an effective and efficient process. We explore the success of VAs in motivating implementation of adaptation practices and offer recommendations on the development of future vulnerability assessments in natural resource management. Implementation of adaptation options may be more closely related to the extent that the VA and associated processes provided an opportunity for social learning.*


## INTRODUCTION

The societal challenge associated with climate change involves not only improving our scientific understanding of the consequences of a changing climate but also communicating that understanding so that resource managers and the public can address the need for adaptation. The continually increasing additions of greenhouse gases to the atmosphere and concerns about consequent climate change have prompted resource managers to consider the need to include adaptation to climate change in the management of ecosystems (U.S. White House 2009; USDI 2009; USDA Forest Service 2012). Adaptation actions for ecosystem management on increasingly altered landscapes of the Anthropocene need a scientific basis (Peterson and other 2011). Initial motivation for understanding climate change began at the global scale (IPCC 1990), far from the scope of resource management; consequently developing adaptation options in resource management necessitates sifting through the accumulated knowledge and applying it to a finer spatial scale.

Adaptation actions also need to reflect the experiential knowledge that forest managers have gained from implementing management in site-specific locations. Initial attempts to communicate the scientific understanding of climate change used descriptions such as ‘novel’, i.e., unlike anything seen in the past; reinforcing a perspective that past and current experience with climate, weather, and forest resources would have little or no relevance to the future. Further, resource managers often were not a part of the conversation that scientists were having in the multi-decadal accumulation of climate change research (Powledge 2008). This lack of recognition and participation disrupted possibilities for mutual sharing of scientific knowledge and experiential knowledge on climate change effects and natural resource responses. Similarly, cultural and institutional differences among concerned groups (scientists, resource managers, diverse members of the public)—even the way language is used—have impeded effective integration of knowledge into climate adaptation projects. This has been problematic especially when efforts were done with limited participation by different interest groups.

Recent reviews suggest that while adaptation actions have been implemented, much is still to be done across federal, tribal, state, and local governments and the private sector in the United States (Ford and Pearce 2010; Bierbaum and others 2013). In a survey of natural resource managers in Colorado, Utah and Wyoming, only 5 percent of the respondents reported that adaptation plans were currently being implemented or carried out (Archie and others 2012). Across the public and private spectrum, Bierbaum and others (2013) noted that the greatest barriers to implementing adaptation actions were mainly lack of funding, policy and institutional constraints, and difficulty in anticipating climate change given the current state of information on change. The greatest barriers identified by federal resource managers in the Pacific Northwest were insufficient climate change impacts information at scales relevant to regional or local level management; insufficient financial and staff resources; and insufficient support and/or knowledge from stakeholder groups (Jantarasami and others 2010). Information barriers were identified as three of the top five barriers to adaptation planning reported by federal resource managers in Colorado, Wyoming and Utah: lack of information at relevant scales, lack of useful information, uncertainty in available information (Archie and others 2012). In a comparison of public lands managers and municipal officials, Archie and others (2014) found that lack of information at relevant scales was a much stronger barrier for federal management than for rural communities.

An early step in nearly all adaptation planning frameworks (NRC 2010; Bierbaum and others 2013) is the assessment of vulnerability. This step accumulates and synthesizes information to develop an understanding of the potential changes in climate and the potential impacts of these changes on natural resources and the human communities. A variety of qualitative and quantitative approaches are being taken to assess vulnerability and risks from climate change, including case studies and analogue analyses, scenario analyses, sensitivity analyses, formalized scenario planning, peer information sharing, and monitoring of key species and ecosystems (Bierbaum and others 2013). However, little attention has focused on how information gathered in the vulnerability assessment phase actively facilitates the implementation of adaptation actions (Archie and others 2014), that is, how and whether VA outputs actually are being used in resource projects. Given that financial and staffing resources remain critical barriers for natural resource managers, the assessment of vulnerability needs to be an effective and efficient process.

We explore the success of VAs in motivating implementation of adaptation practices and offer recommendations on the development of future vulnerability assessments in natural resource management.

### *Defining Vulnerability Assessments for Resource Management and for Climate Adaptation*

At this time, there is no standard definition of vulnerability with respect to climate change or a standard methodological approach for the vulnerability assessment of climate change (hereafter "VA") (Fussel and Klein 2006; USGCRP 2011). Vulnerability with respect to disaster is couched in the context of the social construct of individuals and communities, characteristics such as income level, race, ethnicity, health, language, literacy, and land-use patterns. In natural resources, vulnerability has typically focused on sensitivity of plants, animals, and terrestrial and aquatic ecosystems to climate and other stressors, their exposure to these stressors, and the corresponding implied impact on humans from the resource effect (Glick and others 2011; USGCRP 2011; Furniss and others 2013). In many of the existing assessments, the social and economic effects of climate are under-represented (USGCRP 2011).

Guidelines have been developed for stand-alone VAs using the exposure, sensitivity and adaptive capacity framework (Glick and others 2011; Furniss and others 2013) and for VAs that are embedded in broader adaptation planning efforts (Nitschke and Innes 2008; Peterson and others 2011; Swanston and others 2012). Both Glick and others (2011) and Peterson and others (2011) identify the first step as determining objectives and scope of the assessment (Table 1). Glick and others (2011) stress that the design and execution of an assessment must be based on a firm understanding of the user needs, the decision processes into which it will feed, and the availability of resources such as time, money, data, and expertise. To date, VAs in natural resources have been conducted as research studies (Hameed and others 2013), as stand-alone efforts (Coe and others 2012), or in science-management partnership settings (Swanston and others 2011). Goals of vulnerability assessments have been placed in the context of a larger adaptation planning effort (Raymond and others 2013; Swanston and Janowiak 2012) or as a single focused project related to an opportunity of the moment, funds or political will (Yuen and others 2013).

Gathering of relevant data and expertise, in particular to identify appropriate tools, is the second step in the VA process (Table 1). Relevant data are typically seen as scientific information or resource inventory information (Peterson and others 2011), and they can also include traditional knowledge (Laidler and others 2009), expert elicitation (Alessa and others 2008; McDaniels and others 2010; Moyle and others 2013), as well as the literature synthesis (for example, Johnston and others 2009; Lindner and others 2010; Erickson and others 2012). A wealth of quantitative tools has been developed and implemented either by the developer or a user (NatureServe tool: Young and others 2009, 2010, Amberg and others 2012, Wildlife Action Plan Team 2012; SAVs: Bagne and others 2011, Coe and others 2012, Bagne and Finch 2013, web-based tools: Treasure and others 2012; framework and tools: Swanston and Janowiak 2012; see also Table 2). In addition, assessments reports have been posted online by developers or accumulated on websites such as the State of California (http://www.dfg.ca.gov/Climate_and_Energy/Vulnerability_Assessments/).

**Table 1.** Key Steps for Assessing Vulnerability to Climate Change (from Glick and others 2011)

**Determine objectives and scope**
- Identify audience, user requirements, and needed products
- Engage key internal and external stakeholders
- Establish and agree on goals and objectives
- Identify suitable assessment targets
- Determine appropriate spatial and temporal scales
- Select assessment approach based on targets, user needs, and available resources

**Gather relevant data and expertise**
- Review existing literature on assessment targets and climate impacts
- Reach out to subject experts on target species or systems
- Obtain or develop climatic projections, focusing on ecologically relevant variables and suitable spatial and temporal scales
- Obtain or develop ecological response projections

**Assess components of vulnerability**
- Evaluate climate sensitivity of assessment targets
- Determine likely exposure of targets to climatic/ecological change
- Consider adaptive capacity of targets that can moderate potential impact
- Estimate overall vulnerability of targets
- Document level of confidence or uncertainty in assessments

**Apply assessment in adaptation planning**
- Explore why specific targets are vulnerable to inform possible adaptation responses
- Consider how targets might fare under various management and climatic scenarios
- Share assessment results with stakeholders and decision-makers
- Use results to advance development of adaptation strategies and plans

Vulnerability assessments can be qualitative or quantitative. This third step brings together the information developed and an understanding of confidence in this information (Table 1). Here also, the assessment begins to meld the understanding of vulnerability with the potential for adaptation. Stand-alone vulnerability assessments may complete the process with publication of results. Where the assessment is embedded in a broader adaptation planning process (step 4), the assessment can form the scientific basis for management actions under climate change. Too few examples exist to assess if stand-alone vulnerability assessments will be used in adaptation planning by land management agencies and clearly examples exist where the broader adaptation planning process has failed to develop adaptation actions (Yuen and others 2013). Extant VAs have been critiqued for a lack of clear definitions of vulnerability and adaptive capacity (ability to accommodate change; resilience), incomplete data or information, weakly described interactions between climate change and other stressors in the assessment, lack of tools to successfully prioritize among sensitive resources, and gaps in communication between experts conducting the assessment and the vulnerable groups (USGCRP 2011). Clearly, there is a need to establish a more rigorous link between information provided and information needed in the vulnerability assessment process.

**Table 2.** Vulnerability Assessments of species, habitats, and ecosystems in forested systems.

| Geographic focus | Participants | Methods | Science-management partnership | Adaptation actions identified or Opportunities for social learning outside of the assessment process | Citation |
|---|---|---|---|---|---|
| Arctic region | State and federal scientists | Used existing data and the Delphi method to develop an index of vulnerability; engaged local experts to rate the indicators. Conducted three case studies to get community feedback on the index | No | Proposed as a tool that Arctic communities can use to assess their relative vulnerability–resilience to changes in their water resources from a variety of biophysical and socioeconomic processes | Alessa and others 2008 |
| Canada's tree species | Federal and province scientists | Literature review, modeling exercise | No | Management options identified | Johnston and others 2009 |
| Bushfire vulnerability | Federal, non-governmental, and university researchers | Maps of relevant biophysical and socio-economic indicators to assess exposure, sensitivity and adaptive capacity | No | No adaptation actions identified in the study however results were later used by local governments in ICLEI's Adaptation Initiative Pilot Program which provided these governments with additional opportunities to strategize about adaptation; Workshop setting to present results of the assessment; initial reactions did expand the involvement of stakeholders in the project. Reports released to media | Preston and others 2009 |
| European forest ecosystems | University scientists | Summarizes the existing knowledge about observed and projected impacts of climate change on forests in Europe | No | No adaptation actions identified | Lindner and others 2010 |
| Northern Wisconsin ecosystems | Federal, state, and university scientists, National Forest managers | Literature review | Yes | Provided few options; however the assessment was a component of the Climate Change Response Framework Project which also compiles strategies and approaches for responding to climate change in forests, provides tools for climate adaptation planning. As part of the larger project, several boundary-spanning partnerships were initiated | Swanston and others 2011 |

| | | | | | |
|---|---|---|---|---|---|
| Wildlife and habitat, Massachusetts, Northeast states | Scientists and managers | Expert elicitation; index of vulnerability | Yes | Assessments were part of an effort to make “climate-smart” the northeast states’ existing State Wildlife Action Plan<br><br>http://www.mass.gov/eea/agencies/dfg/dfw/ | Galbraith 2011 |
| | | | | wildlife-habitat-conservation/climate-change-and-massachusetts-fish-and-wildlife.html | |
| | | | | Members of the MA assessment team worked with the State of Massachusetts to develop an adaptation plan that included natural ecosystems and this assessment information. | |
| Climate Change Vulnerability Assessment of Rare Plants in California | | NatureServe tool; 156 rare species in California; on-line excel spread sheets of data on each species; as well as word documents on each species. | Dept of Fish and Game project began in 2011. Project funding and oversight from U.S. Fish and Wildlife Service, and CA Landscape Conservation Cooperative | http://www.dfg.ca.gov/biogeodata/projects/climate.asp | |
| West Kootenay Climate Vulnerability and Resilience Project, Canada | Conservation scientists and managers | Bioclimatic modeling, literature synthesis, expert elicitation | Yes | VA part of a larger project and a later report (Pinnell and others 2012) takes Assessment results and considers practical applications. Results presented at a managers workshop. | Utzig and Holt 2012 |
| Pacific North-west forests | Scientists and Managers, FS and NPS | Educational workshops—Literature synthesis of climate change information, ecological models, Followed by workshops focused on developing adaptation options for hydrology and roads; vegetation, wildlife and habitat, fish and habitat | Yes | Development of adaptation options was integral part of this process. This work motivated NF staff to develop a tree species vulnerability assessment tool and apply to the National System Pacific NW Region. | Halofsky and others 2011 |

**Table 2.** *Continued.*

| Geographic focus | Participants | Methods | Science-management partnership | Adaptation actions identified or Opportunities for social learning outside of the assessment process | Citation |
|---|---|---|---|---|---|
| Pacific North-west tree species | National Forest System staff, State staff | Approach uses life history traits, distribution, and pest and pathogen data for individual tree species—combined with consensus regional climate projections—to rate each species' relative vulnerability. It does not include spatially explicit predictions. The model and data are available at: http://ecoshare.info/projects/ccft/ | No | Specific recommendations fall into three categories:<br>1. Learn about and track changes in plant communities as the climate changes<br>2. Maintain and increase biodiversity and increase resiliency<br>3. Prepare for the future | Aubry and others 2011, Devine and others 2012a,b |
| Wildlife and wildlife habitat, NV | | NatureServe Climate Change Vulnerability Index used to assess 300 species | | | Wildlife Action Plan Team. 2012 |
| Sky Islands, Coronado National Forest, AZ;<br>Fort Huachuca, AZ; Barry Goldwater Range, AZ;<br>Middle Rio Grande Bosque, NM | Federal scientists | Species Assessment Vulnerability (SAVs) tool to assess the vulnerability of vertebrate species; tool is on-line as are case studies: http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/ | No | Guidelines for using assessment results in adaptation planning given; no adaptation actions identified | Coe and others 2012, Bagne and others 2013 |
| Two National Forests and two National Parks in the North Cascades Range, Washington | Federal, state, and local resource managers, federal and university scientists, other user groups | Educational workshop; two-day workshops focused on hydrology, roads, and access; vegetation and ecological disturbances, wildlife and habitat, fish and habitat | Yes: North Cascadia Adaptation Partnership | VA imbedded in an adaptation planning exercise | Raymond and others 2013 |
| Point Reyes National Seashore | University scientists | Expert judgment, predictive vegetation mapping, predictive geophysical mapping, species-specific evaluations | No | No management actions identified; Engaged park managers in feedback twice over the development of the assessment using online survey where responses were anonymous | Hameed and others 2013 |

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### *Context and Priorities*

Who or what motivates the assessment influences the design of the assessment. Governments and institutions broadly mandate consideration of climate change and adaptation (U.S. White House 2009) but it is in the local or regional implementation that priorities and context are set. McCarthy and others (2010) stress the need to frame VAs by identifying key decisions that the assessment will inform, however many VAs have been conducted without consideration of context or use. Nearly all VA reports conclude that the results would assist in the prioritization of conservation or management priorities. However, the set of species, habitats, or ecosystems studied may be opportunistic for the scientist and of low priority for resource managers. For example, assessments often identify vulnerable landscapes where management is not possible (e.g., Wilderness) or where costs would be prohibitively great (suppressing wildfires in remote areas), or where priorities are very low compared to capacity to deal with the competing issues. In these cases, the VA may have little impact on adaptation, and the information is not actionable. To be useful to resource management, the context for the VA must be on species, habitats, or ecosystems that can be managed as part of agency mandates, or over which the institution can establish conservation priorities.

### *Goals*

From the outset, goals and objectives of the VA must be clearly identified, particularly in the context of agency or institutional structure (Glick and others 2011; McCarthy and others 2010). The scope and framing of these assessments, involving many partners from diverse backgrounds, may need to be negotiated, in that conflicting priorities, different world-views, and various degrees of technical understanding are the norm rather than the exception. What constitutes useful information may vary by stakeholder, but in general the more specific it is (e.g., in regard to location, project, resources, actions, costs, time required), the better. Further, initial goals may be revisited where funding is limited or new opportunities arise. For example, in the Western Port case study (AU), the initial goal was to assess both social and ecological consequences. However restriction of funding to human settlements led to a pragmatic decision to narrow the scope (Yuen and others 2013). Alternatively additional partners can bring in new skills and resources to expand the scope, as in the case of the North Cascadian Adaptation Partnership where two National Forests and two National Parks encompassed a geographic scope of over 2.4 million ha (Raymond and others 2013).

In that participants to a VA effort come from diverse backgrounds, Yuen and others (2013) suggest that vulnerability assessments can provide an opportunity for social learning so that collective action eventually can be taken to tackle a shared problem. Learning can be parsed into loops where single-loop learning entails technical changes to meet existing goals; second-loop learning involves reflection on current assumptions about goals/expectations; and triple-loop learning questions and potentially changes values and social structures that govern actions (Yuen and others 2013). In their review of vulnerability assessments, Yuen and others (2013) found that only single loop learning has been occurring in situations to date—i.e., adjustments and corrections of errors in current management practices. When natural resource managers were asked specifically about the hurdles associated with implementation of adaptation activities, lack of perceived importance to the public and lack of public awareness (or demand to take action) were among the top 3 hurdles, with budget constraints identified as the greatest hurdle (Archie 2013). Webb and others (2013) found that integrating biophysical and socio-economic assessments of vulnerability and directly incorporating stakeholders in adaptation identification and evaluation improves the efficacy of adaptation assessments in agricultural planning. Their process surfaces discordant views that may arise from differing management objectives among stakeholders, different adaptive capacity of the stakeholders, and different perceptions about the risk of climate change. Getting to adaptation actions will involve identifying and exercising opportunities to encourage second-loop and triple-loop learning during the vulnerability assessment process.

### *People*

The people involved in developing and using a VA ultimately determine the content and value of the end product. Scientists and resource managers have a role in ensuring that scientific information can be understood and applied in the context of specific assessments. Tapping into local and traditional knowledge can enhance scientific information (Fazey and others 2006). Stakeholders and decision-makers have long been recognized as important contributors to the VA (Schroter and others 2005; Turner and others 2003). Schroter and others (2005) defined stakeholders as people and organizations with specific interests in the evolution of specific human–environment systems. The increasingly altered landscapes of the Anthropocene may highlight a need to engage stakeholders more broadly in understanding the potential effects of climate change and of the Anthropocene, and to discern natural resource management decisions with respect to the evolution of these landscapes. Determining who 'should' be involved, how to identify who should be involved, and what processes to structure the interactions among these people are critical considerations.

Determining who to involve and how to identify people in the VA will be influenced by the scope of the VA and resources available. In addition to resource managers and providers of information, Glick and others (2011) included end users of resources/lands (e.g., hunters, birders, timber industry, oil and gas developers) and opinion leaders (influential and respected individuals within the region or sector of interest, members of special interest groups). Where the potential exists to plan and implement adaptation options, the stakeholder group expands to include the adaptation planners. Tompkins and others (2008) identified stakeholders in coastal management as those with a direct personal 'stake' or those with a role in governance of the resource and/or the area. In addition, those who are calling for the VA may also be important to include. Identification of individual people was an iterative process for Tompkins and others (2008), using published literature to identify expects, discussions with local councils and site visits by the research team.

How to involve people in the process can be as diverse as the VA topic. Engagement can be minimal where results are shared with the public to intensive where stakeholders become partners in the VA. Though VAs are a recent development, reviews suggest that it is important to evaluate the processes used to engage stakeholders. Insufficient discussion in VAs may limit the understanding gained through the VA to incremental solutions (Yuen and others 2013). Salter and others (2010) conclude that the stakeholder engagement must move from a transmissive or extractive model to co-development of knowledge in order to create socially robust solutions.

### *Science-Management Partnerships*

These formal or informal collaborations are an attempt to bridge the development of knowledge with the use of that information. These partnerships have been implemented in conservation (Moore and others 2012) and more recently in addressing climate change (Peterson and others 2011; Littell and others 2012; Neely 2013). These partnerships can range from informal agreements to work together, even as simple as a one-time consultation, to more formal structured agreements with advisory committees (Halofsky and others 2011a,b; Peterson and others 2011; Halofsky and others in press). Initial steps in the partnership involve establishing and agreeing on specific and realistic goals and objectives. Initiating the dialogue can be a challenge; opening the discussion with a series of questions facilitates participant identification of their observations of change as well as goals (Table; see also Gaines and others 2012).

Several factors are critical in the successful application of science-management partnerships. Clear goals and objectives, agreed on by all parties, must be established for the partnership at the outset of a project (Peterson and others 2011; Littell and others 2012; Halofsky and others in press). Useful goals and objectives are those that are specific to time period involved, location, resource conditions, and financing. Goals and objectives should be developed not only for the natural resources under consideration but for the VA process itself—e.g., goals for the roles and responsibilities of the various members and groups, the planning calendar, and the communication processes should be stated. This shared vision needs to be articulated early, often, and kept prominently in the conversation when working through difficult phases (Webb and others 2010). Engagement among the partners is critical (Webb and others 2010) as regular interaction between scientists and stakeholders shapes the ways that knowledge is produced as well as the usefulness as perceived by the stakeholders (Lemos and Morehouse 2005). Co-location of staff as well as continuity of staff can facilitate interactions (Lindenmayer and others 2013). The partnership must create formal opportunities for sharing information, such as in workshops and conferences; but also encourage flexible opportunities and space for regular information exchange between parties, including sharing of experiences, discussion of new ideas, and joint problem-solving (Webb and others 2010; Peterson and others 2011).

Each partner's knowledge and experience needs to be recognized and incorporated where relevant (Peterson and others 2011; Halofsky and others 2011a); in addition their current beliefs, values, institutional roles and responsibilities should be honored (Ogden and Innes 2009; Webb and others 2010). Lemos and Morehouse (2005) identified the importance of interdisciplinarity in integrated climate assessments, scientists from different disciplines working together, as these assessments represent problems that cannot be solved by any single discipline. Such an understanding contributes to building trust and support among the partners (Lindenmayer and others 2013). Further, where differences in background and cultural context exist, clarity in communication and adherence to neutral language becomes critical for ultimate success (e.g., explaining abbreviations and acronyms, defining technical terms and content, avoiding advocacy language).

Collaboration can offer the opportunity to actively work together to achieve things that could not be done alone, such as implementing large-scale monitoring of environmental flows (Webb and others 2010), or addressing resource management challenges across large landscapes (Raymond and others 2013). Close collaboration between the managers and scientists was seen as greatly increasing the likelihood that the research findings or scientific information identified in the process would be actively used to inform future decisions (Webb and others 2010; Raymond and others 2013; Lindenmayer and others 2013). In addition, Webb and others (2010) note that seeing research applied to practical management issues can be gratifying for scientists, and thus feeds back to motivate continued participation and learning.

### *Expert Elicitation*

Expert judgment has been incorporated into the VA as a way to gather critical data on vulnerability and as a step to begin the linkage with management. Hameed and others (2013) developed a multi-functional assessment approach; however they noted that expert judgment was the most widely applicable and flexible assessment method. Jung and Choi (2012) developed vulnerability indicators and their weights with respect to sensitivity, exposure and adaptive capacity for small rivers using a Delphi process. The Delphi method is an anonymous iterative survey that allows experts to see other views and can produce a converged opinion in a short period of time. Lemieux and Scott (2011) sought to identify and evaluate climate change adaptation options across the primary management areas of a protected area agency in Canada. They used a policy Delphi to uncover both consensus and disagreement, in contrast to the conventional Delphi, which explicitly seeks to create consensus. McDaniels and others (2010) linked the VA to an evaluation of potential management actions, where the vulnerability assessment information was provided to scientific and management experts who then were surveyed on the potential management actions.

### *Traditional Knowledge and Local Knowledge*

Vulnerability assessments can engage participants from the greater population beyond resource managers. When larger groups of stakeholders are involved, many different knowledge traditions emerge. Traditional ecological knowledge and local knowledge, for example by people who have lived and worked in rural communities for many years, are important to recognize. Laidler and others (2009) conducted a VA of Inuit vulnerability to sea ice change. Here indigenous knowledge, uses, and changes of sea ice from Inuit community were important perspectives in the dialogue with scientific information. This knowledge from the Inuit elders was formally cited in Laidler and others (2009) as contributions equally weighted and acknowledged as the academic sources. Science-management partnerships can facilitate this synthesis of local and traditional knowledge (Ogden and Innes 2009).

### *Stakeholders*

Identifying how to involve people in the assessment process is an important step. McCarthy and others (2010) recommended that a broad-based set of partners be engaged in the VA, noting that with more partners, the process could take longer to complete. However, the end result could be better buy-in over the long run. Critically, Yuen and others (2013) noted that when some stakeholders are excluded from the process, such as those with knowledge of bureaucracies, this could result in critical knowledge/information being omitted.

How the public is involved in the VA and how scientific information is brought into the VA can influence the receptivity of the assessment information. For example, detailed spatial metrics were used to visualize potential wildfire risk under climate change in communities surrounding

Sydney, Australia and captured the attention of stakeholders at workshops where the information was presented (Preston and others 2009). However, stakeholders were reluctant to embrace these representations of vulnerability as they differed from their own perceptions of hazard. Not until the stakeholders were able to translate these metrics into their own perception of risk, which involved more public dissemination of the information and a process of validation of the assessment results, could the information be taken up in local government risk assessment and adaptation planning.

### *Tools*

Tools that help the user focus on their specific resources, projects, and decision space will likely best assist them in developing adaptation options. A wide variety of tools have been developed to help structure the assessment of vulnerability for species, ecosystem processes, hydrological processes, and landscapes. Tools in this context can range from qualitative frameworks, such as the climate project screening tool (Morelli and others 2012) and decision-support flowcharts to quantitative climate and bioclimatic projections such as the Climate Wizard (Givertz and others 2009) and Tree Atlas (Prasad and others 2007). Selection of a tool should support the attainment of goals and objectives and produce actionable information. Importantly, the user should be aware of the tool's capacities and limitations, the inherent geographic and biological scope, capacity to include climate projections, handle uncertainty, and what expertise is needed to use the tool (Beardmore and Winder 2011; Wilsey and others 2013). Consulting with the developer about the use of a tool may facilitate a greater understanding on the tool's utility; this information is not always included in the user guide.

Stakeholder familiarity with the tools used in the vulnerability assessment can have an impact on the success of the projection. In Shire case study (AU), a participatory approach was used that engaged a diverse range of residents to contribute their knowledge of past climate-related events (flooding, fire) with the goal of using this experience to develop concrete solutions. Unfortunately, the project ran out of funding before concrete solutions could be identified and the local community was unsure of how to take the interviews and develop adaptation options (Yuen and others 2013).

Existing resource management tools, particularly ones that assess environmental risks, may overcome the need to learn new tools and offer an opportunity to incorporate climate change into the existing management practices ('main-streaming climate change considerations"). For example, through the science-management partnership on the Olympic National Forest, it was recognized that the current technique used to prioritize road maintenance could be enhanced with climate change information on increased risk of landslides and high intensity rainfall; thereby use an existing tool to evaluate increased risk associated with climate change (Halofsky and others 2011b). Modifying existing tools may also facilitate the comparison of climate change considerations with other non-climatic stressors or considerations.

### *Climate Projections for Vulnerability Assessments*

An estimate of the change in climate is a fundamental component of the VA. To date, estimates in VAs have used qualitative descriptions (e.g., hot/dry), synthesized summaries of detailed climatological studies (e.g., $4^{o}$ C increase in mean annual temperature), or a detailed suite of regional or locally downscaled climate projections. In literature reviews or where indices of vulnerability are generated, the projected climate is typically summarized as expected changes in mean temperature and precipitation (annual or season) based on climatological studies of the area of interest (Lindner and others 2010; Galbraith 2011; Bagne and Finch 2013; Gardali and others 2012). In assessments where quantitative ecological models are the tool for analysis, downscaled climate projections are drawn from web portals or other sources (for example, Maurer and others 2007; Climate Wizard: Girvetz and others 2009).

The choice of which scenario and how many climate projections to use vary widely across VAs, and usually reflect the availability of models and the experience of the VA participants. Preston and others (2009) used a single projection, the mean projected change in average maximum January temperature in 2030, based on 12 different climate models and different emission scenarios. US BOR (2011a) used the available suite of 112 downscaled climate projections to analyze river hydrology in western United States. The use of different scenarios and models makes it challenging to compare across VAs in terms of likely impact and appropriate management responses. In addition, Harding and others (2012) warn that no matter what the criteria, selection of only a few projections will inevitably produce a bias in the climate projected and in the vulnerabilities identified. In other words, the specific projections selected will not represent the entire uncertainty space of known climate projections, and the assessment could reflect a future climate characteristic of only a small range of potential future climates.

The estimate of climate change used in a VA must be vetted from two different perspectives. First, that estimate must be understood in the context of the uncertainty space of available climate projections. Second that estimate must be relevant to the ecological sensitivity of the ecosystem or natural resources studied in the VA. Rarely are these concerns identified as part of the selection of climate scenarios for use in a VA, often resulting in the use of projections as if they were actual predictions of future conditions. Even where they are identified, the ability to estimate ecological response to climate futures involves far more uncertainties than with physical parameters. Thus, "mis-matches" between the level of resolution and/or precision in a climate model often cannot be met in ecological understanding and management response.

**Table 3.** General Questions to Facilitate Initial Dialogues on Climate Change Adaptation. These questions are intended to establish the local management context, elicit overarching management responses to climate change, and promote mutual learning within the science-management partnership. Questions can be designed to accommodate local interests and preferences (from Peterson and others 2011).

- What are priorities for long-term resource management (e.g., 50 years)? How can climate change be integrated in planning at this time scale?
- What is the policy and regulatory environment in which management and planning are currently done?
- What are the biggest concerns and ecological/social sensitivities in a changing climate?
- Which management strategies can be used to adapt to potentially rapid change in climate and resource conditions?
- Which information and tools are needed to adequately address the questions above?
- Which aspects of the policy and regulatory environment affect (enable, inhibit) management that adapts to climate change?

The uncertainty space of climate projections encompasses underlying assumptions about future emission levels, the atmospheric physics captured in the model, and the nature of the downscaling techniques used to develop projections at the local scale of interest. Guidance on the use of scenarios recommends obtaining as many climate projections (models and emissions scenarios) as possible, often made more useful by an ensemble that characterizes consensus or variability among projections (IPCC-TGICA 2007; Mote and others 2011; Glick and others 2011). However, if resources are such that only a single estimate of change (e.g., qualitative) or a few projections can be used, then the estimate of change or the selected climate projection(s) should be explicitly presented in the context of the agreement (or disagreement) among multiple climate models on the projected change in temperature and precipitation for the region of interest. In other words, the VA must identify whether the future climate studied is warmer or wetter than the outputs of many climate models. This is clearly an area where more collaboration between climate scientists, natural resource scientists working on climate change, and resource managers is needed. The existing tools to establish the context for selected projections or even the estimate of change are very limited and require technical facility with large data sets.

The estimate of climate change, whether qualitative or quantative, must reflect the aspects of climate to which the natural resource is sensitive, as well as be relevant to the parameters of the specific ecological or physical resources being assessed. The objective of the VA is to discern the degree to which a system is susceptible to and unable to adjust to adverse effects of climate change. Climate variables that directly or indirectly affect the resource of interest may be known or can be identified using expert elicitation (McDaniels and others 2010), empirically (Walters and others 2013), or through the use of a conceptual model (Snover and others 2013). The VA should then explore a range of estimates or the outputs from multiple climate models so that the climate-related uncertainty is translated into the dynamic responses of the natural resource. This is also an area where more collaboration between climate scientists, natural resource scientists working on climate change, and resource managers is needed. Uncertainties need to be clearly communicated by authors of climate projections to resource managers to ensure that development of subsequent adaptation practices will correctly accommodate the inherent variances.

## CHALLENGES AND OPPORTUNITIES FOR EFFECTIVE VULNERABILITY ASSESSMENTS

### *Lack of Vulnerability Science Relevant to Management*

Another possible reason why adaptation actions are not considered within the VA process is that the current wealth of scientific information on climate change focuses on impacts. Few established scientific fields explore scientific questions in the context of management (Jacobson and others 2013). Further, climate change science developed at scales far from the resource manager's decision space. Consequently at this time, very little climate change research focuses on the interactions of climate change/impacts and resource management or the effectiveness of management actions assisting in the adaptation or mitigation of climate change. Hence, the literature available to synthesize in the VA focuses on impacts and may have little or no bridge to resource management.

In most research fields related to natural resource management, the connections between resource manager and scientist in the past and at times now, were facilitated by a long-term partnership where the objectives/design of research were established collaboratively (McKinley and others

2012). In this relationship, the scientific understanding of forest was matched by the manager's experiential knowledge of implementing treatments on a particular landscape. Over time, for a variety of reasons, this close working relationship weakened. As scientific fields developed with their own standards for credibility, management and research separated further. For climate change research, there was never really a link with on-the-ground managers from the very start. This has made the link to on-the-ground challenging. While there is currently limited literature to glean in a VA about successful adaptation options, this lack of available information could be remedied by the recognition of experiential knowledge and a more cohesive effort among scientists and forest managers in the VA process.

Further, communication and translation of scientific knowledge is often limited to journal publications and/or online information and may not be effective in fostering an understanding of vulnerability, or facilitating implementation of adaptation actions. This situation has been described as the 'loading dock' problem, where scientific information is 'dropped on the loading dock' with no further discussion on use or implementation, resulting in manager's lack of understanding on how or what to use or concluding that the information is unrelated to their priorities or work/process/schedule (Cash and others 2006). Publishing only in scholarly journals that have peer science readers continues to promote science developing along the lines of what the scientist considers as important, which is not always what management sees as important. In the end, the scientific information is not useable (Dilling and Lemos 2011). This also could be remedied by a more cohesive effort among scientists and managers in the vulnerability assessment process.

### *Focus of Assessments*

Most VAs are narrowly focused—typically on species, habitats, and in some cases, ecosystems and watersheds. While this narrow focus facilitates attention to some details, resource management encompasses many objectives and the entire physical, biological, and often also the relevant social system. This narrow focus presents challenges and limitations; scientists and resource managers know these challenges from past experience. As in the context of population viability assessments (PVA) and endangered species assessments (ESA), the fine-scale nature of assessing species or ecotype vulnerabilities can result in a situation of seemingly infinite needs. Cumulative effects and relative priorities must be considered during assessment. In the ESA context, the coarse-filter/fine-filter approach was developed, where coarse filter evaluations address general problems and umbrella solutions, while the fine filter focused on those few specifics that were urgent and addressable. The structure of current VAs seems to suffer similarly, in that coarse filter aspects have not been as much in focus as ecological specifics (fine filter).

An alternative or complementary approach is to focus on geophysical analyses of land and water to identify places of ecological resilience and biodiversity (Anderson and Ferree 2010; Beier and Brost 2010). In this approach, land characteristics are the focus with the assumption that a full spectra of physical stages or facets offer many microclimates and refugia for species and processes under a changing climate.

Including social indicators in VAs is important yet to date little integrated. Potential impacts to ecosystem services, availability of alternative resources, and resilience of rural and urban communities to change are as important to assessments as understanding ecological and physical dynamics. As the magnitude of climate change accumulates, natural resources will increasingly reach tipping points where major shifts in state become inevitable. These must be planned for and met on the social side, where expectations of continuing flows of goods and services in perpetuity remain the norm.

### *Baselines for Evaluations*

All VAs have a temporal baseline for evaluating the effects of climate change—it is either implicit or, better, explicit. The temporal baseline can be implicit in tools where literature is synthesized. Here the temporal period reflects the current state of knowledge, likely based on current dynamics of a species or ecosystem in recent historical conditions. Alternatively, many VAs have used specific historical conditions from observations as a baseline for evaluating change and sensitivity. In broad terms there are two categories of historical period that have been used as baselines or visions of healthy systems relevant to anthropogenic climate change. First is the recent past, e.g., the last 4-5 decades, which is a period of readily available observational data. Since the 1980s, temperature has been warming in most areas of the United States, such that there can be a distinct temperature signal in periods after 1980s but not necessarily before. Such a short time, however, captures little of the natural variability in Earth's climate system, and thus provides a very short-sighted view of change. Further, observational monitoring stations are often located in lowland areas, far removed from mountain and wildland situations of natural resource focus, making their relevance to VAs questionable.

McWethy and others (2010) stress that 'the last century is an inadequate reference period for considering future climate change because it does not capture the range of natural climate variability that vegetation responds to or the magnitude of climate change projected for the near future.' To this end, ecologists have also long used deeper baselines as references for evaluating vulnerability and assessing health of ecosystems. This is known as the historical range of variability (HRV) approach to characterizing dynamics of ecosystems. In these cases, long-term historic climate reconstructions, such as from tree-rings and sediment cores provide information about conditions over hundreds to thousands of years in the past. While this information is useful for informing scientists and managers about patterns and pace of natural climatic variability and ecosystem response, using HRV as a baseline for evaluating current health, or as targets for future ecosystem conditions is usually inappropriate. Changing climates over time means that the past does not resemble the present or future and that historic ecosystems adapted to different climate conditions than present climate (Jackson 2013; Millar 2014). Static views of ecological dynamics can hamper VAs and potentially lead to prescription of management treatments less effective for future conditions, such as prescriptions for reforestation that assume the same mix of species as in the past century will be adaptive in the future.

The use of historic conditions, thus, either the recent past (20$^{th}$ Century) or deeper time can be useful for understanding ecosystem dynamics, but also can hamper understanding of current and future vulnerability. The distinction between these roles for historic information must be clarified to all stakeholders at the onset of the evaluation process.

Pertaining to baselines also is the time horizon used in VAs for the future. The time span of ecological relevance often does not parallel institutional realities. In that climate projections often estimate conditions decades ahead (e.g., 2100), agency planning processes at best focus on 10-20 year futures, while budget cycles are predominantly annual. A partial solution is for VAs to project outcomes at multiple temporal scales: detailed conditions for the near term (e.g., 1-5 years), and increasingly coarse detail at middle (10-20) and long (many decades) terms. This approach resembles the coarse-filter/fine filter but in a temporal context. Another issue regarding time that hasn't been adequately addressed relates to when in the adaptive management cycle a new VA is called for. This may be prescribed by official direction (e.g., as part of a formal national forest plan revision), or in response to natural-resource conditions. For instance, if changes in resources occurred more rapidly or in ways or magnitude not anticipated, a new VA would be appropriately undertaken.

### *Evaluating Uncertainty and Risk; Anticipating Surprises*

Increasingly, VAs are attempting to capture uncertainty in some manner, even if only an acknowledgement of the nature of how uncertainty creeps into the quantitative analysis (US BOR 2011a,b), or where uncertainty reflects a consensus or lack of consensus in the scientific literature or a group of experts (Galbraith 2011; Bagne and others 2011). Even with these caveats, the assessment still provides a seemingly black and white picture of the future.

Most of the VAs tools currently available do not incorporate the potential for surprise, or even for reflection of surprise. Yet surprises have become an increasing result in the climate science literature; the rate of melting in the Arctic faster than climate models projected (Stroeve and others 2007), the counter-to-expectation downhill shifts in plant species as they tracked regional changes in water balance rather than temperature (Crimmins and others 2011); identification of highly vulnerable species that are not yet conservation concerns (Foden and others 2013), acute cold stress to montane mammals in winter from loss of insulating snowpacks (Beever and others 2010). Warming winter air temperatures in eastern US result in cooling soil temperatures, as snow depth changes and, under continued climate change, increased soil freezing, that will likely affect soil organisms (Groffman and others 2012) and could exacerbate soil cation imbalances already caused by acidic deposition (Comerford and others 2013). Invasive species might become key ecosystem drivers under future climates; however it is exceedingly difficult to project their behavior because their processes in the exotic landscapes are likely very different from life-history expectations in their native habitat.

How is it possible to anticipate surprises in VAs? Some of the unknowns can, in fact, become known-unknowns. Climate models often project changes, usually statistical probabilities, in frequency of extreme events, for instance, such as severe floods (Dettinger and others 2011), hurricanes (Webster and others 2005), and extreme heat waves (Meehl and Tebaldi 2004). In other situations, understanding of past natural conditions and ecological, both paleohistoric and recent history, can provide insight into the nature of infrequent disturbances, unusual combinations of conditions (e.g., unseasonal fires), or surprising ecological responses. Reviewing the historic literature prior to a VA and interviewing people with local experience over long times can help to identify potential unexpected vulnerabilities.

### *Resistance Strategies; Need for Strategies to Assist Transitions*

Many VAs continue to recommend climate-resistance actions that prescribe "paddling upstream treatments" (Millar and others 2007). These derive from the desire to maintain status quo or historic baselines. In many cases these result in efforts to enforce and restore conditions that are no longer what the land/climate can uphold naturally (i.e., conditions have changed). In the Sierra Nevada of California, for example, attempts are made routinely by land managers to maintain mountain meadows free of invading conifers by cutting seedlings. Although past human uses sometimes interact, studies clarify that climate is the main regional driver of ongoing conversions of meadows to forest in this region (Millar and others 2004). Consequently, increasingly aggressive effort is required to enforce the prescriptions, and, as climate trajectories proceed, success becomes increasingly unlikely.

Another example from the Great Basin is the concerted efforts underway by public land managers to remove pinyon pine and juniper recruitment into sage steppe ecosystems. Again, while historic suppression of fire and livestock grazing (including invasives) interacts, climate is a major force driving the conversions from sage steppe to pinyon-juniper woodlands in the northern Great Basin (Lanner and Frazier 2011). Efforts to remove—either manually or with managed fire—are unlikely to keep up with extensive force of the natural reproduction.

## PUTTING VULNERABILITY ASSESSMENTS TO WORK—THE WAY FORWARD

### *Collective Learning*

Absorbing the current information on climate change is a challenging task for scientists who have had some link to this accumulating body of knowledge. Articulating the changes on the landscape as resource managers have seen them is a critical step in applying the current knowledge about how climate change will affect plants, animals, and ecosystems. It is the dialogue between these two knowledge systems that is fundamental in extending this knowledge to adaptation. Science-management partnerships can provide the setting for a two-way learning so that the current understandings about the impacts of climate change can be brought into the conversation. Further, the experience and practice of management can focus that understanding on how humans influence the environment as they attain ecosystem services. This two-way learning is a critical step in producing actionable information.

Completion of an assessment does not guarantee that a decision on adaptation is ready to be made. Implementation of actionable information likely needs the engagement of the public and decision makers in the vulnerability assessment or as part of the adaptation process. The nature of their engagement can be as participants in the vulnerability assessment (participatory research) or as part of the effort to determine scope, targets, and next steps on adaptation. Collective learning, information that emerges from experience and/or human interaction during which people's different goals, values, knowledge, and point of view are made explicit and questioned to accommodate conflicts, is the basis for identifying the collective action to tackle a shared problem (Yuen and others 2013). The challenge for vulnerability assessments and the larger effort developing and implementing adaptation actions is how to incorporate opportunities where the underlying ecological and social assumptions about resource production and management can be surfaced (second and third loop learning). The actual implementation of adaptation options may be more closely related to the extent that the VA and associated processes provide an opportunity for such social learning and through that learning, the identification of collective actions that the stakeholders and institutions can take.

### *Case Studies Examples*

Case studies help to communicate model processes and highlight successful (and sometimes not) actions; Table 2 compiles a set of recent projects. Case studies where multiple site-specific assessments are on-going can serve as peer learning on data sources and techniques to assess vulnerability, as in the Watershed Vulnerability Assessments project where assessments were being completed on each of the 11 National Forests (Furniss and others 2013). Case studies also serve to engage participants who may then go on to implement the same type of VA or a modification of the VA, as in the Pacific Northwest example below. Reflections after a series of case studies offer the opportunity to evaluate what worked well and what did not, as was done after the Four Corners Assessments by The Nature Conservancy (McCarthy and others 2010).

In Massachusetts, expert elicitation was used to refine an initial assessment of habitats developed by scientists; scientists and resource experts were engaged in the process through a series of meetings and discussions (Galbraith and Price 2009; Galbraith 2011, see also Table 2). Findings from the habitat vulnerability report were also used in the Climate Change Adaptation Report for the State of Massachusetts (http://www.mass.gov/eea/air-water-climate-change/climate-change/climate-change-adaptation-report.html). In addition, the Massachusetts model served as a springboard to expanding the model to the entire Northeast area (Manomet Center for Conservation Sciences and National Wildlife Federation, 2012), and served as a template for a vulnerability assessment on the Badlands National Park (Amberg and others 2012).

In Halofsky and others (2011b), a workshop series approach was employed where the objective was to develop adaptation options for federal lands on the Olympic Peninsula. The framework consisted of sessions on climate change impacts and then sessions on management options for specific resource areas, such as hydrology and roads, fisheries, vegetation, and wildlife. Here the assessment of vulnerability involved meetings with managers from the Olympic National Forest and National Park and research scientists from the USFS and the University of Washington. In addition literature and available modeling output were synthesized and provided to the participants. Even though these sessions provided the opportunity for dialogue, some topics were more successful in terms of getting to actions that linked climate change with resource management on the ground. For the hydrology and roads topic, the interaction allowed resource managers to share their road management strategy and the tools associated with that strategy. With this understanding, scientists could identify how to add quantitative information on climate change. While the vegetation session might not have developed as concrete a set of climate adaptation actions, NF staffs were motivated to build on the work of Halofsky and others (2011b) and develop an assessment tool and conduct a VA more narrowly focused on tree species (Aubry and others 2011; Devine and others 2012a, 2012b). In this later effort conducted primarily by NF staff, adaptation options were developed with focused guidance for on-the-ground management of individual tree species. Opportunities for others to learn from these efforts can also result when such literature is recommended as reading for vulnerability/adaptation workshops [EcoAdapt, 2013, http://ecoadapt.org/workshops/sierra-nevada-adaptation-workshop identified recommended readings (Halofsky and others 2011a; Peterson and others 2011) for their workshop participants].

### *Embedded Vulnerability Assessments*

To be most effective in implementing adaptation actions, VAs should be embedded in adaptation planning, and those embedded in general land and water management plans. If, as the literature repeatedly emphasizes, resource management will need to change in response to a changing climate, then VAs need to bring in how management is currently implemented and examine how the vulnerabilities of the socio-ecological system will be mitigated by resource management. Without the firm goal of developing adaptation to climate change guiding the VA, these efforts may serve the purpose of synthesizing the literature or quantifying the effects of climate change but fall short of facilitating adaptation planning or putting actions onto the ground. A question for reflection at the start of the VA might be: Will the information gathered be sufficient to change management?

A simple approach to evaluate the need for change in management prescriptions is the climate project screening tool (CPST; Morelli and others 2012). The CPST provides thought-cues for evaluating whether a project is likely to be influenced by changing climate, whether the existing project design adequately addresses those changes, whether modifications to the design need to be made prior to implementation, and whether the project should proceed to implementation or not. Boxes within the CPST form allow the specialist or deciding officer to document that appropriate considerations of various climate concerns have been made, and that evaluation to proceed as is, modify, postpone, or cancel a project has been made. The CPST review is best undertaken by a small group of specialists interacting in a science-management partnership. However it is adaptable, and can be used to assist a single specialist or a large team of peers in reviewing the climate vulnerability (or not) of projects, and thus to rank and prioritize them for funding and action.

Many currently identified adaptation actions build on current management experiences, often tied to current goals and objectives for management. Very little research has focused on testing the effectiveness of management under climate change. At this time, the dialogue between scientists and managers may be the first step in identifying potential interactions of current management and climate change effects. If different or novel ecosystem services become goals and objectives, then new management practices may be needed. Here is where scientist-management partnerships can make a significant contribution.

### *Transformative Change*

Transformative change at the societal level will require a larger understanding in society about the potential effects of climate change and of the Anthropocene—suggesting that VAs and adaptation planning consider the role and objective of social learning in these activities. In the Anthropocene, VAs will need to address the entire socio-ecological system—plants, animals, and human society. Vulnerability assessments need to bring into the assessment how management is currently implemented to deliver the current set of ecosystem services. Humans have the capacity to influence the physical, biological and ecological dynamics in local, regional and global environments. Assessing the vulnerability of plants, animals, ecosystems to climate change leaves out the expectations and influence of humans on how these environments are to be managed—critical information that managers and decision-makers will face to develop adaptation options. If adaptation to climate change requires societal transformative change, then scientists and managers will need to be engaging in testing adaptation practices in the field.

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