Drought Risk and Adaptation in the Interior United States: Understanding the Importance of Local Context for Resource Management in Times of Drought*

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ABSTRACT

Drought is a natural part of the historical climate variability in the northern Rocky Mountains and high plains region of the United States. However, recent drought impacts and climate change projections have increased the need for a systematized way to document and understand drought in a manner that is meaningful to public land and resource managers. The purpose of this exploratory study was to characterize the ways in which some federal and tribal natural resource managers experienced and dealt with drought on lands managed by the U.S. Department of the Interior (DOI) and tribes in two case site examples (northwest Colorado and southwest South Dakota) that have experienced high drought exposure in the last two decades. The authors employed a social–ecological system framework, whereby key informant interviews and local and regional drought indicator data were used characterize the social and ecological factors that contribute to drought vulnerability and the ways in which drought onset, persistence, severity, and recovery impact management. Results indicated that local differences in the timing, decisions, and specific management targets defined within the local social–ecological natural resource contexts are critical to understanding drought impacts, vulnerabilities, and responses. These findings suggest that manager-defined social–ecological contexts are critically important to understand how drought is experienced across the landscape and the indices that are needed to inform adaptation and response strategies.

1. Introduction

Severe drought impacts are among the costliest weather and climate disasters in the United States (Smith and Katz 2013). The north-central region of the United States (i.e., northern Rocky Mountains/high plains) has experienced a series of extreme to exceptional droughts in recent decades with widespread impacts across sectors. One report on the 2002 drought impacts estimated a loss of $3 billion to the agricultural sector in Nebraska and South Dakota (Hayes et al. 2004). The Rocky Mountains across the region have experienced forest die back (Allen et al. 2010;

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Hicke et al. 2012), increased pest and pathogen disturbances (Hicke et al. 2012; Logan et al. 2010), and intensification of forest fires (Dennison et al. 2014). Additionally, "mega droughts" may impact the region in the future, which could pose major threats to natural resources and the decisions to manage those resources (Kallis 2008; Schwinning et al. 2008; Seager et al. 2007; Stahle et al. 2000; Cook et al. 2015). A key finding from the 2014 National Climate Assessment Great Plains regional report suggested that climate change, streamflow overallocation, increases in population and development, and both energy extraction and use pose significant risks of increased competition over scarce water resources (Shafer et al. 2014; Ojima et al. 2012). Finally, drought is a "wicked" problem, characterized by competing values and risk perceptions, which results in fundamentally different ideas about the nature and severity of a "drought," and consequently, the ways in which drought is experienced and managed (Botterill and Cockfield 2013).

Recent efforts in the U.S. Department of the Interior (DOI) have established a set of regional Landscape Conservation Cooperatives and Climate Science Centers to support natural resource management decision-making in response to climate change (Department of the Interior 2009). The DOI plays multiple roles in natural resource management and livelihoods in the region. For example, the Bureau of Land Management (BLM) leases grazing permits on public lands, the National Park Service (NPS) and the U.S. Fish and Wildlife Service (USFWS) manage fish and wildlife, the Bureau of Indian Affairs (BIA) manages resources on tribal reserved lands, and the Bureau of Reclamation (BOR) (and BIA) manage reservoirs and water releases for agriculture. All of these DOI entities operate in shared drought-impacted landscapes that have multiple land ownership and authorities for management.

Drought risk and adaptation are inherently both social and biophysical processes (Glantz 1994). The National Drought Mitigation Center's (NDMC) Drought Impacts Reporter, for example, demonstrates that what constitutes a drought is broader than the analysis and information provided by scientists on meteorological, hydrological, and numerical economic indicators alone (Botterill and Cockfield 2013). The sociocultural dimensions of drought impacts and responses are multifaceted, and when compared to other natural hazards are not well understood (Wilhite et al. 2007; Wilhite 2005). This includes a lack of documented drought impacts in the management context of public and tribal reserve lands. Some progress has occurred for assisting managers with drought preparedness and management through various incentives, programs, and tools (McNutt et al. 2013; Brusberg and Shively 2015). However, additional work is needed to localize drought monitoring information for planning within and across scales and to provide simple and usable access to information and tools (Knutson and Haigh 2013). Therefore, there is a need for a systematized way to understand and document drought at scales that are *meaningful* to resource managers.

Toward that effort, the authors have initiated a research project to examine drought risks and responses in the North Central Climate Science Center (NCCSC) region (the Northern Plains and Rockies) using a case study approach combined with drought indicators. The initial, exploratory phase of research was to scope out the problem, identify key DOI and tribal drought-impacted management issues, identify drought indicators, and lay the foundation for additional research inquiries. The study is ongoing, and we do not report full results here. However, we discovered early in the research process several key insights worth reporting that demonstrate the importance of an empirical understanding of local context and management issues impacted by drought. We draw from in-depth interviews with a carefully selected group of key informants who have detailed local knowledge and experiences on the landscapes they manage. The purpose was to characterize the ways that some federal and tribal natural resource managers experienced and dealt with drought on DOI and/or tribal lands in two case site examples that have experienced high exposure to drought in the 2000s. In this regard, we answer the following research questions: 1) What are the local social and ecological factors that contribute to vulnerability to drought on DOI and tribal lands in each case site example? 2) What are the examples across the case sites that demonstrate the different ways in which drought onset, persistence, and magnitude impacts management decisions and responses?

We organize our initial findings herein around manager-defined exposures, sensitivities, impacts, and responses to drought, and how management decisions and responses were impacted by differences in drought exposure with regard to onset, persistence, severity, and recovery. This exploratory phase of the research was not meant to be indicative of management in the context of drought for all DOI and tribal land and resource managers, and therefore we did not seek quantitative comparisons across management agencies or case sites. Instead, we intended to illustrate the utility of emphasizing local knowledge and the social–ecological context for drought adaptation research.

2. Approach

a. *Conceptual framework*

We utilized a social–ecological system (SES) framework on drought, which recognizes that social and ecological systems are interconnected, in that people depend on the services that ecosystems provide, while the integrity of the ecological system and its capacity to provide those services are the result, in part, of management decisions (Adger et al. 2009; Chapin et al. 2009a; Moser and Ekstrom 2010; Nelson et al. 2007; O'Brien et al. 2007; McNeeley 2014; Smit and Wandel 2006; Turner et al. 2003). An SES framework emphasizes the feedbacks that operate between social and ecological components, thus providing the means by which to better identify those factors that enable or constrain decision-making than an approach that assesses the social or ecological components of the system separately (Chapin et al. 2009b).

Conventional scientific assessments of climate risks are typically formulated as a function of probability, severity, and outcomes (Adger et al. 2012). However, the social science of risk and risk management emphasizes a much broader set of complex and contextual variables that characterize how people both perceive and respond to risks (Verweij et al. 2006; Renn 2011; McNeeley and Lazrus 2014; O'Brien et al. 2007). In this regard, the vulnerability of a system to climate variability and change is framed in the context of the exposure to a climate stressor, the sensitivity to harm, and adaptive capacity, which is the potential to respond to or prepare for change (Polsky et al. 2007; Turner et al. 2003; McNeeley and Shulski 2011; Adger et al. 2007). Capacity to respond to drought can be limited by social, political, and regulatory barriers, which are important to understand for building capacity and implementing adaptation strategies (Adger et al. 2009; McNeeley 2012; Moser and Ekstrom 2010; Bierbaum et al. 2013). Therefore, adaptive capacities are determined with the stakeholders themselves rather than identifying them a priori (Smit and Wandel 2006).

Additionally, although it is commonly understood that everyone perceives drought in the same way as "abnormally dry," a deeper SES understanding reveals that people define and understand drought and drought risks, and consequently respond, in very different ways. This recognizes that local knowledge and experiences shape management decisions and responses, thus emphasizing the role of human agency in affecting social–ecological dynamics (Eakin and Luers 2006). Therefore, an integrated SES approach to drought vulnerability identifies which individuals, groups, and resources are impacted; the multitude of social and environmental factors that may facilitate or inhibit the capacity of individuals to respond; and the ways in which human actors' perceptions of drought can affect responses (Smit et al. 2000; Ford and Smit 2004).

b. *Methodological approach*

The purpose of this study was to characterize the ways that some DOI and tribal natural resource managers experienced and dealt with drought on lands they manage in two case site examples that have experienced high drought exposure in the 2000s. We use "bottom up" qualitative research methods and "top down" local and regional drought indicator data (e.g., Drought Risk Atlas) to illustrate the biophysical and social context of drought in both case examples. This exploratory phase of research consisted of key informant interviews with a small, purposive sample of natural resource managers affiliated with DOI and tribal lands. The interviews were then analyzed using a modified grounded theory approach to identify 1) manager-defined exposures, sensitivities, impacts, and responses to recent drought episodes and 2) how drought onset, persistence, severity, and recovery differentially impacted these landscapes.

1) Step 1: Natural resource manager key informant interviews

Semistructured interviews were conducted with key informants who are DOI and tribal natural resource managers in high-drought-risk landscapes through a combination of in-person and phone interviews. We identified the appropriate managers to interview through purposive (i.e., targeted) sampling within DOI and tribal offices that have some decision-making role in managing drought-sensitive lands and natural resources. The identification of interviewees occurred through contacts made by one of the authors (S.M.) during previous work, through agency websites, and through contacting supervisory staff to help identify the best people in their offices to interview on the topic. Some non-DOI managers were interviewed [e.g., Natural Resource Conservation Service (NRCS), state water managers] where they had a direct role in a DOI/tribal management issue and worked closely with DOI or tribal managers.

Purposive sampling of key informants is a nonprobability sampling technique that is used extensively for qualitative data collection (Bernard 2006). The benefit of this sampling procedure is that it provides the means by which to select participants who have extensive local knowledge, observations, and expertise that pertain to the research goals (Patton 2002). Key informants can provide rich, detailed information as to what occurred on the landscape during recent drought episodes in the context of specific management targets that were of concern. These perspectives also help illustrate the complex social and ecological contexts in local scales, and thus how the case examples were similar and/or different. The number of key informants in purposive sampling is intentionally small and therefore is not intended to provide broad generalizations across our case sites or to be a representative sample of DOI and tribal natural resource management. The interviews consisted of 10 questions pertaining to drought definitions; risk perceptions; management decisions and responses affected by drought; drought indicators and climate science used; impacts on livelihoods, fish, and wildlife; and adaptive capacity and barriers to respond to drought (see the appendix).

2) Step 2: Data analysis

Data were analyzed using a modified grounded theory methodology (GTM). GTM is an inductive discovery process where concepts, meaning, and theory are derived from analysis of the data themselves in an effort to minimize researcher bias, rather than deductively where theory and assumptions are imposed on the analysis (Mills et al. 2006; Glaser and Strauss 1967). The modified GTM argues that data analysis should be a compromise between inductive and deductive inquiry and provides the means by which to identify concepts, patterns, and interactions that arise from the data as in a traditional grounded theory method, but also to analyze the data in the context of relevant literature (Charmaz and Bryant 2010). For example, in this paper, a determinants approach was used to identify what determines or causes drought vulnerabilities and adaptive capacities (Fussel and Klein 2006; Grothmann and Patt 2005; Ford et al. 2010). General determinants and types of drought adaptation decisions identified in the literature were used to develop the interview protocol and the initial coding scheme. However, those that were context-specific were derived from the resource managers themselves (Smit and Skinner 2002).

Semistructured interviews were analyzed using Atlas.ti (http://atlasti.com/), which is a tool for organizing qualitative and narrative data to create nominal variables (i.e., codes) that can then be queried for analyzing the patterns among, and relationships between, those variables (Hwang 2008; Lewis 2004). First, each of the interviews was transcribed and uploaded to a single database within Atlas.ti. Second, segments of text were coded, which represent themes or categories that arose while analyzing the interviews. Third, we conducted a series of analytical functions commonly used in Atlas.ti, including, for instance, the number of times various codes occur (i.e., groundedness) and the ways that individual codes are related to one another (i.e., co-occurrence, which is the number of times two codes appear in the same segment of text; Gibson and Brown 2009). Code queries and network analyses of these codes and code relationships were used to identify the interactions between climate exposures, ecological impacts, and management responses and to determine the different ways in which historic drought manifested on these landscapes. It is through this iterative process of running the various tests described above that allows researchers to become increasingly grounded in the data, and in doing so provide a deeper understanding of the social and ecological contexts within each case site. Initial insights from the analysis are presented in the form of real-world examples of drought impacts on management issues using exemplar quotes from resource managers across the two case sites. These examples demonstrate the importance of local understandings of drought impacts that cannot be generated through drought indicators based on climate and other climate-related physical variables alone.

3. Drought-impacted and natural resource management in two case examples

Initially, we selected two field sites across the north-central United States in northwest Colorado and southwest South Dakota (Fig. 1). These locations were chosen to reflect a variety of DOI bureaus and tribal lands across management agencies (BLM, NPS, FWS, BIA) and among land managers with diverse expertise (Table 1). These areas have experienced high exposure to and impacts from drought, especially over the last two decades.

a. Northwest Colorado

The Yampa River basin (YRB) in northwest Colorado covers approximately 7660 mi^2. Precipitation varies greatly across an east–west gradient, from over 60 in. in the eastern, mountainous areas to less than 10 in. at the state line with Utah (CWCB 2009). Water availability comes from high-elevation snowmelt during peak runoff periods (mid-May to mid-June), which is dependent upon winter and spring snows. Managers rely heavily on winter snow/precipitation for livestock and wildlife forage production and adequate streamflow for beneficial uses such as irrigation, fisheries and riparian ecosystems, coal-fired power production, municipal use, and recreation/tourism. Snowpack is typically abundant in the higher, eastern portions of the YRB. However, during times of extreme drought there is limited water both physically and legally available to distribute between consumptive and nonconsumptive uses (McNeeley 2014). The agricultural sector contributes to the bulk of water use in the YRB (~80%), although it is projected that the power and municipal sectors will increase demands two- and threefold by 2045, respectively (Roehm 2004).

b. Southwest South Dakota

The Black Hills, Badlands, and surrounding area of southwest South Dakota contain public lands managed by the NPS, BLM, and BIA and include the headquarters of the InterTribal Buffalo Council (ITBC) and two Indian reservations (Pine Ridge and Rosebud). Ranching of cattle and bison are primary livelihoods in

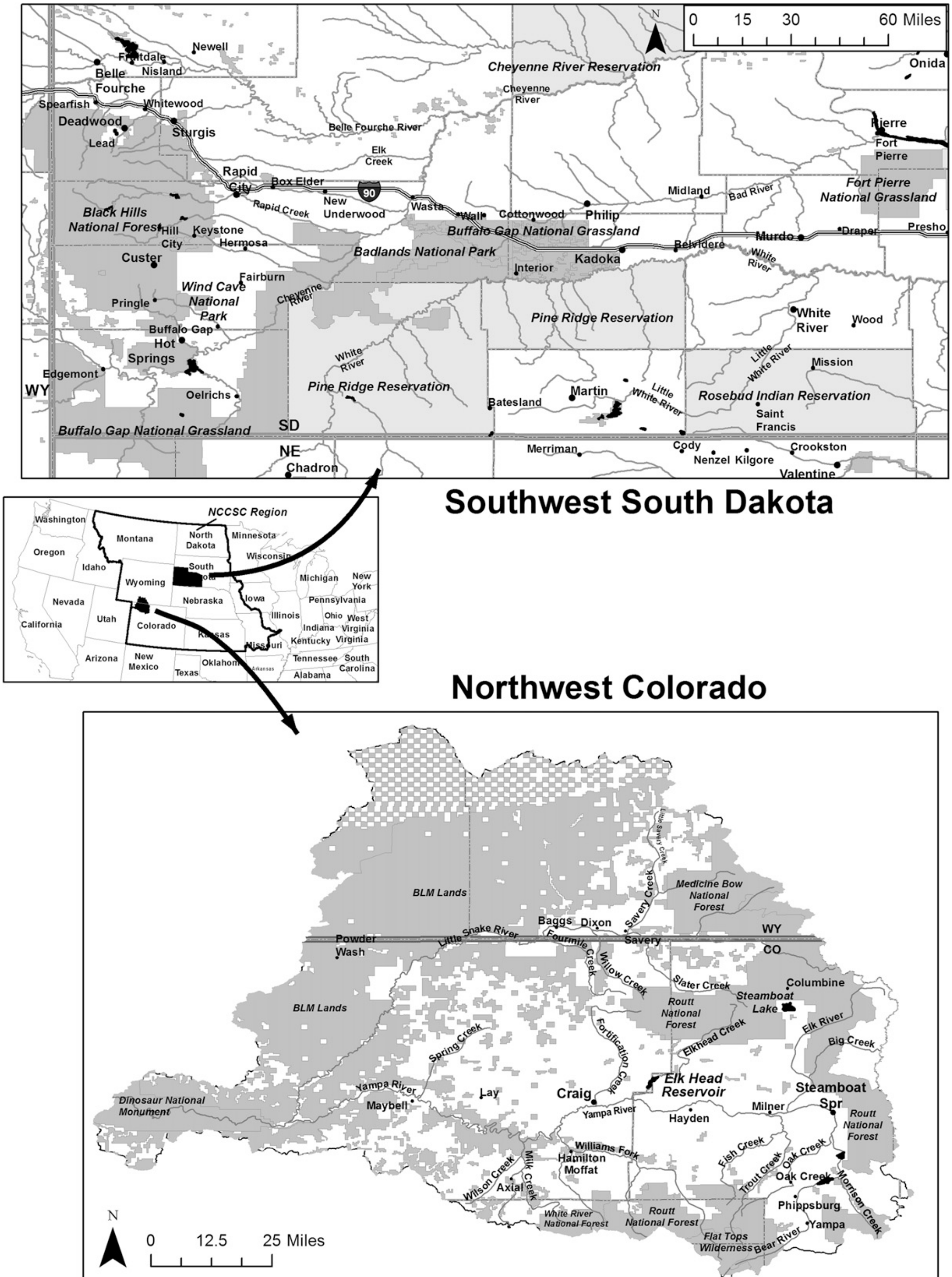

FIG. 1. Location of case sites in relation to North Central Climate Science Center (NCCSC) region (map credit: Robert Flynn, NCCSC). Features in dark gray are federally managed lands; features in light gray are tribal reserved lands.

TABLE 1. Interviews by affiliation and position in northwest Colorado and southwest South Dakota case sites.

Case sites No. of interviews	Northwest Colorado 7	Southwest South Dakota 13
Affiliation	DOI ($n = 4$) [BLM ($n = 2$), USFWS ($n = 1$), NPS ($n = 1$)], water managers ($n = 3$)	DOI ($n = 7$) [NPS ($n = 5$), BLM ($n = 2$)] NRCS ($n = 1$), ITBC ($n = 1$), Rosebud Reservation ($n = 2$), Pine Ridge Reservation ($n = 2$), OSPRA ($n = 1$)
Position	Water managers ($n = 3$), ecologist ($n = 1$), refuge manager/park superintendents ($n = 2$), rangeland manager ($n = 1$)	Wildlife biologists/technicians ($n = 6$), ecologists ($n = 2$), rangeland managers ($n = 3$), fire manager (1), tribal college natural resource management faculty and staff ($n = 2$)

the region, and the NPS and tribes manage multiple bison herds.

The region is part of the northwestern Great Plains ecoregion, a semiarid environment that is dominated by grassland communities and badlands formations (National Park Service 2004). Annual precipitation is variable, but averages approximately 16 in. in the area surrounding Badlands National Park, 70% of which falls during the growing season in May and June (Amberg et al. 2012; Smart et al. 2005). Snowpack is limited but an important source of water availability for rangelands, which depend on winter snow runoff and spring precipitation to fill streams, seeps, and springs for livestock and bison. However, during drought episodes the amount of water that reaches these areas becomes limited (Amberg et al. 2012).

Although climate projections suggest a slight increase in precipitation across the northern plains, the region is expected to be drier because of increased evapotranspiration, and the timing and amount of precipitation will be altered (Ojima et al. 2015). It is well understood that precipitation is the primary factor driving forage production in rangelands (e.g., Lauenroth and Sala 1992; Oesterheld et al. 2001), and in the northern plains the timing of precipitation events is a critical factor (Smart et al. 2005). Spring and early summer rain is responsible for over 90% of total annual forage production (Smart et al. 2005; Heitschmidt and Klement 2004). Therefore, drought and changing precipitation patterns limit water availability, possibly reduce forage productivity [Brookshire and Weaver (2015); also see Amberg et al. (2012) for discussion on this topic], and result in impacts to ranching and agriculture sectors and wildlife.

4. Findings: Differential drought manifestations across two case examples

Although a full examination of the regional climate is beyond the scope of this paper, we briefly introduce drought events from 2000 to 2012 to situate our case studies within the regional context. The north-central U.S. region has experienced several extreme to exceptional droughts in the first two decades of the twenty-first century, most notably the droughts of 2002, 2006, and 2012. The 2002 drought was widespread and severe; 50%–60% of the region was under extreme to exceptional drought, including all of Colorado and large areas of Wyoming, Nebraska, and South Dakota (Fig. 2). Drought conditions persisted in some areas into 2003–05, though the extent of severe drought conditions was significantly reduced. The drought of 2006 was much less widespread, but high exposure was seen throughout South Dakota. Parts of Wyoming, Nebraska, and Colorado were also impacted (Fig. 2). The percent area under extreme drought in 2012 was comparable to the 2002 drought episode. Large areas of Colorado, Kansas, and Nebraska were affected. However, the area under exceptional drought was more widespread in 2012 (~30%), which started in the spring and early summer and lasted into the spring of 2013 in some areas (Fig. 2). The 2012 drought was much less persistent across the north-central U.S. region, relative to the 2002 drought.

While there are many impacts that land managers discussed with regard to these drought periods, herein we report on some key early insights from one high-priority management issue for each case to demonstrate the importance of local experiences and understandings of drought from DOI and tribal managers' perspectives. In northwest Colorado we focused on endangered fish recovery, and in southwest South Dakota we focused on bison management. Table 2 illustrates the top co-occurring codes with each management target that helped frame our findings around the most relevant climate exposures, impacts, responses, and constraints experienced by the managers that we interviewed.

a. *Northwest Colorado: Endangered fish recovery*

Multiple sectors and resources were affected by the exceptional 2002 and 2012 drought periods in the YRB, but here we focused particularly on impacts associated with the Upper Colorado River Endangered Fish Recovery Program (Recovery Program henceforth) because

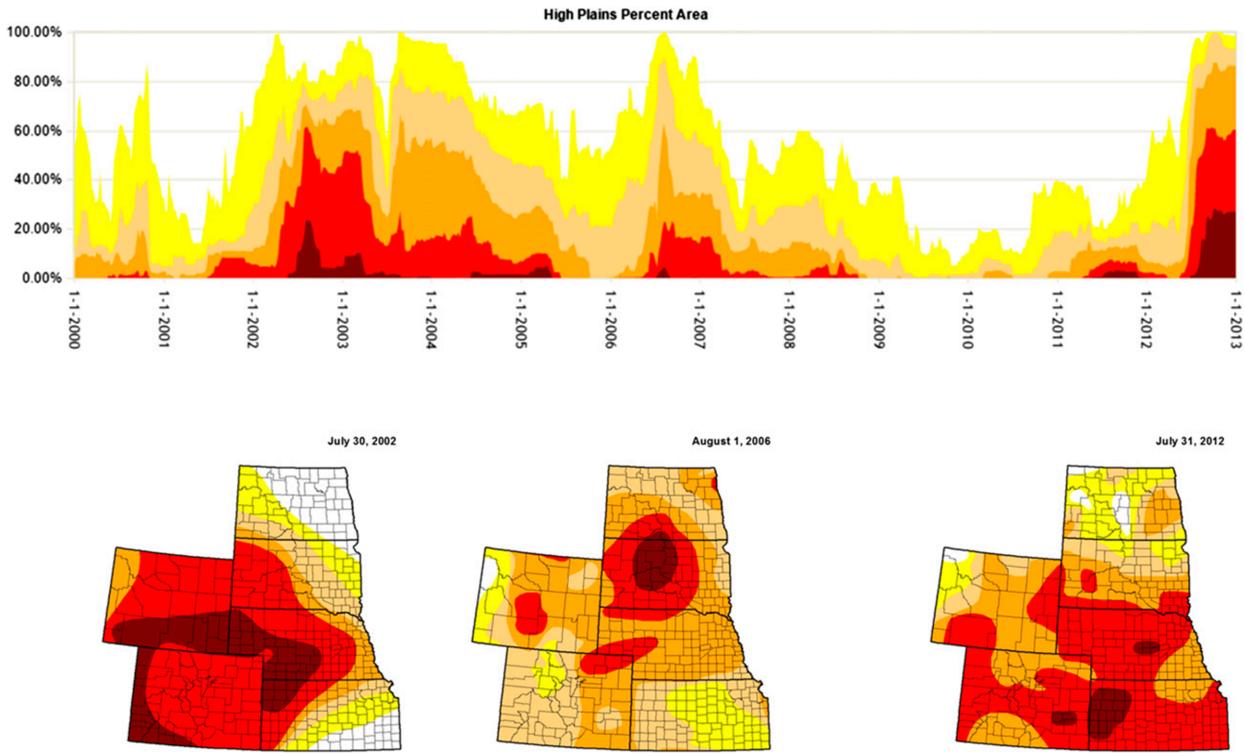

FIG. 2. U.S. Drought Monitor depicting (top) percent area of northern Rocky Mountains/high plains region under various drought severities for the period January 2000 to December 2012 and (bottom) weekly drought severity reports during the last week of July or first week of August for the three drought years, 2002, 2006, and 2012. Drought severities are D0, abnormally dry (yellow); D1, moderate drought (brown); D2, severe drought (orange); D3, extreme drought (red); and D4, exceptional drought (dark red). Drought categorizations are based on several indicators, including the Palmer drought severity index, the Climate Prediction Center (CPC) soil moisture model, USGS weekly streamflow, Standardized Precipitation Index, snowfall, objective drought indicator blends, and local observations. The U.S. Drought Monitor is jointly produced by the NDMC at the University of Nebraska–Lincoln, the U.S. Department of Agriculture, and NOAA. Map courtesy of NDMC (http://droughtmonitor.unl.edu/MapsAndData/WeeklyComparison.aspx).

it is a DOI high-priority conservation target; is a collaboration between the USFWS and other local, state, and federal agencies, along with environmental groups; and was discussed extensively among resource managers in the YRB. The Recovery Program is intended to protect critical stretches of habitat along the mainstem of the Yampa River, from the town of Craig west 140 river miles to the confluence with the Green River near the Utah border, for four endangered native species in the upper Colorado River basin (humpback chub, bonytail, Colorado pikeminnow, and razorback sucker; Roehm 2004). The Recovery Program managers negotiate reservoir releases for instream flow (ISF) with water managers to protect riparian environments and fish spawning habitats (Speas et al. 2014), remove and inhibit nonnative species in the stretch (Breton et al. 2014; Zelasko et al. 2015), construct and maintain fish passages (Roehm 2004), reintroduce endangered fish into historic habitats (Zelasko et al. 2011), and monitor and assess endangered fish and their habitats (Bestgen et al. 2012).

The Recovery Program was initiated in 1988, an exceptional drought year, following the signing of a cooperative agreement among USFWS, Colorado, Wyoming, Utah, Western Area Power Administration, and the Secretary of Interior, stemming from concerns of other sectors that enforcing the Recovery Program would impact water allocation in the basin (Recovery Program 1988). The Upper Colorado River Basin Compact of 1948 codifies that Colorado may not deplete more than 5 million acre-feet (AF) over a 10-yr period from the Yampa River. Although historic usage in the basin has been on the order of 160 000 AF per year (AFY) and the Compact has not served as a constraint on usage, the Recovery Program has recently called for continued water use and for development of up to an additional 50 000 AFY for consumptive use, which may impact water administration in the future (CWCB 2009). It is important to note that while usage is low relative to Compact terms, during drought years the basin is still stressed, as we will demonstrate below (see Fig. S1 in the supplemental material).

TABLE 2. Top co-occurring codes with respect to the management target in each case site. (Co-occurrence is a term used in Atlas.ti to refer to the number of times two codes occur together in the same segment of text.) The frequency of co-occurrence indicates the number of times that these individual codes co-occurred with fisheries in northwest Colorado and bison in southwest South Dakota.

Northwest CO: Endangered fish recovery		Southwest South Dakota: Bison management	
Variable	Frequency of co-occurrence	Variable	Frequency of co-occurrence
Streams, rivers, and streamflows	11	Vegetation	28
2012 drought	8	Ranching and grazing	24
Threatened and endangered species	8	Forage ecosystem services	17
Energy	7	Precipitation	16
Water use	7	Water availability	16
Municipal or domestic water use	6	Prairie dogs	15
Reservoirs and storage	6	Streams, rivers, and streamflows	15
State government or agencies	6	Elk	14
Vegetation	6	Adaptive capacity	13
Fish and wildlife service	5	Climate change	12

Water allocation in Colorado is governed in accordance to a prior appropriation system—that is, ‘‘first in time, first in right,’’ whereby senior (older) water rights holders have priority over junior (newer) rights holders. Under this allocation scheme, senior rights holders who do not receive their full right in a given water year may place a legal curtailment call, which forces junior rights holders to reduce their usage. State water engineers and regional water commissioners are responsible for determining how much each user is able to divert (or not), and in times of shortage may take control of diversion head gates for those junior users who are out of priority. The majority of senior water rights are held by agricultural operations and energy companies and not by the Recovery Program, thus creating differential sensitivities throughout the basin. An additional sensitivity is that there are no large, federally managed storage facilities in the study area, which instead consist of relatively small facilities. However, despite limited water availability and complex water rights, there has yet to be a formal curtailment call on the mainstem of the Yampa River, which is primarily due to collaborative efforts between multiple agencies and industries during drought periods (McNeeley 2014).

The 2002 drought was gradual in its onset, characterized by below-average accumulation and warm temperatures during the winters of 1999–2000; hot temperatures, low soil moisture, and high transpiration rates in the summer of 2000; and two drier-than-normal years leading into 2002 (Table S1; Pielke et al. 2005; McNeeley 2014). The surface water supply index for the basin indicated severe drought throughout the peak runoff periods, peak flows were one-third of the average, and runoff occurred 7–10 days earlier than is typical (Colorado Division of Water Resources 2002). By March of 2002, land managers in the YRB knew the basin was going to experience a bad drought year, as indicated by reduced snowpack during the winter months. Water levels were so low in some parts of the river that the region saw deleterious effects to riparian ecosystem health. Upper Yampa Water Conservation District managers responded in early April by implementing voluntary reservoir releases to avoid a formal curtailment call (McNeeley 2014). Releases were made continuously during this period until a precipitation event in mid-August pulled the system out of drought. As one water manger said, ‘‘the reservoirs definitely were a saving grace... even the division engineer in 2002 said the river virtually would have been dry had it not been for reservoir water’’ (K. Bower 2013, personal communication).

Several actions were taken following the 2002 drought, including a state statute that allows water rights owners to loan water to the Colorado Water Conservation Board, who then are able to authorize water leases on short notice during a drought emergency. This statute provides greater flexibility to manage ISF resources ‘‘in season’’ and foregoes the longer processing times and costs of requesting leases through the Water Court (McNeeley 2014). Additionally, the Yampa River Endangered Fish Management Plan was established, and Elkhead Reservoir was expanded to include more water for the Recovery Program and other uses (McNeeley 2014). These changes provided additional protection for fisheries in the critical habitat stretch; provided extra storage within close proximity to the local power plant, the city of Craig, and the critical habitat stretch; and allowed for innovative solutions for sharing and short-term leases.

The onset of the 2012 drought episode occurred much quicker than the 2002 drought period and followed a record wet year in 2011 (Table S1). According to one manager, ‘‘it just seemed like it was dry from the very start [of 2012]. We didn’t have any runoff, we didn’t have any moisture in the ground, [and] nothing turned green’’

(K. Bower 2013, personal communication). Similar to 2002, when it became apparent that drought was coming, weekly conference calls were administered between USFWS and other agencies (e.g., TriState Power, Colorado Division of Water Resources, NOAA) to monitor flows and discuss reservoir releases for the fish from Elkhead Reservoir. The Recovery Program recommends that releases be made from Elkhead Reservoir when flows fall below 93–134 cubic feet per second (cfs) during the period August to October to maintain fish habitat. However, in early July, daily flows near Maybell were 34 cfs, and releases were initiated (Light 2013). In fact, discharge rates were 2–3 times lower than the decreed amounts for portions of the YRB for several weeks (Fig. S1), and reservoir releases continued constantly from July until the system pulled out of drought in mid-September. A water manager mentioned that the limited runoff in 2012 did not fill the reservoirs, but because there was a lot of carryover from 2011 there was a sufficient amount of water in the YRB (Anonymous water manager 2013, personal communication). In fact, the period between the two drought periods was characterized as a wetter moisture regime, and one manager discussed the resilience of the system to drought given appropriate time for recovery (Anonymous BLM representative 2013, personal communication). However, managers worried about how persistent drought of 2002-like severity for 2 or more years would impact the system. The releases during both drought periods benefited the Recovery Program, as well as the agriculture, municipal, and energy sectors. It is estimated that the Recovery Program has contributed $300 million in savings to users across the upper Colorado River basin over the last 10 years as a result of reduced water and litigation costs (Loomis and Ballweber 2012).

b. *Southwest South Dakota: Bison management*

Southwest South Dakota experienced three periods of extreme to exceptional drought during the 2000s (Fig. 2). Similar to YRB, the area experienced exceptional drought conditions in 2002 and 2012. However, the area was also impacted by exceptional drought conditions in 2006 (Fig. 2). Managers suggested that drought impacts persisted from the earlier 2002 drought to 2007, and finally broke in 2008. This observation is in general agreement with Palmer drought severity indices for the region and time period (Fig. S2). Therefore, we report impacts and responses for the persistent drought of 2002–07 and the shorter-lived 2012 drought. Although many sectors were affected by these drought episodes, we focused on bison management in the NPS (Badlands and Wind Cave National Parks) and among tribal land managers.

Bison are an emblematic species of the Great Plains that once roamed across the United States, and they have a high degree of cultural significance to tribal communities. Bison are considered a keystone species for grassland ecosystems as they increase biodiversity, regulate nutrient redistribution and functioning to influence productivity, and their wallowing creates microhabitats for wetland species (Knapp et al. 1999). The DOI has made great efforts to restore bison to their native range and historic role in grassland systems through management of bison on NPS-, BLM-, and USFWS-managed lands, and in collaboration with tribal land managers. In Wind Cave and Badlands National Parks, bison management is part of the enabling legislation, and they frequently partner with the Oglala Sioux Parks and Recreation Authority (OSPRA) of the Pine Ridge Reservation and the ITBC to round up and provide surplus bison to tribes in order to facilitate bison restoration on tribal lands for conservation, economic development, and to maintain cultural values (Department of the Interior 2014; Freese et al. 2007). Additionally, South Dakota is the top state in the United States for private-sector bison production markets (Department of the Interior 2014).Therefore, it is not surprising that among the land managers we interviewed on tribal and NPS lands, bison management was one of the most significant concerns that was discussed in the context of drought.

Bison are managed as a ''natural'' population on most DOI-managed lands, meaning that bison are considered wildlife that are in settings characteristic of their historic range with sufficient access to resources. Therefore, to date, management plans for supplemental feed and water delivery tend to be limited or nonexistent. However, in most cases bison are confined to fenced enclosures that do not represent natural boundaries and create unique pressures on water and forage resources for bison and other wildlife during drought. As a rangeland manager from the ITBC emphasized, ''a big impact that we need to address, particularly, [is] stocking rates and nutrition and feeding of the bison...we consider them wildlife, but, unfortunately....we have to, of course, have a fence, so we have to try to figure out ways to keep them wild but still be able to manage them'' (T. Ecoffey 2013, personal communication).

The drought of 2002–07 was relatively gradual in onset and long in persistence, characterized by 3 out of the 6 years with below-average rainfall (Tables S2, S3; http://droughtatlas.unl.edu/). During this period a lack of winter snow accumulation and spring rain resulted in reduced surface water availability and forage quality for bison and other wildlife. Packing and trampling occurred in riparian areas, creating bank destabilization issues and soil erosion. At Pine Ridge Reservation, many of the springs that bison rely on ran completely dry, and managers responded by opening up springs (T. Ecoffey 2013, personal communication). At Wind Cave National Park, park officials began to investigate ways to provide additional water to the park and determine their water rights as the prolonged drought started to become a concern. Increased development along the Beaver Creek, which flows into the western portion of the park, further stressed water availability in the park. Fortunately, however, the drought broke early in 2008 before any drastic measures were required, and was followed by 3 years of above-average precipitation. However, managers worried whether the existing management strategy for bison was sustainable under future climate change, and they argued that addressing water rights and spring development in the park was critical, especially considering the conflict that may occur if bison were to break out of enclosures onto adjacent private land in search of water, where they would be considered trespass livestock (G. Schroeder 2013, personal communication).

The 2012 drought onset was more sudden, and importantly, followed 3 years of above-average (and even record) rainfall. The years 2008–10 rank as some of the wettest years across the time period 1980–2012 in the region (Tables S2, S3; http://droughtatlas.unl.edu/). The 2012 drought was also characterized as a much more severe, unusually hot and dry summer. The year 2012 was the hottest year on record for the period 1980–2012 and was the second or third driest year, according to weather stations near Wind Cave National Park and Badlands National Park, respectively (Tables S2, S3; http://droughtatlas.unl.edu/). Similar to the 2002–07 drought period, Badlands National Park and Pine Ridge Reservation experienced issues of wildlife packing near riparian areas and as a consequence suffered similar impacts to those described above. Managers on NPS and tribal lands try to limit supplemental feed supplied to bison, but during the 2012 drought bison managers at Pine Ridge Reservation had to purchase hay, which was a significant expense for the tribal herd managed by OSPRA (T. Ecoffey 2013, personal communication). However, managers suggested that the impacts overall were not as severe in 2012, in part because the onset was relatively quicker (months to a year versus many years) and was preceded by three years of above-average precipitation, and the drought was not as persistent in duration as those events earlier in the decade, the combination of which allowed for sufficient recovery in places.

However, it did surprise Wind Cave National Park managers in terms of how quickly a drought could impact resources. As one manager mentioned, ‘‘last summer [2012] it was not any drier [than previous drought years] but it was much hotter than usual and it really just sucked the moisture out of the ground and all of the springs and ponds and perennial streams. It was amazing, in one year's time what a deficit we had in soil moisture and those kinds of things’’ (D. Roddy 2013, personal communication). In response, park managers implemented a long-term monitoring and assessment program to document grazing impacts to riparian areas and forage availability. Land managers were concerned about the impacts that would be associated with a hot and dry drought episode, similar to that of 2012, that persisted for multiple years. A wildlife biologist mentioned that ‘‘if last year would have lasted to this year it would have hit us much harder and quicker and what I'd call a prolonged drought. . . . if it would have been as hot as it was last year over those four to six years [2002–2007] I'm not sure [what would have happened]. . . we would have really been scrambling at that point’’ (D. Roddy 2013, personal communication).

Maintaining proper stocking densities was another major issue that was discussed in the context of bison management. Typically, managers strive to alternate between years with higher stocking densities and years with lower densities to balance grazing pressure on forage and provide ample time for recovery. On NPS-managed land, this is achieved through bison round-ups that occur annually (Buhnerkempe et al. 2011). Surplus bison from DOI lands are donated to tribal herds in coordination with the ITBC and OSPRA for bison restoration or are culled. Private tribal bison producers at times can distribute surplus bison for family and ceremonial use and for community health programs (Zontek 2007; Pickering and Jewell 2008). However, maintaining bison stocking densities are limited when compared to livestock. For instance, rounding up bison logistically requires more energy to conduct, the market available to sell off bison is not as large and established as it is for cattle production, and funding or institutional constraints may preclude round-ups from occurring. In these circumstances, managers are forced to manage for populations above carrying capacity. For instance, bison are confined to a 64 000-ac enclosure in the North Unit of Badlands National Park, where recommended carrying capacity is between 600 and 700 bison (Amberg et al. 2012; Department of the Interior 2014). However, at the time of the interviews, managers estimated anywhere between 1000 and 1200 bison in the park. As a manager at Badlands National Park mentioned, ‘‘I always worry, if we have a drought, are we going to have enough forage for the bison? Or are they going to damage it by overgrazing?’’ (M. Harr 2013, personal communication). This concern was echoed at Wind Cave National

TABLE 3. Vulnerability of the SES in northwest Colorado and southwest South Dakota to drought.

	Northwest Colorado: Endangered fish recovery	Southwest South Dakota: Bison management
Exposure	Reduced winter snowpack	Reduced winter snowpack
	Reduced streamflow, timing of flows altered	Reduced spring rain
Sensitivity	Limited storage facilities	Bison confined to enclosures
	Complex water rights limits water allocation across sectors	Stocking densities above recommended at times: round-ups limited by financial and institutional constraints
		Increased development outside of park
Impacts	Reduction in riparian and fisheries health	Reduced forage productivity
	Limited surface water during drought	Reduced water availability in streams, seeps, and springs
		Packing in riparian areas, soil erosion
Responses	Voluntary reservoir releases	Opening of springs
	State statute for leasing of additional water for ISF	Supplemental feed
	Expansion of Elkhead Reservoir	Initiation of long-term monitoring and assessment plan
	Establishment of Yampa River Endangered Fish Management Plan	Discussion of water rights and water delivery

Park, where a manager suggested that, ‘‘if we see drought coming, or we know drought’s going to be coming more and more often, we’re not going to get the recovery, so we can’t take the chance to be at a high intensity grazing’’ (G. Schroeder 2013, personal communication).

5. Discussion: Differential drought risks and responses across space and time

Key differences in the SES context of the place and management issues in each case site determined how drought exposures manifested locally and how certain managers responded to the impacts based on their respective response capacities or barriers. Differences in the local contexts of these management issues demonstrated why these distinctions matter for empirically understanding local vulnerabilities to drought. Table 3 summarizes the SES exposures, sensitivities, impacts, and responses presented above from the two case examples, which are briefly reviewed here.

In the northwest Colorado case example, limited snowpack in the preceding winter reduced, and altered the timing of, streamflow available for downstream consumptive uses during both the 2002 and 2012 drought periods. These factors, coupled with the system’s small storage facilities and complex water rights that give priority to the agricultural and energy sectors, resulted in limited surface water during drought years, with deleterious effects to fisheries and riparian health. Managers across jurisdictions utilized social capital to administer voluntary reservoir releases during both drought periods and responded to the 2002 drought period directly by implementing a state statute for management of ISF (Table 3). Additional factors supported the management of fisheries in the YRB during dry years, such as the establishment of the Yampa River Endangered Fish Management Plan in 2004 and the expansion of the Elkhead Reservoir.

Reductions in winter snowpack and spring rain impacted land and resource management in the southwest South Dakota case example during both the 2002–07 extended drought and the 2012 drought. These climate exposures were exacerbated by sensitivities that characterize bison management in the region. For instance, bison are confined to fenced enclosures that restrict long-range foraging, while financial and institutional constraints limit the ability of managers to maintain proper stocking densities. Additionally, increased development in areas created additional stresses on water management for bison under these conditions. The combined effects of drought exposure and sensitivities resulted in significant reductions in forage productivity and water availability (Table 3). Additionally, packing occurred in riparian areas where water and forage did remain, creating soil erosion issues. Managers responded by opening springs and supplementing feed in late summer on tribal lands. NPS field office managers initiated a long-term monitoring plan to assess drought impacts on grazing and riparian areas and sought clarification of water rights in the event that additional water would be required for bison (Table 3).

The differences in each case example with regard to the onset, persistence, and recovery time of the drought episodes differed within and between each case example. As a result, the management targets of concern differed, as did the impacts and responses undertaken. In the northwest Colorado case example, the 2002 drought episode was more severe than the 2012 drought because of below-average rainfall for a number of years preceding the 2002 drought, which had repercussions for the amount of carry-over water that was held in the small storage facilities in the basin. However, the return to a wetter moisture regime in the interim between drought periods provided significant time for the recovery of resources in places. Managers worried that persistent drought of 2002-like severity for 2 or more years would severely impact water availability in reservoirs, which is the only thing that keeps rivers flowing and fish alive during times of drought.

The drought periods of the 2000s across southwest South Dakota resulted in differential impacts to bison management across time. Both periods stressed water and forage resources, thus altering management decisions on the ground. However, it appears that, at least for this area, the prolonged 2002–07 drought had more lasting impacts, due in part to the extended period of below-average precipitation (i.e., persistence), but also because the 2012 drought was preceded by 3 years of above-average precipitation. Managers' major concerns were that under persistent drought, especially under conditions that are both hot and dry, as was the case in 2012, traditional grazing management options for alternating between high and low stocking densities may not be viable because of reduced recovery time for forage production.

The drought of the mid-2000s was much more significant to managers we interviewed in the South Dakota case versus the Colorado case because of the longer onset and persistence that resulted in managers having to respond in unprecedented ways given the lack of water for bison. Therefore, it is clear that drought is not uniform but is dependent upon the resource management issue along with variability in drought onset, persistence, severity, and recovery across space and time (Wilhite et al. 2014).

6. Conclusions

The impacts of drought and the response options available to individuals are the product of both social and biophysical processes. Therefore, drought impacts and adaptation cannot be understood solely on the basis of meteorological, hydrological, and economic indicators. Instead, a method of inquiry that considers the sociocultural dimensions of drought with respect to local nuances and issues that are relevant to those who are responsible for managing resources during drought events is warranted.

The purpose of this exploratory study was to illustrate the ways in which some DOI and tribal natural resource managers experienced and dealt with drought episodes in the 2000s in two case examples across the north-central region of the United States. Specifically, we drew from in-depth interviews and drought indicator data to identify management targets of concern; social–ecological vulnerabilities to drought; and how the onset, severity, and persistence of drought episodes affected management.

Our findings indicate that although drought is a phenomenon that occurs at broad, regional scales, the social–ecological contexts within which natural resource management occurs matters for local impacts and responses. And while large-scale tools for monitoring, such as the U.S. Drought Monitor, are useful for understanding broad patterns of drought, there is no "one size fits all" dataset or tool for understanding local drought impacts and response. In particular, our research findings provide initial insights that differentiate drought impacts associated with specific management targets. In the northwest Colorado case example, the importance of managing for endangered fish recovery resulted in issues of streamflows, reservoir releases, water rights, and institutional collaborations and cooperation being the key determinants to managing the system under severe to exceptional drought conditions. In the southwest South Dakota case example, on the other hand, bison management required an understanding of forage production and water availability in streams, seeps, and springs, along with cultural and tribal implications and institutions. Additionally, our findings illustrate the different ways that drought onset, severity, persistence, and recovery impact vulnerabilities in local contexts and between natural resource management targets.

These findings together illustrate the importance of identifying the local contextual factors that determine vulnerabilities to change and point to a few specific insights. First, it is clear that drought is a biophysical and social process and that analyses that consider either in isolation are insufficient. Instead, an SES perspective is needed to characterize drought vulnerabilities and differences with respect to drought onset, persistence, and severity. Second, there are no generic drought responses. Instead, responses are embedded within local social, political, economic, and ecological contexts, and the decisions that are made to manage these lands are in part determined by these factors along with the local knowledge and experiences of the individuals who manage these lands. Third, regional drought monitoring tools are insufficient tools for supporting management decisions when used in isolation, which is due in part to the fact that drought events are not uniform. These tools overlook the locally embedded factors described above; however, they also ignore distinctions between flash and creeping drought impacts and ways that recovery time, or lack thereof, impacts natural resource management. In a similar vein, the particular exposures that create drought impacts may differ between drought periods, and therefore, so too will the indicators used to monitor exposures. All of these nuanced issues should help shape the science that we do in terms of spatial and temporal scales of analysis as well as the drought indicators that are most important to the place of interest and meaningful to the managers themselves. It is not to say that monitoring tools are not capable of such considerations, but rather, to point out the insights that can be gained when using them in conjunction with social science research methods that emphasize the importance of local knowledge and experiences to produce more meaningful and relevant tools that support decision-making under drought.

A next step for this research will be to explore providing more accurate storylines for climate monitoring tools and projections by incorporating insights and lessons learned from experts and local knowledge into climate science. This is consistent with the goals of the DOI regional Climate Science Centers to provide managers and other decision-makers with climate science tools that are salient, relevant, and legitimate resources to support effective land and resource management under drought.

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APPENDIX

Drought Risk and Adaptation in the Interior (DRAI) Interview Questions Protocol

1) How do you define or think about drought in the context of your landscape?
2) Do you view drought as a significant risk to your management activities?
3) [if yes to #2] At what time of year is drought most problematic (how/why) [this is getting at seasonality/timing issues]?
4) What year (or years) was the worst drought in this area? What happened?
5) What management decisions do you have to make that are affected by drought?
6) a. What, if any, indicators do you use to know if/when/how drought is going to cause negative impacts on your landscape? b. What do you consider to be the best source or sources of information on drought?
7) Are there fish, wildlife, and/or plant species you haven't mentioned impacted by drought in your landscape?
8) a. Are there human livelihoods or other activities impacted by drought in your landscape? b. Does this cause any conflicts? c. Do you collaborate with other stakeholders or jurisdictions on drought-related issues? If so, with whom and how?
9) Do you have the capacity to either respond to or prepare for drought?
10) Are there barriers that inhibit your ability to respond to or prepare for drought?
11) Anything else we haven't discussed?

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