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Assessing Drought Vulnerability Using a Socioecological Framework

By Joel R. Brown, Doug Kluck, Chad McNutt, and Michael Hayes

On the Ground

- Drought is a persistent problem on rangelands and adjusting management to respond appropriately is critical to both preserving natural resources and to maintaining financial viability.
- We explore the value of using a structured assessment approach to determining both social and ecological vulnerability.
- This approach allows for the identification of vulnerable ecosystems and business operations at regional and local scales as a basis for developing effective policies and programs.

Keywords: rangeland drought, vulnerability assessment, policy, climate change.

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Drought (an extended period of relatively low precipitation) is a natural part of the environment and is inevitable in rangeland ecosystems.[1] It is an important ecological filter that shapes species, communities, landscapes, and regions. And, it is one of the most important factors defining rangelands and makes rangeland ecosystems unique.

Unfortunately, it also presents a major challenge to rangeland managers in their quest for sustainability, both ecological and economic. From a manager's perspective, drought tends to be a creeping and insidious natural hazard that is experienced by degrees, usually over an extended period of time. It can be difficult to determine when a drought begins or ends, and impacts can extend over a larger geographical area compared to other natural hazards, such as fire, flood, or disease.

Traditionally, the response to drought in rangeland-based livestock grazing systems has been based on maintaining financial viability while retaining as many reproductive units (cows, ewes) as possible for post-drought recovery.[2] However, changes in the economics of ranch management and an enhanced understanding of the impacts of drought on ecosystem function have forced a reevaluation of these principles. With increasingly frequent and intense drought forecast in most rangeland ecosystems due to a changing climate, responsible stewardship demands that we develop a more systematic approach to anticipating and responding to drought.

Joyce et al[3] suggested that a more structured, systematic approach to assessing the vulnerability of individual rangeland socioecological systems could help policy makers and managers develop more realistic approaches to climate change. A socioecological system is defined as a complex bio-geo-physical unit and associated social actors and institutions, all interacting in an adaptive manner to produce outcomes.[4] Importantly, a socioecological system approach not only examines the impacts of a stressor, like drought, on a system, but also takes into account what tools are available to respond. While an understanding and an ability to predict drought intensity is a valuable component, it is only relevant within the context of the specific socioecological system. A meaningful drought response approach will include policies, programs, and management developed with knowledge of the social, economic, and ecological impacts of drought and a thorough understanding of the ability of individuals and institutions at a local level.

Assessing the Vulnerability of Rangeland Socioecological Systems to Drought

The diversity of rangeland ecosystems and livestock production systems requires an approach that includes a wide range of environmental, social, and economic impacts of drought. This broad range of socioecological conditions precludes a one-size-fits-all approach to both management and policy. Vulnerability is commonly expressed as f (impact [exposure, sensitivity], adaptive capacity) (Fig. 1). Determining the potential impact of drought requires developing realistic estimates of both the exposure and the sensitivity, and integrating those two factors.

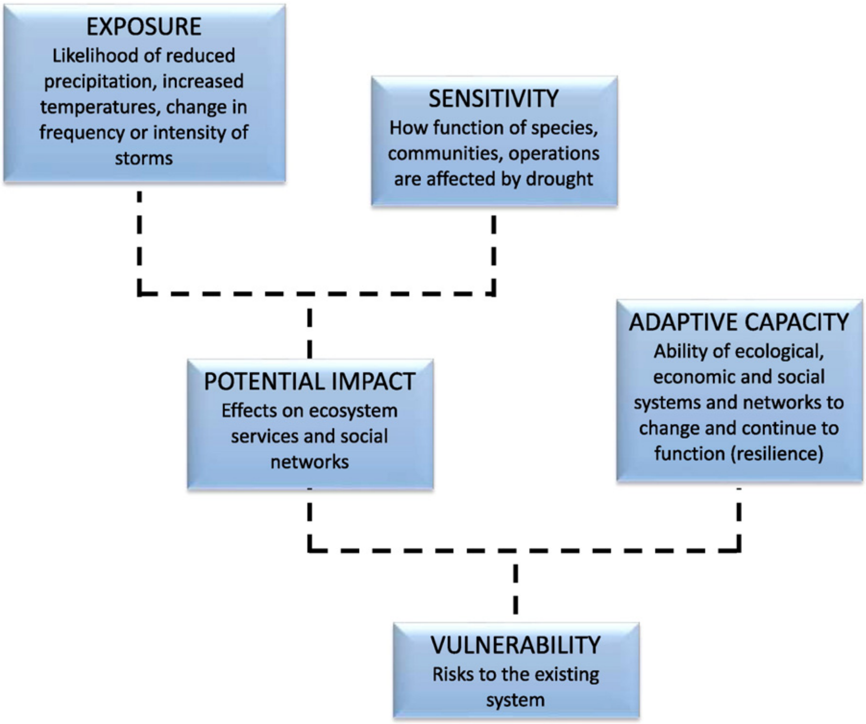

Figure 1. A vulnerability assessment framework for rangeland drought following Joyce et al.[3]

While an improved understanding of the impact of drought can be helpful in responding during a drought or post-drought recovery, a similarly rigorous estimate of the adaptive capacity is necessary to improve preparation for coming drought. Any credible vulnerability assessment requires attention to all of the components.

Exposure is the likelihood of an event occurring: how often and how severe is the drought? The vast majority of work in the research community has focused on improving the ability to predict the frequency and severity of drought. Unfortunately, accurate long-term (beyond a few weeks) prediction of precipitation is a difficult challenge. Temperature forecasts have more skill and have seen improvement but numerous gaps in monitoring, model refinement, and basic understanding of user needs across time and geographical scales make long-term drought prediction quite a difficult proposition. The National Oceanic and Atmospheric Agency Climate Prediction Center routinely issues both monthly and seasonal drought outlooks for the United States but their accuracy is limited. Seasonal forecast skill is markedly improved during strong climate events (i.e., El Nino Southern Oscillation); however, even during these rare events a particular outcome is not guaranteed.[i] National scale prediction is often not of great utility to local and regional users.

Current and antecedent data, along with the seasonal predictions, can be employed to provide an estimate of the level of drought risk *exposure*. These tools, collectively referred to as drought early warning systems show promise.[5] Where model predictive skill is lacking, engaging partners and other proven local and regional information sources to determine explicit needs (decision points) can increase the value of information and improve utility. The National Integrated Drought Information System has developed such a drought early warning system in several regions of the country. In the Missouri Basin, for example, a broad partnership of climate, agriculture, water resources, and other professionals issue a regional three-month summary of climate conditions and potential impacts of those events, including sector-specific outlook sections. In addition, there is a monthly webinar for the north-central United States to consolidate and interpret the large amount of information from state, federal, and academic sources.

Sensitivity is the term that defines how a particular organism, community, or system (economic or ecological) will respond to a particular event. A realistic sensitivity analysis requires a well-developed understanding of how the individual, community, or operation functions, particularly inputs, outputs, and feedback processes. For instance, a substantial amount of effort has been devoted to developing 'bioclimatic envelopes' for individual species to predict the impact of changing climatic variables on species distributions, and the make-up of plant communities via quantitative changes in ecological processes.[6] Climate scientists and ecologists have collaborated to make predictions of the effects of changes in temperature and rainfall on establishment, growth, reproduction, and recruitment of individuals and how those lifecycle

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[i] For example, see https://www.climate.gov/news-features/blogs/enso/what-expect-winter-noaa%E2%80%99s-outlook-reveals-what-conditions-are-favored.

processes will interact with other species and environments to create new plant communities in response to a changing climate.[ii]

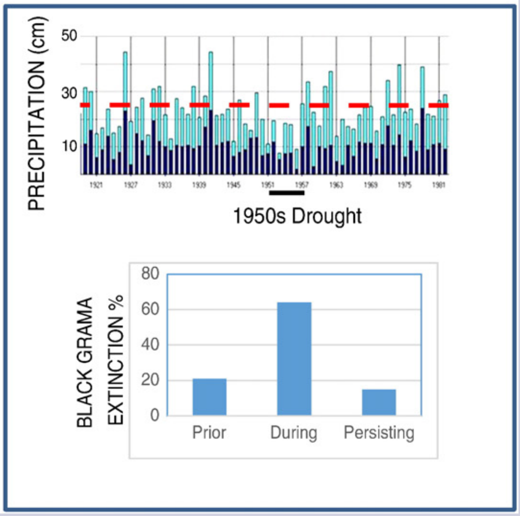
Potential impact integrates drought exposure and local sensitivity to predict how an event might affect any given rangeland socioecological system.[3] For instance, an extreme drought can have dramatically different effects on forage production, and livestock operations, depending on the soil and vegetation combinations (*see examples from the Chihuahuan Desert and Kansas prairie in the sidebars*). Although exposure to drought was similar in the mixed grass prairie of Kansas and the Chihuahuan Desert in southern New Mexico, the sensitivity of the Desert Grassland was obviously far greater than the prairie. The more resilient prairie has maintained the ability to respond and recover quickly while the plant communities of the desert system have been permanently altered. Clearly, response to drought from both a management and a policy perspective needs to be very different in these ecosystems.

An integrated combination of sensitivity analysis and exposure to drought can provide a realistic prediction of the *impacts* of drought on socioecological systems. The key is to independently develop estimates of the risk of drought (e.g., how much will precipitation be reduced and when) and sensitivity to drought (how will the reduced precipitation affect forage production for livestock operations). Then, a range of potential impacts for a particular region can be developed (e.g., cool season forage will not be affected, but warm season forage will be reduced). This approach will better define the range of possible responses of a socioecological system to varying degrees of drought frequency and intensity –the potential impact.

Adaptive capacity is a measure of how well a particular plant community, ranch, region, or sector can withstand the impacts of a drought based on the ability of individuals and institutions to respond positively. When applied to ecological systems, adaptive capacity can usually be determined by some measure of diversity (genetic, species, landscape) or how many

Effects of drought on Chihuahuan Desert Grasslands (1912-1980)

Drought has interacted with grazing and other landscape factors to have a dramatic effect on Black Grama (*Bouteloua eriopoda*) populations at the Jornada Experimental Range. Both rainfall and grass populations have been monitored for more than 100 years in a series of small plots using a pantograph technique. Total rainfall (mean=red line) is highly variable and is normally concentrated in the late summer (light blue). The 1950s drought was particularly devastating to black grama populations. Only about 20% of the sample plots completely lost black grama prior to the drought (including the 1930s). But, almost 65% of the sampled plots lost all black grama during and shortly after the 1950s drought. About 15% of the plots have persistent black grama populations. Although there are other soil and landscape factors required to explain the dynamics, it is clear that drought has had a devastating effect on the populations of the dominant forage producing species in the Chihuahuan Desert. A historical analysis of the socioecological vulnerability has chronicled a simultaneous decline in the forage base and the reduction of the livestock sector as an economic engine in this region. In this ecosystem, ecological, economic and social components have similar vulnerabilities[16].

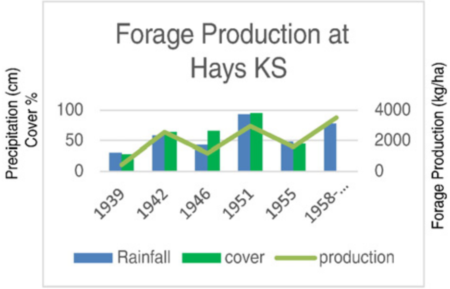


[ii] See www.climatechangesensitivity.org.

Forage Production at Hays KS 1930s-1950s

Nowhere has drought been more influential on socioecological systems than the High Plains of North America. Researchers at Fort Hays State University and the Fort Hays Experiment Station (now KSU Western Kansas Agricultural Research Center) have, for many years, followed perennial grass populations as they respond to both rainfall and grazing. The two species of major interest are blue grama (*Bouteloua gracilis*) and buffalograss (*Buchloe datcyloides*). Between them, these two species often make up more than 80% of the total rangeland forage production, especially on the upland sites represented in this figure. The drought of the 1930s (exposure=high temperatures and low precipitation) was devastating to both forage production and plant cover (sensitivity and impact), but both quickly recovered with increasing precipitation in the 1940s. The 1950s drought had a similar, but less devastating, impact on production and cover. However, within a very short period of time, a return to normal and above average rainfall quickly reestablished both plant cover and forage production. Clearly, the mixed grass prairie is highly resilient and can tolerate even extreme drought, although there are wide swings in production. History has shown that the High Plains are not particularly vulnerable in an ecological sense, but social and economic systems frequently need support to maintain stability.

Figure is compiled with data extracted from Albertson[17], Launchbauch[18] and rainfall data from Dr. Keith Harmony, KSU-Fort Hays Experiment Station.



different individuals within the system that can either tolerate or avoid the drought, and then recover post-drought. From a socioecological perspective, diversity is also important, but is generally defined as both the array and flexibility of the individuals and institutions, and their ability to either avoid or tolerate the economic effects of drought, communicate adaptation techniques, and then recover post drought.[7]

Highly adaptive systems have a diversity of members with many connections and flexibility of resource allocation. Adaptive capacity is often described in terms of resilience, the ability to recover from perturbation.[8] Whether the subject of the analysis is a plant community, a ranch, a regional livestock production system, or a national industry sector, it seems that a diverse set of players and a high degree of structured interactions are necessary to survive stressful situations.

At the extreme end of the scale, more frequent and intense drought may require *transformation* in some socioecological systems.[3] Transformation is the process in which the members and ecosystem services associated with a changing ecosystem may not survive. Some species, operations, ecosystem services, institutions, and businesses may very well cease to exist. While these transformative situations are difficult to accept, it is critical that transformation be considered as a possible outcome to avoid permanent resource degradation, loss of species, and widespread societal impact.

The framework (Fig. 1), originally conceived in a broad sustainability context by Turner et al.[9] offers a logical, repeatable approach that can be used to assess the vulnerability of a defined socioecological system to drought. In our case, it also offers a valuable means of evaluating information sources and analytical tools that can be deployed within each of the individual components as a relative guide to allocating institutional resources to improve the quality and utility of drought vulnerability assessment.

Improving Drought Vulnerability Assessment in a Socioecological Framework

Despite the fact that drought has been a recurring and important feature of rangeland management for more than 120 years, little progress has been made in the effort to alleviate its impact on ranchers and rangeland ecosystems. In this section we examine the individual components of drought vulnerability and review some of the information sources and analytical tools available to improve decision-making.

Improving drought exposure prediction will require a substantial and sustained commitment of resources to implement a variety of new and improved tools. The large potential benefit and demand from users for such predictions warrants a serious consideration of this investment. The broader community including national and international operational and research centers have recognized the magnitude of the challenges associated with improving the accuracy and utility of short-term climate forecasts as documented in the recent National Research Council report[iii] and establishment by the World Meteorological Organization of the Sub-seasonal to Seasonal research project.[iv]

The primary composite indicator used to assess and monitor drought is the US Drought Monitor (USDM). Because of the complexity of drought impacts over space and time, there is no one index that effectively describes all aspects and types of drought. The USDM, and the process that is used to create three weekly products,[v] is the best overall indicator because it integrates multiple data sources and derivative products from local to national scales and incorporates feedback and input into the process by utilizing an expert user group of over 350 people from across the country that serve as a ground truth for the indicators. For rangeland producers, the USDM is significant in that it is used as a trigger to initiate and/or terminate several programs in USDA's Farm Service Agency (FSA). FSA uses the USDM in areas seeking approval of emergency haying and/or grazing through the Conservation Reserve Program, as well as grazing losses due to drought under the Livestock Forage Disaster Program. The Internal Revenue Service also uses the USDM for tax deferrals for livestock producers that involuntarily sold livestock due to drought conditions. While producers and range managers may not be able to utilize the USDM due to its national scale, producers can engage the local drought monitoring groups that are providing input and ground-validation into the weekly USDM process. These groups include FSA, local National Weather Service Weather Forecast Offices, state climate offices, county Extension offices, etc.

Two tools that can improve estimates of current and potential *impacts* are the Drought Risk Atlas (DRA[vi]) and the Drought Impact Reporter (DRI[vii]). The DRA helps contextualize a region or location's historical experience with drought. The DRA is a web-based tool and has the ability to help producers visualize and assess risks related to frequency and intensity of drought in their area. The DRI is also a web-based mapping tool but it is designed to compile and display impact information across the United States in near real-time from the media, government agencies, and the public. Users can assess impacts at different spatial and temporal scales. There are several efforts to increase the quantity and quality of the impact information going into the DRI. One effort is to utilize the distributed network of citizen scientists that participate in the Community Collaborative Rain, Hail & Snow network (CoCoRaHS[viii]).

Another emerging area applicable to predicting *impact* of drought on range management decisions is monitoring for rapid onset droughts known as "flash drought". Flash droughts can evolve in a matter of weeks and are usually characterized by a relatively short period of low rainfall combined with an extended period of anomalously high temperatures. An example of a flash drought was in 2012 across the Central Plains where summer precipitation deficits were the highest on record and were preceded by record-breaking temperatures in the winter and spring. Flash droughts often result in rapidly deteriorating pasture and range conditions but the existing set of indicators and seasonal forecasts lack sensitivity to respond to rapidly changing conditions. To address these deficiencies two new indicators have been developed. The Evaporative Stress Index (ESI) assesses evapotranspiration (ET) anomalies as a proxy for root zone soil moisture content, where below average ET during the growing season suggests plants are experiencing moisture stress.[10] The second indicator in development is the Evaporative Demand Drought Index (EDDI) that measures evaporative demand to surface drying anomalies that occur when either there is a sustained drought and moisture is limited at the land surface, or due to increases in advection, radiation, or temperature, or decreases in humidity. Like the ESI, the EDDI has shown to be a leading indicator of drought particularly when soil moisture is not yet limited. Both the EDDI and ESI indicators are being tested through the USDM and could serve as an improved early warning indicator for rapid onset drought.

An improved ability to predict and characterize exposure is necessary, but not sufficient, to develop realistic estimates of drought impacts. A systematic way of addressing *sensitivity* of specific socioecological systems that matches exposure estimates in space and time scales is also required. Existing approaches to determine the sensitivity of individual species or plant community to changes in climatic variables[6] are highly quantitative and are particularly helpful in establishing priorities for monitoring. There have also been efforts to assess impacts of global change on the supply of ecosystem services.[11] These approaches take into account both the exposure (likelihood of an event occurring) and the sensitivity (the effects of specific events on ecological processes), in a risk analysis framework. The challenge is to make impact assessments of drought spatially and temporally specific enough to provide confidence for individual ranchers or managers to

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[iii] See the NRC Report in Brief, Intraseasonal to Interannual Climate Prediction and Predictability, at http://www.scribd.com/doc/44556291.

[iv] For more on the the Subseasonal to Seasonal research project see http://s2sprediction.net/.

[v] See more on the US Drought Monitor at http://droughtmonitor.unl.edu/.

[vi] For more on the DRA see http://droughtatlas.unl.edu/About.aspx.

[vii] For more on the DRI, see http://droughtreporter.unl.edu/.

[viii] For more on CoCoRaHS, see www.cocorahs.org.

prepare a range of possible responses. Although there are some nascent efforts, there should be a concerted commitment to adapt these sensitivity analysis approaches to predicting and evaluating the effects of drought events on rangeland ecosystems and operations.

A national or regional centralized approach to drought response that ignores local conditions provides little of relevance for land managers.[12] While a national framework is essential for establishing priorities and supporting local scale implementation, a lack of precision in predicting *exposure, sensitivity*, *and impact* makes it difficult to identify what type of drought events are likely to differentially affect resilience and stability at a scale where managers make decisions, and where policy and program interventions can make a difference.

Similarly, making a credible assessment of the *adaptive capacity* for a particular sector, county, or ranch requires an approach that examines multiple potential events and putting those combinations into an actionable framework. Although ranchers are keenly aware of the importance of drought and drought response, there appears to be little in the way of systematic decision making in a strategic context. Yung et al.[13] found that most ranchers maintain a belief that droughts are part of a normal cycle and felt that adaptation was critical in surviving drought; however, they were highly uncertain about what adaptation steps would work. Coppock,[14] utilizing survey results, found Utah ranchers affected by a previous drought and still in business were much more likely to develop drought adaptation plans, but that percentage of total ranchers remains relatively low. The objective should be accessible drought forecasts, logic-based sensitivity analyses, relevant impact projections, and useful adaptation options integrated into a drought toolkit that explicitly states how the estimates were made and provides access to supporting information. The vulnerability assessment framework could give users (policy makers, program staff, technical advisors, and managers) a much more nuanced and realistic idea of the risks associated with droughts and their options to respond.

There has been substantial progress in the development of tools to better quantify *exposure*, but there has been little serious effort in the area of integrating exposure tools with improved methods of *sensitivity* to develop a common metric for *impact*. Finally, there is a very poor understanding of the importance of *adaptive capacity* in coping with drought and, more importantly, how policy and programs can help improve individual adaptive capacity.

Policy Implications

Our recommendations are based on the assumptions that good science leads to good tools, which lead to good policy, which leads to good management. Although these connections are not foolproof, it is hard to imagine that good policy and good management can happen in a profession without good science and good tools to provide support. Although the emphasis on predicting regional exposure to drought (precipitation) has been helpful, it is inherently limited in its ability to predict the impact of drought on both ecosystems and people. The process of vulnerability assessment is relatively well understood and there are examples of information sources and analytical tools that can contribute to the process, but the collective will to face, and act on, the results of the assessment are the limiting factors. For this reason, we highly recommend that the technical effort to predict drought vulnerability at a regional and local scale be separated, in terms of funding, development, and execution, from the process of developing drought response policy. Although these two processes are equally important and must be integrated seamlessly on the ground, they should be conducted independently to insure that desired, but potentially unrealistic or politically motivated responses do not override a scientifically valid, defensible drought vulnerability assessment.

Resource degradation should have equal weight with economic concerns in developing drought response policy and programs. We know that different ecosystems respond differently, and recover differently. Policy for actions during a drought and post-drought recovery should consider the mid-term implications on plant, soil, and wildlife resources in addition to short-term implications for livestock and ranching operations. This does not mean that we value nature over people, but that drought policy and programs should be constructed with the inherent vulnerabilities of the whole socioecological system in mind, with the goal of preserving resources, processes, and businesses.

Finally, the development of realistic drought policy cannot ignore the possibility of transformative events. It may be that a business, industry, or sector ceases to exist as we know it. Acknowledging this possibility does not require a callous approach that ignores difficult decisions and actions, rather it elevates the concern for those most affected to a higher level and requires a greater effort to minimize negative impacts.

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