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# Expanding vulnerability assessment for public lands: The social complement to ecological approaches

Shannon M. McNeeley [a,*], Trevor L. Even [a], John B.M. Gioia [b], Corrine N. Knapp [c], Tyler A. Beeton [a]

[a] Colorado State University, North Central Climate Science Center, United States
[b] Western State Colorado University, United States
[c] Center for Environment & Sustainability, Western State Colorado University, United States

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ABSTRACT

In recent years, federal land management agencies in the United States have been tasked to consider climate change vulnerability and adaptation in their planning. Ecological vulnerability approaches have been the dominant framework, but these approaches have significant limitations for fully understanding vulnerability in complex social-ecological systems in and around multiple-use public lands. In this paper, we describe the context of United States federal public lands management with an emphasis on the Bureau of Land Management to highlight this unique decision-making context. We then assess the strengths and weaknesses of an ecological vulnerability approach for informing decision-making. Next, we review social vulnerability methods in the context of public lands to demonstrate what these approaches can contribute to our understanding of vulnerability, as well as their strengths and weaknesses. Finally, we suggest some key design principles for integrated social-ecological vulnerability assessments considering the context of public lands management, the limits of ecological vulnerability assessment, and existing approaches to social vulnerability assessment. We argue for the necessity of including social vulnerability in a more integrated social-ecological approach in order to better inform climate change adaptation.



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* Corresponding author.
*E-mail address:* shannon.mcneeley@colostate.edu (S.M. McNeeley).

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## 1. Introduction

Recent and continuing changes in climate have resulted in alterations to both human and natural systems across the globe, necessitating adaptive measures by decision makers acting at all levels of socio-ecological systems (i.e., systems in which humans are interconnected to and dependent on natural systems) (Bierbaum et al., 2013; IPCC, 2014). In the United States, significant impacts from climate change have already been felt, and warming is projected to continue for the foreseeable future (Walsh et al., 2014). As a result, changes to natural resources and the social systems that rely upon them will continue through decreased snowpack and more rapid snowmelt, more pronounced drought impacts and variability in precipitation regimes, increased incidence of wildfire, longer but more variable growing seasons, and a variety of other factors (Melillo et al., 2014; Walsh et al., 2014). In the United States, the federal government has introduced several Executive and Secretarial Orders directing federal agencies to prepare for and adapt to climate change (e.g., EO 13514, 2009; EO 13653, 2013; EO 13693, 2015; DOI Order 3226, 2001; DOI Order 3289, 2009), and several states have taken similar actions (e.g., Colorado's House Bill 13-1293; Washington's Senate Bill 5560) (Colorado General Assembly, 2013; Washington, 2009). However, work within individual agencies to meet these mandates has been uneven at best, with significant work remaining to be done in assessing vulnerability and developing actionable adaptation plans at scales relevant to the wide variety of administrative domains at play in the complicated U.S. governance system (Bierbaum et al., 2014, 2013). Here we define "vulnerability" as the susceptibility of an individual, household, or community to suffer from the impacts of climate change, which is a function of their exposure to climate stress, their sensitivity to being affected by it, and their adaptive capacity to respond to or prepare for climate change (IPCC, 2014).

For the U.S. Bureau of Land Management (BLM), whose management mandate includes huge tracts of publicly-owned land in the Western U.S. and Alaska - and even more widespread mineral resources – efforts to plan for and adapt to climate change present a variety of complex challenges. The BLM mediates multiple land uses, including extraction and conservation, which requires managers to take into account both the needs and environmental impacts of a broad array of human activities. In particular, communities heavily invested in livestock ranching and outdoor recreational tourism depend on public lands for economic, social, and cultural well-being. At the same time, their uses impact the biophysical environment and ecosystem services (e.g., production of food and water, maintenance of nutrient cycles and pollination to crops, and recreational or spiritual benefits) that public lands agencies manage. Similarly, agency management decisions, in turn, impact human livelihood viability, both in the immediate and long-term (Kachergis et al., 2014).

Given these feedbacks between land-based livelihoods, ecosystems, and management, and the resulting impacts to the vulnerability and adaptive capacity of each (Kachergis et al., 2014), it has been noted at a variety of levels that there is a need to better understand the climate vulnerabilities of those individuals and communities that depend upon resources managed on public lands (Archie et al., 2012; DOI, 2014; Joyce et al., 2009). However, ecological vulnerability assessment has been the primary approach for assessing vulnerability and planning adaptation actions on public lands, despite a broad and growing body of research examining the complex economic and cultural ties between public lands and the human communities that rely upon them (e.g., Bates, 1993; Bergstrom, 2012; Dombeck et al., 2004; Eichman et al., 2010; McNeeley and Shulski, 2011; McNeeley, 2012; Loomis, 2013; Sheridan, 2007; Yung et al., 2010; Knapp et al., 2015). There has also been relatively little consideration of the unique context of the U.S. public lands management system in climate vulnerability research. While there have been a small set of reviews of social vulnerability methods in the context of public lands (Preston et al., 2011; Hinkel, 2011; Fischer et al., 2013; Murphy et al., 2015), a comprehensive argument for the importance of an integrated social-ecological approach in contrast with purely ecological vulnerability approaches has not been made, nor have key principles for such an integrated approach been identified. We argue for the necessity of including social vulnerability in a more integrated social-ecological approach in order to better inform climate change adaptation for public lands and natural resource management.

In this paper, we describe the context of public lands management with an emphasis on the Bureau of Land Management to highlight this unique decision-making context. We then assess the strengths and weaknesses of an exclusively ecological vulnerability assessment approach for informing decision-making. Next, we review social vulnerability methods in the context of public lands to demonstrate what these approaches can contribute to our understanding of vulnerability. Finally, we identify three key principles for this more integrated social-ecological approach that includes: 1) participatory stakeholder engagement, 2) consideration of institution-actor relationships, and 3) the integration of scientific with local knowledge.

## 2. Public lands management context

Nationwide, the federal government manages over 640 million acres of publicly owned lands, just under a third of the nation's total land surface. Of this, 440 million acres are managed by two distinct but often spatially adjacent agencies: the United States Forest Service (USFS) and the Bureau of Land Management (BLM) (Vincent et al., 2014). In this paper,

we focus primarily on the BLM, which relative to the USFS has received less attention in the climate change vulnerability literature.

The BLM manages for multiple use within different ecosystems, the majority of which are arid to semi-arid rangelands, grasslands, shrublands, and deserts (as compared to the primarily forested areas within the US Forest Service). These lands remained in the public domain due to repeated refusals or failures by either private individuals or states to take possession of these lands during the various waves of western expansion during the 19th and early 20th century, mainly due to their aridity and lower plant productivity (Wilson, 2014; Huntsinger et al., 2010; Steenburgh et al., 2013). Because of the relative marginality of these lands, the social and ecological systems that have developed alongside BLM managed lands are both diverse in character and highly variable within specific landscapes with mining, logging, livestock ranching, hunting, and recreational users all taking on roles of differing importance depending on local geology, geography, and vegetation (See Sayre et al., 2009). For example, in Colorado, livestock ranching, hunting, and oil and gas extraction dominate, while in Idaho and Oregon, logging of those areas' relatively more forested BLM lands plays a much more important role. As Sayre et al. (2012) note, however, even users within a given class can vary widely from place to place, with some public land livestock grazers entering into cooperative grazing agreements on public land tracts, others working within conservation programs to diversify income streams, and others utilizing complex, high-frequency livestock rotation schemes. As a result of historical climate variability, many of these systems are already highly-adapted to periodic droughts, wildfire, and a variety of climatic extremes. Yet, they face significant increased exposure to negative impacts from climate change – particularly, extended and severe droughts (and possible "mega-droughts"), changes in landscape composition, and the loss of winter snowpack – and are already undergoing ecological transformations from climate change in many areas, such as tree die offs in the watersheds that many public land ecosystems rely upon for streamflow in the western U.S. (Seager et al., 2007, 2012; Garfin et al., 2014; Mote et al., 2014).

Thousands of small, rural communities intermingle with the broader public lands system, which represents 80% of land ownership in western US states (Gorte et al., 2012). These communities, many of which include prominent livestock agriculture, hunting, fishing, and recreation sectors, rely on ecosystem services provided by public lands for both economic and cultural viability (Bates, 1993; Gentner and Tanaka, 2002; Brogden and Greenberg, 2003; Rasker, 2006). Because these various land-based livelihoods are exposed directly to climate stressors, climate change has the potential to reduce overall livelihood sustainability and degrade cultures that define western identity and place. However, social behavior – of government actors, private markets, or cultural advocacy groups – relating to climate change can also have major effects on the viability of land-based livelihoods, as their dependency upon public resources draws them into a nexus of numerous actors moving within systems at national and global scales. In both livestock ranching and outdoor recreation, direct feedbacks to and from ecosystems, in the form of availability and quality of ecosystem services, determine the viability of livelihoods. For example, if managed carefully, rangelands can maintain soils that consistently provide water filtration, carbon storage and sequestration, flood mitigation, and forage for wildlife and domestic livestock (Havstad et al., 2007). However, they are also highly vulnerable to poor management practices that could lead to degradation, loss of minerals, and poor water infiltration, vulnerability that is further exacerbated by climate exposures to drought or intense erosion episodes (Hatfield et al., 2014). Similarly, adequate snowpack, runoff, and healthy forests and wildflowers are ecosystem services that dictate the length of winter and summer tourism seasons, the success of nature-based festivals (i.e. wildflower festivals), and wildlife behavior during hunting seasons, all of which are critical to the success of outdoor recreation and tourism activities. These variables not only directly affect these ecosystem services, but also visitation patterns and broader-scale economics of the recreation industry (Jedd et al., 2015; Nelson et al., 2013). And, as with livestock grazing, poorly managed recreational activity can quickly diminish the quality of the landscapes on which they take place. As such, these livelihoods present both a serious challenge to climate adaptation planning as well as a significant opportunity for maintaining overall ecological resilience.

Multiple levels of federal governance across the broader BLM, ranging from field offices to legislative and executive policy makers in state and federal offices, create additional layers of complexity in planning for and implementing adaptation strategies. The utilization of specific grazing allotments, recreational permits, or other public land permits is directly contingent upon decisions made in places removed from the landscapes where public land users make their living. At the broadest level, federal and executive decisions can completely reshape usage constraints on large tracts of land (e.g. National Monument designation and funding of local departments). State level policies and resource economies can put public lands under increased pressure from private property markets, as in various efforts to cede control of public lands to state control (e.g. Keiter and Ruple, 2014). Local field office management priorities can limit flexibility for some users while providing proactive support to others based on their interpretation of top-down mandates or local stakeholder behavior (Loomis, 2013). At the same time, conflicts can arise between user groups themselves, as in cases where the externalities of one use type negatively impact the resource availability of others, or two or more uses of a given landscape are seen as mutually exclusive (Archie, 2014; Loomis, 2013). Examples of this include hunters who are impacted by the noise of off-road vehicle recreationists, or conflicts between wild horse management and livestock grazers over grazing management, and conservationists and logging communities who have different values around forest management (e.g., Spotted Owl conservation in the northwestern U.S.).

The range of adaptation measures various public land permittees can undertake is limited in ways that go beyond the restrictions found in private land leases. Planning processes can take years for landscape modifications like stream bank repair, water storage projects, or new fencing arrangements, due to the complex requirements and incongruous time horizons involved with permit related resource management plans. On a broader level, the BLM national headquarters, the

Department of Interior secretarial, or presidential policy mandates can have substantial effects on access to resources that have the ability to confound the long-term planning horizons required in land-based livelihoods.

In addition, the management of endangered, threatened, or candidate species on public lands, as well as general land management policies, have the potential to compound vulnerabilities to climate exposures by limiting livelihood viability (Eakin and Conley, 2002; Knapp et al., 2015). While Eakin and Conley (2002) found that the vulnerability of livestock ranching communities dependent on BLM-managed lands in Arizona is the result of intersecting factors (including climate variability, political factors, pressure from environmental advocacy groups, and agricultural economics), Knapp et al. (2015) further explored ranchers' perceptions of a species listing decision and found that the listing decision compounds other non-ecological stressors (e.g., increased recreational use, increased regulation of grazing) that increase concern about ranching livelihood viability. Thus, whatever climate-driven stressors public land users are exposed to – which, in some livelihoods and regions, can be substantial and highly variable year to year – their capacity to acknowledge and adapt to those stressors will always be constrained by the particulars of their relationship with the land management system and the various management plans they and the BLM have developed. Public land users' vulnerability is not merely the product of climate stressors, but emerges from the confluence of climate, management, and social, cultural, and economic stressors, necessitating a holistic investigation of each of these in determining social vulnerability (Fischer et al., 2013; McNeeley and Lazrus, 2014).

## 3. Review of vulnerability assessment methods for climate change on public lands

Vulnerability assessments play an important role in guiding adaptation planning and implementation (Bierbaum et al., 2014; DOI, 2014; Hinkel, 2011; Smit and Wandel, 2006). The Department of the Interior's Climate Change Adaptation Plan states that conducting vulnerability assessments is a priority for the BLM and highlights the adverse impacts of climate change-related events on livelihoods, economic interests, and biophysical resources (DOI, 2014). The DOI's recognition of climate related impacts to both social and ecological resources suggests that vulnerability assessments should necessarily consider system-wide feedbacks between social and ecological components in order to respond to the challenges that climate change poses to coupled social-ecological systems (DOI, 2014; Eakin and Luers, 2006; O'Brien et al., 2007; Turner et al., 2003; Weaver et al., 2014). However, these social and ecological approaches have often been conducted separately and have different definitions of the primary components of vulnerability in each (Table 1).

In the next section we describe both the ecological and social approaches to vulnerability and review the strengths and weaknesses of each in the context of public land management.

### 3.1. Ecological vulnerability assessment

Public land management agencies in the United States have focused vulnerability assessment efforts and guidance primarily on biophysical resources (e.g., Bureau of Land Management's *Rapid Ecoregional Assessments*; National Park Service's *Climate Change Response Program,* the National Wildlife Federation's *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment*) and much less so on the human communities whose livelihoods depend upon sustained provisioning of ecosystem services (Fischer et al., 2013). While ecologically-focused vulnerability assessments are helpful to: (1) set conservation target-based management and planning priorities; (2) assist in informing and crafting adaptation strategies; and (3) enable more efficient allocation of scarce resources, the determinants of vulnerability (exposure, sensitivity, and adaptive capacity) are tailored to ecological resources and omit characteristics unique to human systems (see Table 1).

Ecosystems-based approaches to vulnerability assessment are useful where conservation targets are of primary concern (e.g., Glick et al., 2011). However, with a relatively narrow focus on the vulnerability of species, habitats, and ecosystems they preclude humans as actors in interconnected social-ecological systems, and do not provide the analytical framework

**Table 1**
Definitions of components of ecological and social vulnerability (exposure, sensitivity, adaptive capacity) applied to public land contexts adapted from Glick et al. (2011), Fischer et al. (2013), Knapp, (2011) and Sonwa et al. (2012).

| | Natural Resource Management Vulnerability Assessment Definitions | Definitions in the Context of Social Vulnerability and Public Land Management |
|---|---|---|
| *Exposure* | The character, magnitude, and rate of changes to which a particular species or system is exposed | The character, magnitude, and rate of changes to which a human community is exposed |
| *Sensitivity* | The degree to which a species, habitat, or ecosystem is or is likely to be affected by or responsive to climate changes | The degree to which a human community is susceptible to harm or likely to be affected by climate changes and/or decision-making on public lands; the degree to which a human community depends on the provisioning of ecosystem services, and thus sustainable resource management, to support land-based livelihoods |
| *Adaptive Capacity* | The ability of a species, habitat, or ecosystem to accommodate or cope with climate change impacts with minimal disruption | The ability of human communities to generate and apply new knowledge, make decisions, and act collectively in order to reduce climate exposures and modify sensitivities, thus reducing overall vulnerability; the prevalence of supportive and equitable decision-making processes in public lands management |

to integrate social variables, interactions, and feedbacks operating in those systems. In fact, an ecosystems-based vulnerability assessment can at times conflict with local livelihoods, such as the case with 'threatened' and 'endangered' species, for example, when protection of those species or habitats constrain access or use for other land users (Knapp et al., 2015; Eichman et al., 2010). In the Glick model, humans are only involved as managers who identify issues and implement actions based on the assessment of ecological (i.e., that of non-human species, habitat, ecosystems) vulnerability assessment. Yet, humans are dynamic actors who live, work, and recreate in systems and who play a role in both managing and receiving ecosystem services. In reality, these actors represent more than a mere opportunity for engagement. Rather, they comprise both an important source of observational data on climate impacts and ecosystem functioning as well as a reciprocal force within those ecosystems where they also provide "services to ecosystems" in the form of maintenance and enhancement of those systems such as maintaining landscape connectivity, defense against invasive species, and the protection of culturally-significant species (Comberti et al., 2015). Those engaged in land-based livelihoods are connected to and rely upon the landscapes and therefore have an intrinsic interest in maintaining functional and healthy landscapes.

One relevant example of an ecological vulnerability approach is the *Climate Change Assessment for Colorado Bureau of Land Management,* in which the authors looked at mid-century climate projections to assess the vulnerabilities of terrestrial and freshwater ecosystem types along with plant and animal species of interest across three regions in Colorado (eastern plains, mountain, and western valleys) (CNHP, 2015). While the intention is that the assessment will help guide climate adaptation strategies for the Colorado BLM, the temporal and spatial scales of the assessment do not a) align with field office manager's decision-making scales, or b) account for important management issues such as cattle grazing and wildlife management for hunting and forage production (elk, deer, and wild horses, for example, were not among the species in the assessment – all important species for BLM management). As such, further refinement will be necessary to align the assessment with the relevant decisions and temporal and spatial scales for BLM management and planning. In the following sections we provide insights from social science approaches to help this type of an effort.

### 3.2. Applying a social Lens to climate change vulnerability assessment on public lands

In this section, we review several approaches to understanding social vulnerability – social indicators, mixed methods that complement indicators with qualitative data, scenarios, and case studies. We discuss the strengths and weaknesses of these approaches and then offer some key guiding principles for assessing social-ecological vulnerability, i.e., the degree to which human communities and land-based livelihoods are susceptible to climate exposures. In this paper we provide some guiding principles on how to better incorporate social indicators into vulnerability assessments. While beyond the scope of this paper, we acknowledge the importance of designing a fully integrated methodology for social-ecological vulnerability assessment from the start.

Social indicators approaches have been used in climate vulnerability research, particularly for their ability to quantify vulnerability, aggregate data, and make comparisons across geographic regions. For instance, the Social Vulnerability Index (SoVI) was developed specifically to identify indicators that could be used to measure social vulnerability to natural hazards at the county scale (Cutter et al., 2003). The SoVI provided the means by which to compare aggregate demographic variables known to be associated with heightened impacts during natural disaster processes, such as socioeconomic status, age, gender, race, and local development levels. While some of these indicators might be useful for understanding human vulnerability in a public lands context, the focus on hazards or extreme events does not provide a tight fit to the types of exposures (e.g., seasonality changes such as amount of snowpack and timing of runoff) that impact ranchers, for example, with grazing permits on public lands. In addition, the applicability of the SoVI and other similar indices are limited to the spatial scale of the data aggregation (i.e., the county or census tract level). This can mask sensitivities of certain groups within otherwise wealthy areas, such as poor households or communities in an otherwise very wealthy rural tract, for example.

Another social indicator approach, the Spatially Explicit Resilience Vulnerability (SERV), was designed to address this problem and capture sub-county variation in resilience and vulnerability (Frazier et al., 2014). The SERV model showed that vulnerability does vary at the sub-county level, and is considered useful for decision makers who are responsible for allocating scarce resources for hazard mitigation and disaster planning and preparation (Frazier et al., 2014). However, the SoVI, SERV, and other relatively coarse-scale approaches – that is, those that rely on publicly available, county- and census-tract level social data – are unable to assess many of the place-specific determinants of vulnerability that are often difficult to quantify, such as community connectivity or the diverse ways in which specific groups interact with and view one another during periods of resource or political conflict (Birkmann, 2007; Cutter and Finch, 2008; McNeeley, 2014).

Real-world vulnerability (as opposed to theoretical or computer-modeled) is a continuously changing and evolving *process*, not a static *measurement* (Ford and Smit, 2004; Luers, 2005). Therefore, indicator-based approaches used in isolation cannot capture those sources of adaptive capacity that are more dynamic, such as social and cultural capital, land tenure and use, livelihood flexibility, and political agency (Eakin and Luers, 2006; O'Brien et al., 2004, 2007). Additionally, it has been suggested that approaches that focus on county-, state-wide, or coarser scales may actually lead to maladaptive strategies that further marginalize vulnerable populations, particularly in rural areas where census blocks cover relatively large geographic areas (Eakin and Luers, 2006; Frazier et al., 2014; McNeeley, 2014).

Nevertheless, indicators approaches can be considered key components of social vulnerability assessments, particularly when they are complemented by information gathered through qualitative, participatory research methods (CWCB, 2013; Fischer et al., 2013; Keskitalo et al., 2011). Social science methods, such as in-depth interviews and focus groups, are

considered effective ways by which to characterize the social and political factors that moderate or exacerbate climate exposures and sensitivity in local contexts (O'Brien et al., 2004; McNeeley, 2014). For example, Colorado's Drought Mitigation and Response Plan, led by the Colorado Water Conservation Board, initially used an indicators approach to evaluate drought vulnerability across sectors (e.g. municipal and industrial water supply; agriculture; recreation and tourism) and state assets (e.g., agricultural and livestock businesses; fisheries; wildlife) (CWCB, 2010). Quantitative vulnerability scores were developed based upon impact metrics (e.g., average annual user days on rivers; reduction in herd size on ranches). In an updated and revised version of the CWCB assessment, these metrics were augmented with qualitative interviews, and subsequently amended, to more accurately reflect place-specific factors that influenced vulnerability, and which were not captured in quantitative analyses (CWCB, 2013; Thomas and Wilhelmi, 2012). These factors included things such as: 1) access to already stressed or limited water resources within the larger water system; 2) communication and collaboration between water users to share resources and minimize impacts; and 3) interactions between hazards such as drought and fire, which both restrict use and drive away tourists. Espiner and Becken (2014) used a similar top-down approach with climatological data to determine vulnerabilities to recreation and tourism industries and then combined that with a bottom-up approach by conducting key stakeholder interviews that demonstrated the top-down indicators of vulnerability were not perceived as major threats by key stakeholders. This mixed-methods approach can be more robust than a purely quantitative analysis, especially when it helps to "ground truth" quantitative analyses (Keskitalo et al., 2011; McNeeley, 2014; Reed et al., 2006).

Social indicators approaches can be combined with qualitative research to adjust or weight indicators for their importance locally (CWCB, 2013; Keskitalo et al., 2011; Li et al., 2015) and thus develop a more refined understanding of how vulnerability manifests at smaller scales. However, given the limited utility of an indicators-only approach to assess the role of humans as actors in social-ecological systems (Lindoso et al., 2014), it is important to note that the specific metrics used for indicators approaches may have as much of an impact on the results as the scale at which the analysis is undertaken, suggesting the need for expert and stakeholder engagement to determine the most important inputs rather than making *a priori* determinations (Schmidtlein et al., 2008; Smit and Wandel, 2006).

Scenario approaches to climate vulnerability assessment use a range of climate projections (based upon emissions scenarios and climate models) in order to understand potential impacts to ecological and social systems. Climate change scenarios were used in northeastern U.S. to assess projected vulnerability between the snowmobiling and skiing industries due to reduced snowpack (Scott et al., 2008). However, the study did not attempt to interview visitors to understand whether reduced snowpack would actually result in decreased visitation. This is important because an analogue study demonstrated that modeled climate impacts (e.g., reduced snowpack) do not necessarily correlate with reduced visitation since the ski season length and adaptive measures such as snowmaking played a stronger role than climate in isolation (Dawson et al., 2009). Indeed, 'vulnerability as experienced' by the vulnerable people themselves requires a thorough understanding of perceptions that may be rooted in other sources of stress besides climate (Adger, 2006). Sheppard et al. (2011) conducted scenario-based research in British Columbia and found scenarios that integrated local knowledge and data resulted in an easily accessible tool for stakeholders and decision-makers to consider during interviews. They also provided a springboard that allowed local actors to engage with specific vulnerabilities and adaptive capacity (Sheppard et al., 2011).

Scenario approaches can be used to contemplate baseline and projected vulnerabilities, thus considering both the current and evolving nature of vulnerability (Cobb and Thompson, 2012; Jackson et al., 2009; Knapp, 2011). It is important that scenarios are connected to issues that managers are dealing with or planning for in the present (Bär et al., 2015; Dunford et al., 2015; Knapp, 2011), so that they are meaningful and salient to the end-user. Engaging policy-makers, managers, and other stakeholders in the difficult task of contemplating uncertain futures can lead towards locally relevant and feasible adaptation actions (Beach and Clark, 2015).

For example, in the Gunnison Basin of southwest Colorado, where public lands account for more than 80% of total land ownership, interviews with public land managers and resource users (ranchers and recreation outfitters) co-determined baseline vulnerabilities and considered future vulnerabilities by reflecting on two scenarios (Knapp, 2011). By examining resource-user perceptions and values about current and projected climate, the study revealed a number of insights about sector-specific and crosscutting vulnerabilities such as increasing drought intensity, the unpredictability of spring runoff, and increased recreational pressure on lands. Further, by analyzing existing climate adaptations among rural livelihood groups, the study was able to demonstrate how to connect existing, culturally-accepted climate adaptation strategies to future adaptation efforts through their connection with existing needs (e.g., for greater flexibility in accessing water and land resources) and value systems of groups that might otherwise resist attempts by outside authorities to assess and control their land use practices (Knapp, 2011).

Subsequent research in the Gunnison Basin found the participatory scenario approach showed that, for example, contrasts existed between how recent migrants to the area, long-term residents (mainly ranchers), and biologists viewed landscapes – as "untouched nature," "working lands," and sites for conservation and experimentation, respectively (Clifford, 2014). These contrasts, in turn, led ranchers, in particular, to feel their "on the ground" knowledge was unfairly devalued by the other two groups. At the same time, the ranchers' valuation of their own local experience and knowledge made them more skeptical of scenarios and modeling approaches, even if they were interested sin the findings. The scientists spent a great deal of time qualifying their scientific knowledge as different from the ranchers' valid personal experiences and knowledge. The incorporation of the diverse value and knowledge systems enabled the participatory scenario approach to effectively evaluate baseline vulnerabilities at a scale relevant to the actors most engaged in future adaptation efforts. That said, efforts to scale up the findings of such an approach are limited barring their replication across the broad array of places and

local socio-ecological systems of interest to governing entities like the BLM. Yet, the same *approach* can be used across case sites, which we will discuss in more detail below.

Case studies that utilize participatory qualitative research methods such as participant observation, interviews, and focus groups present researchers with perhaps the greatest opportunity to apply local knowledge to questions of land use and ecological change (Baird et al., 2014; McNeeley and Lazrus, 2014). In the context of social vulnerability assessment of land-based livelihoods, case studies have engaged resource users in generating an understanding of place-based particulars of vulnerability (McNeeley and Shulski, 2011; Knapp, 2011; McNeeley, 2014; Wilhelmi et al., 2008). In northwest Interior Alaska, social vulnerability was determined through a place-based, participatory case study, building upon the framework of Smit and Wandel (2006), in which determinants of vulnerability are understood as a result of stakeholder input rather than being predetermined by the scientists (McNeeley, 2009; McNeeley and Shulski, 2011). This study revealed how the rigid local regulatory framework for subsistence and wildlife management constrained indigenous adaptive capacity and contributed to vulnerability through increased food insecurity (McNeeley, 2012). Another case study found that fragmented governance regimes (public/private lands) can constrain the abilities of public land management agencies to implement adaptation measures, thus heightening vulnerability to climate change (Smith and Travis, 2010). These examples demonstrate the types of context-specific factors contributing to vulnerability of land-based livelihoods that can be identified in case studies, but may be overlooked with other methods.

Because social vulnerability and its components (exposure, sensitivity, adaptive capacity) vary temporally and spatially, comparative case studies are useful for uncovering local-level socio-ecological linkage dynamics and dependencies (e.g., market access pressures during drought when feed shipping is in high demand), and can also yield more generalized conclusions applicable across scales and regions (Eakin, 2005; Ford et al., 2010). Case studies by Eakin (2005) conducted in three distinct communities in Mexico revealed regional heterogeneity in sensitivity to agricultural crop losses and adaptive capacities, as well as broader policy-relevant conclusions reflecting institutional impacts to vulnerability. In particular, this study noted how factors like labor availability for irrigation construction, access to markets for nationally subsidized crops, and livelihood diversification capacity all varied widely across specific regions, with local political dynamics between business owners and rural small holders often playing a powerful role (Eakin, 2005). Another project in arctic communities identified the inapplicability of existing cultural knowledge systems in the face of new and unfamiliar climate and sea ice conditions as a systematic determinant of vulnerability across sites (Ford et al., 2010). The comparative case study method can reveal location-specific characteristics that vary between and within sites, yet still lead to more generalized conclusions about determinants of vulnerability.

Case studies that ask the "how" and "why" questions related to the processes that structure or create vulnerability can be time and resource intensive and often require significant stakeholder and researcher commitment, leading to concerns about "stakeholder fatigue" (Engle et al., 2014; Fischer et al., 2013). Moreover, the participatory process can provide valuable insights into both short and long-term vulnerability factors such as different developmental goals at different levels of an institution, incompatible styles of learning across sub-divisions of an organization, or differing cultures of accountability and information dissemination within bureaucracies (Engle et al., 2014). Synthesizing case studies can also require significant commitment from both researchers and project sponsors, making their achievement difficult in shifting political and institutional climates.

Social climate change vulnerability assessments will most successfully prepare public land management agencies for adaptation if the assessments consider both social and ecological baseline vulnerabilities to climate change and the qualitative factors that influence human actions in social-ecological systems (Cutter et al., 2003; Ford et al., 2010; Moser and Boykoff, 2013). Furthermore, the scale at which social vulnerability assessments are conducted should be aligned with the scale at which decisions will be made on public lands. Each of the approaches discussed exhibits strengths and weaknesses in the context of public land management. For example, while an indicators approach can allow quantification of vulnerability at larger scales, these approaches tend to be static measures and their utility depends on the scale at which indicator data was aggregated. In comparison, scenario approaches help consider projected vulnerability, but can overlook baseline vulnerability, synergistic factors contributing to vulnerability, and can be difficult to scale up. Finally, comparative case study approaches are place-based and capable of encompassing local nuance, but they are often time intensive.

## 4. Key design principles for social-ecological vulnerability assessment on public lands

Based upon our review of existing approaches to social and ecological vulnerability assessment, the strengths and weaknesses associated with each, as well as the unique context of public lands, we suggest three primary design principles that are most appropriate for conducting social-ecological vulnerability assessments for public land management agencies: (1) participatory stakeholder engagement; (2) consideration of institution-actor relationships, including barriers and opportunities for adaptation; and (3) the integration of "top-down" modeling or indicators-approaches with "bottom-up" local knowledge networks to discern management-scale heterogeneities. We argue that this integrated, participatory approach to assessing baseline vulnerability and the roles of humans as actors in dynamic social-ecological systems can provide a deeper, more grounded understanding of feedbacks between land-based livelihoods and ecosystems than focusing solely on ecosystem vulnerability. Consequently, the foundation will be laid for effective, equitable, and actionable climate change adaptation strategies.

### 4.1. Participatory stakeholder engagement in research co-production

Stakeholder engagement, trust, and support (i.e., engaging those who are both using and managing the land and natural resources being assessed) are fundamental to vulnerability assessments if subsequent climate change adaptation plans are to be successfully adopted and implemented (Tompkins et al., 2008; Tribbia and Moser, 2008; Fischer et al., 2013). The successful application of new knowledge derived from vulnerability assessments for climate adaptation is connected to whether or not end-users perceive it as credible, salient, and legitimate (Cash et al., 2003; Turner et al., 2003; Shaw et al., 2009; Dilling et al., 2015). Assessments conducted for particular stakeholders can help to formalize communication channels, tailor assessment outcomes to local decision-making needs, and establish trust relationships necessary to addressing the numerous uncertainties inherent in dealing with climate projections (Eakin and Luers, 2006). Vulnerability assessments that consider the complex policy framework within which they are working provide more understanding of the decision context in which they will be used, thereby increasing the chances of informing decision making or adaptation actions (Dilling and Romsdahl, 2013; Klein and Juhola, 2014; Wellstead et al., 2013; McNeeley and Lazrus, 2014; McNeeley, 2012). As the United States Global Change Research Program articulates in its strategic plan (USGCRP, 2012), the effectiveness of global-change research rests on the successful co-production of knowledge between scientists and practitioners (Weaver et al., 2014; Mauser et al., 2013; Hegger et al., 2012). Co-production is an equitable, shared, end-to-end, iterative process of research between scientists and decision makers to establish research goals, conduct research, and work toward implementing that research with relevant partners (Lemos and Morehouse, 2005). Participatory approaches, however, can also be time-consuming and require skills and experience that scientists may lack, requiring interdisciplinary partnerships. Despite these challenges, we believe this approach is critical for generating useful and usable research, especially in the context of multiple use on public lands.

Two federally funded research networks (detailed below) exemplify the importance of participatory stakeholder engagement and the co-production of research through collaborative partnerships, goal setting, and iterative and on-going decision-maker involvement in vulnerability assessments and adaptation research (Bales et al., 2004). These "boundary organizations" – those that operate at the intersection between science and decision making – are designed to sustain interaction between researchers and managers throughout a project's timeline, and increase information usability (Kirchhoff et al., 2015a).

The US Department of the Interior's (DOI) Climate Science Centers (CSC) are a federal-academic network of regional university-based research centers whose mission is to "provide scientific information, tools, and techniques that land managers and other interested parties can use to anticipate, monitor, and adapt to climate change impacts" (www.doi.gov/csc/). The National Oceanic and Atmospheric Administration's (NOAA) Regional Integrated Science Assessments (RISA) comprise another network of regional research centers whose success has been grounded in the ability to "create lasting relationships with decision makers from the public and private sectors including local, regional, and state governments, federal agencies, [and] tribal governments" (www.cpo.noaa.gov). The CSCs and RISAs collectively contribute to the literature describing decision-support tools and the importance of co-producing them with the end users themselves (Archie et al., 2012; Dilling and Lemos, 2011; Dilling and Romsdahl, 2013; Lemos and Morehouse, 2005; Kirchhoff et al., 2015a,b; Meadow et al., 2015).

Given the suite of barriers to climate change adaptation in public lands, including nested governance regimes, legislative constraints, multiple use mandates and others (see Archie et al., 2012; McNeeley, 2012), and the relative success in co-producing research goals and outcomes of the RISAs and CSCs, public lands social vulnerability assessments that co-produce goals and develop desired outcomes in concert with land users can help to successfully navigate institutional frameworks and constraints. Engaging managers to participate in the research design offers the opportunity to develop research goals jointly and understand the specific needs (e.g., directing research not just toward projected climate changes, but toward impacts to resource-dependencies) and decision-making context of that particular management unit, thus making the vulnerability assessment most useful to the end users (Kirchhoff et al., 2015b; Weaver et al., 2014).

### 4.2. Focus on institution-actor relationships

Understanding the role of institutional rules, values, and frameworks for action related to ecological decision making and social support systems is of critical importance to successful adaptation, as is the need for further research on how institutions and individuals interact to affect vulnerability and (or) impede adaptation (e.g. Adger and Kelly, 1999; Adger et al., 2005; Folke, 2006; McNeeley, 2012; McNeeley and Lazrus, 2014; Hinkel and Bisaro, 2015; Smithers and Smit, 1997). Adger et al. (2005) focus on issues of scale, indicating that the nested nature of institutional authority has substantial implications for climate change vulnerability due to the ways in which local, state, and national level priorities and conceptualizations of problems can conflict and hinder the application of feasible solutions on the ground. The authors suggest that multi-level social networks and systems of governance are necessary to respond to social-ecological challenges that transcend management jurisdictions and political boundaries. In the context of BLM management scenarios, these suggestions apply to problems related to watershed management, invasive species control, endangered species protection, and the management of rights of way, all of which often involve multiple property ownership types and large organizational linkages between field offices, counties, and other federal agencies.

Researchers have argued that social capital (i.e., the ability to forge, maintain, and utilize inter-personal and inter-organizational relationships) is an important determinant of local adaptive capacity and the ability of institutions to react collectively and effectively to complex, multi-stakeholder problems, especially in slow to change institutions (Pelling and High, 2005; Adger, 2003). For example, in northwest Colorado the Upper Yampa Water Conservancy District led a collaborative effort that leveraged social capital and informal networks of information exchange to facilitate voluntary reservoir releases and reductions in water use during a period of exceptional drought in 2002 that limited the impacts of the drought on water users and avoided the need for legal actions (McNeeley, 2014). Alternatively, rigid decision-making processes in the dual state-federal regulatory system that govern traditional land use patterns in northwest interior Alaska create vulnerabilities and barriers to adaptations by the indigenous people that rely on public land management for access to wild foods for subsistence (McNeeley and Shulski, 2011; McNeeley, 2012). Hinkel and Bisaro (2015) also highlight the importance of institutional analysis, particularly that which focuses on describing and evaluating the multiple roles of governance structures (e.g., in law, policy, policy regimes, and informal norms and customs) at play in adaptation contexts and how these collectively contribute to climate change vulnerability. This occurs by way of the structural determinants of poverty, power, and the pathways through which individual actors possess and realize their ability to act. Institutions such as municipal, state, and federal regulatory systems or tribal cultures and communities, for example, can also play a key role in what individual actors and sub-groups understand and perceive about their world, thereby shaping both their responsiveness to climatic stressors and their planning capacity over the long term (McNeeley and Lazrus, 2014). In examining adaptation work in California, Ekstrom and Moser (2013) noted how municipal institutions' efforts to address climate change adaptation goals were stymied by poor integration across relevant agencies with many unable to effectively transmit knowledge and resources between organizations, and thereby, unable to implement solutions to various climate-driven problems, such as effective water distribution. However, they also note that the elicitation of the barriers throughout the course of their work helped to develop specific cross-boundary organizations that worked to overcome the various organizational and legal barriers to mitigation or resilience building work in the region (Ekstrom and Moser, 2013). In Washington state, researchers found that *intra*-institutional barriers – namely, geographically static species protection laws and a lack of field-level mandates for project implementation – were seen by managers as limiting the ability to undertake climate change adaptation strategies in US National Parks and Forests (Jantarasami et al., 2010). These examples point to the benefit of paying attention to actor-institution relationships in vulnerability assessments, as failure to do so may lead to unrealistic or incomplete understanding of vulnerability and/or options for adaptation.

### *4.3. Integration of top-down with bottom-up data and local knowledge*

Integration of local or stakeholder-derived knowledge has become more common in vulnerability assessments and adaptation planning in order to promote equity, benefit from diverse knowledge, and result in more useful outcomes (Knapp et al., 2014; McNeeley, 2014; McNeeley and Lazrus, 2014; Smit and Wandel, 2006; Turner et al., 2003). Assessments that solicit and integrate local knowledge present the opportunity to cultivate equitable decision-making processes and highlight local capacities for resource protection in ways that assessments driven solely by expert, "top-down" knowledge cannot (Tompkins et al., 2008; Fatorić and Morén-Alegret, 2013; Ross et al., 2015; Beck and Krueger, 2016). While competing societal values and goals are commonly encountered in natural resource management issues, incorporating local knowledge and observations presents the opportunity for a deeper understanding of what climate change means to the diverse actors and groups within the study (Adger et al., 2009; Eakin and Luers, 2006; Espiner and Becken, 2014; Klein and Juhola, 2014; McNeeley and Lazrus, 2014; Moser and Ekstrom, 2010; O'Brien and Wolf, 2010; Ross et al., 2015). Furthermore, when stakeholders define relevant exposures and sensitivities, instead of being predetermined by researchers, the assessments can more effectively assess a region's adaptive capacity (McNeeley, 2014; Smit and Wandel, 2006). In the BLM and public land context, local knowledge is critical to understanding the linkages between local communities and the ecosystem services that they rely upon for their livelihoods, and how both are and will be affected by annual climate variability and long-term change, governmental decision-making, and broader economic pressures. It can also shed light on ways in which existing valuations of various ecosystem processes can be utilized as leverage for the implementation of adaptation strategies be it in the framing of climate or ecological science, the development of locally-legitimate parameters for models, or the development of actionable adaptation options for specific land use systems (e.g., controlling invasive vegetation, executing controlled burns, and protecting vulnerable ecosystems or species in ways that mutually support the resilience of both local land users and ecosystems).

Bottom-up approaches that incorporate the knowledge of local land users can also help to capture how the diverse knowledge systems that interact with public land resources conflict or reinforce one another, and serve as a mutually agreed-upon record of on-going change and provide a broad, culturally-accepted base for implementing various adaptation strategies (Knapp et al., 2014). The aforementioned case study in northwest Colorado found that top-down approaches to measuring climate exposures (e.g., drought measured quantitatively through precipitation and temperature data) would be insufficient in terms of understanding vulnerabilities and opportunities for adaptation and decision-support without the integration of bottom-up approaches that thoroughly investigated how drought impacts manifest locally (e.g., how does local social capital affect the ability of water users to respond to drought conditions?) (McNeeley, 2014). McNeeley and Shulski (2011) found that "indigenous observations and understanding of climate (IC)" enhanced and, in some ways, conflicted with top-down methods of data collection based on western-scientific definitions of seasons versus more nuanced

**Table 2**
Summary of key principles for public lands vulnerability assessments.

| Participatory Stakeholder Engagement | Consideration of Institution-Actor Relationships | Integration of Top-Down and Bottom-Up Data and Local Knowledge |
|---|---|---|
| Enables: | Enables: | Enables: |
| Co-production of knowledge | Engagement with multiple scales of decision making and powerful actors that have local impacts on vulnerability | Improved accuracy of findings by incorporating relevant information from various scales |
| Determination of local needs | | |
| Explanation of uncertainties and acceptable levels of confidence | Explication of social networks, social capital, and other informal systems | Increased legitimacy of assessment findings |
| Identification of locally feasible (and desirable) pathways for adaptation | Identification of barriers and opportunities within and between organizations | Better understanding of local level exposures and sensitivities, e.g., seasonality and timing needs and flexibility |
| Requires: | Requires: | Requires: |
| Significant commitment of time and resources | Knowledge of multiple distinct organizations at play in the study area | Ability to navigate multiple knowledge systems effectively |
| Consideration of equity and other systemic factors | Engagement across a broad array of stakeholder groups | Engagement with stakeholders and bureaucracies at multiple levels and with varying levels of power |
| Existence of – and ability to – cultivate base levels of trust | Capacity to adequately address and account for barriers within systems | Attention to issues of data equity and scalability |
| Ability to work within and around numerous systems of governance and organizational structures | Diplomacy to navigate/negotiate political & cultural differences/conflicts | |

indigenous seasonality based on harvest periods and climate change. This showed how climate change shifted seasonal patterns during warmer falls, which caused a mismatch between moose behavior and the official hunting season that then negatively impacted subsistence harvest success. Through an investigation that incorporated both western science and indigenous observations a clearer picture of climate change vulnerability emerged.

Ultimately, the integration of readily available, "top-down" indicators of social vulnerability with place-specific, locally derived expertise helps to discern local and regional differences and dynamics that shape both vulnerability and the on-the-ground adaptation landscapes that managers and land users work within. Whether the result of varying land use dynamics, regional climate or topography, locally-specific socioeconomic factors, or cultural dynamics between managers and land users, vulnerabilities will always be shaped by a variety of factors both unique to particular places and set within broader, more generalized contexts. As such, vulnerability assessments – especially those for multi-use agencies like the BLM will require a corresponding multi-level approach to knowledge acquisition and development. Since vulnerability is an evolving process, the processes that affect vulnerability should also be examined from bottom-up and top-down perspectives (Fischer et al., 2013; Ford and Smit, 2004; Luers, 2005) (Table 2).

## 5. Conclusion

Public land management agencies such as the BLM operate in the context of multiple land-use missions, top-down mandates to incorporate climate change, and local economic dependencies on natural resources and their ecosystem services from public lands. Given this context, these agencies need to consider how their decision-making will affect the vulnerability of the user groups that rely upon those resources to support land-based livelihoods, such as livestock ranchers and recreation outfitters. If humans are left out of vulnerability assessments, local economies and cultures can be at risk and impacts of management on ecosystem and livelihood resilience will be overlooked. In recent years research has shifted from climate change projections to assessing and evaluating the current impacts of climate change in order to mitigate and adapt (Bierbaum et al., 2013). Despite the breadth of research on social vulnerability (e.g. Adger and Kelly, 1999; Eakin and Luers, 2006; Frazier et al., 2014; Heltberg et al., 2009; Smit and Wandel, 2006; Turner et al., 2003), there has been little attention to vulnerability assessments for public land management agencies, especially for BLM lands (for one USFS example, see Murphy et al., 2015).

The components of climate change vulnerability have been measured in a variety of ecological, social, and coupled social-ecological settings. However, measuring these components through conventional methodological approaches provides only a "snapshot" of vulnerability, while assessments that consider vulnerability as both a static *profile* and a changing *process* to be evaluated and dealt with over time provide a more realistic assessment of vulnerability, and therefore, may lead to more appropriate adaptation strategies (Fischer et al., 2013; Ford and Smit, 2004; Luers, 2005). Some work has been done to advance this understanding of vulnerability at statewide (WA State DOT, 2011; Gordon and Ojima, 2015; CWCB, 2013), regional (e.g., Climate Assessment for the Southwest (CLIMAS) (Bales et al., 2004), and national scales (e.g., the National Climate Assessment (Melillo et al., 2014)). However, these efforts were not produced specifically to address social vulnerabilities on public lands, which is of particular importance in the western US where federally managed lands account for a significant proportion of total land ownership.

In this paper, we reviewed the strengths and weaknesses of existing approaches to social and ecological vulnerability assessment in the context of public lands. We illustrated how humans are actors in – and an interconnected part of – the overall vulnerability in any biophysical or social-ecological system. This necessitates their inclusion *analytically* in understanding vulnerability on public lands, as opposed to simply viewing them as the recipients of information on ecological vulnerability that they will use to make decisions and adapt accordingly. Therefore, this paper argues for inclusion of social vulnerability in an integrated social-ecological vulnerability assessment to climate change for public land management agencies, particularly those managing natural resources for multiple uses.

We provided three design principles that are most appropriate for conducting social-ecological vulnerability assessment on public lands, which include 1) iterative and participatory stakeholder engagement, 2) consideration of institution-actor networks and the role of boundary organizations, including the barriers and opportunities for adaptation, and 3) the integration of "top-down" indicator approaches with "bottom-up" case studies that integrate local knowledge and observation. This multi-faceted approach can provide a more complete understanding of social-ecological system feedbacks and place-based vulnerability determinants, while at the same time offer opportunity for meta-synthesis and more generalized conclusions applicable at larger scales. This is an appropriate approach for public land management agencies that manage large areas at nested (e.g., field office and state-level) scales. A participatory approach that incorporates multiple case studies can provide a deeper understanding of these feedbacks by assessing baseline vulnerability and the roles of humans as actors in social-ecological system dynamics. While the design principles provided herein can guide the development of a social-ecological vulnerability assessment, determinants and processes will vary spatially and temporally and thus render this review merely a starting point to developing an appropriately scaled and designed social-ecological vulnerability assessment. While beyond the scope of this article, we suggest an important next step is to expand on our principles herein to refine and operationalize appropriate frameworks, processes, and methods for conducting integrated social-ecological vulnerability assessments from the start.

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