Rangeland Responses to Predicted Increases in Drought Extremity

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On the Ground

- Rangeland managers actively focus on the potential to induce a shift in a site to an alternative state, but predicted changes in climate, particularly the likelihood of more extreme drought, necessitate reevaluating risks for alternative states.
- Rangelands will differ in their susceptibility to undergo state changes due to climate change in general and for droughts of the future, in particular, which may be hotter.
- Trees, shrubs, and grasses are expected to differ in their sensitivity to drought, with trees likely being most sensitive; this affects the likelihood for state changes in grasslands, shrublands, woodlands, and savannas.
- Considering these differences can help rangeland managers deal with the challenges of increasing drought that is forecast to occur with climate change.

Keywords: drought, state and transition, grassland, shrubland, woodland, savanna.

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Managing rangelands is challenging and will become more difficult as the frequency and intensity of climate extremes, such as drought, increases as forecasted with climate change. Rangeland management has advanced beyond reliance on assumptions of a predictable plant community moving back and forth between unstable (early successional) and stable (late successional) states. Rangeland managers now recognize the potential for more pronounced, difficult-to-predict changes in vegetation dynamics that might not be directly or readily reversible. The broader framework for considering these more pronounced changes has been defined in terms of the different "states" that a rangeland site might fall into, which can vary over a set of site conditions, and the "transitions" that drive a change from one major vegetation state to another.[1]

For fire and grazing, the potential to induce a shift in a rangeland to an alternative state under some conditions has been well documented and is a major priority of rangeland managers. However, there has been less emphasis on understanding the role of climate change and climate extremes as drivers of state transitions, in contrast to shorter-term changes in productivity and composition. This distinction is important given that the challenges associated with managing rangelands under climate extremes, such as drought, are likely to become greater due to climate change, as their magnitude and frequency are expected to increase with changes in precipitation patterns.[2] Moreover, because of warming trends, future droughts are likely to co-occur with higher temperatures than prior ones, independent of other factors affecting drought intensity and frequency. In the United States, heat waves have become more frequent and intense, especially in the west, and droughts in the southwest and heat waves everywhere are projected to become more intense.[3] Changes in climate are increasing the likelihood for these types of extreme events.[2,3] These climate change consequences need to be considered in the context of managing rangelands under drought.

In the present study we discuss the following:

1. The direct implications of drought under climate change for state transitions in rangelands and the indirect effects of the interaction of drought with other drivers of vegetation dynamics such as wildfire and pest or pathogen outbreaks;
2. Vulnerabilities of grassland, shrubland, woodland, and forest rangeland systems to state transitions with more extreme drought; and

3. General considerations for managing rangelands to avoid undesirable state transitions as droughts become drier and hotter in the future.

Climate Change and Increasing Drought Extremity

An important aspect of developing and applying state and transition theory is to identify events that can drive a transition from one state to another as opposed to normal climate variability or management practices that cause variation within a given state. Extreme climate events (*sensu* Smith[4]), such as extreme droughts that elicit large and potentially irreversible ecological responses, are important drivers of state change. The mechanisms underlying these state changes are expected to be the mortality of dominant life forms, shifts in plant community composition, and/or establishment of novel life forms or species (Fig. 1). Each of these mechanisms is expected to elicit substantial responses that may play out over different time frames, with mortality-driven changes in composition and turnover of life forms (e.g., change from woody- to grass-dominated) potentially resulting in transitions to alternate states.

Although rangeland managers have been dealing with droughts for decades, warming conditions will result in droughts that are expected to be hotter on average than prior droughts.[5] Moreover, changes in precipitation means and variability will result in more frequent and extreme droughts with respect to the long-term climate record.[4] Indeed, many areas, such as the southwestern United States, are projected to become both hotter and drier; these combined conditions will likely increase frequency of extreme dry years as well as the intensity (or statistical extremity) of drought. Even small increases in average temperature can be important for increasing drought intensity. First they can increase soil evaporation rates, leaving less water for plants.[6] Second, they can increase physiologic stress on plants, reducing growth and even resulting in plant death under extreme conditions.[5,6] Warmer temperatures increase atmospheric demand for water directly, leading to increased plant stress. As plant stress increases with increasing extremity of drought, plants can be pushed beyond their physiologic limits, resulting in mortality (Fig. 2), shifts in composition, and ultimately transitions to new states.

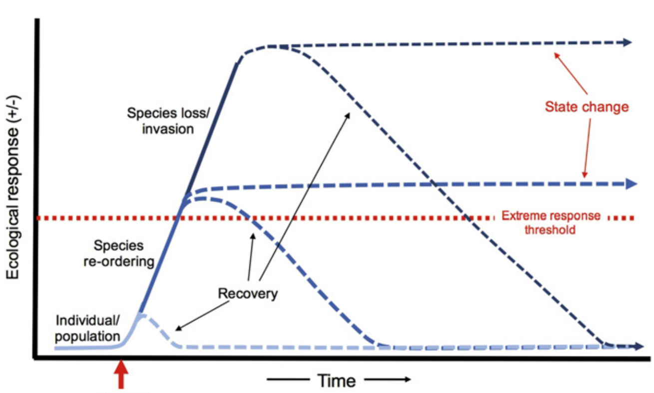

Figure 1. Processes that underlie state transitions with extreme drought. A drought that affects physiology and growth (individual-level responses) will have a smaller effect (positive or negative) on ecological processes (i.e., productivity) than one that results in large shifts in species abundances (species reordering), or in mortality of species or invasion by others. A state transition is likely to occur as a consequence of crossing an extreme response threshold (dotted red line) in which significant changes in abundance or loss of dominant life forms results in large ecological effects. These changes may be characterized by prolonged recovery or may lead to persistent state changes.
Modified from Smith.[4]

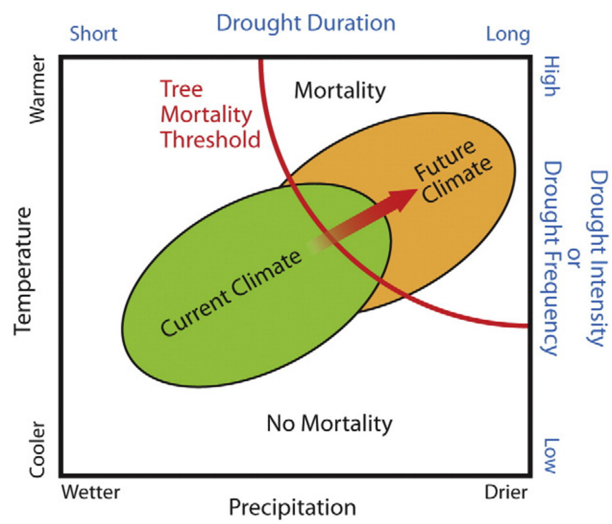

Figure 2. Conceptual diagram, showing range of variability of "Current Climate" parameters for precipitation and temperature, or alternatively for drought duration and intensity, with only a small portion of the climate "space" currently exceeding a species-specific plant mortality threshold. "Future Climate" shows increases in extreme drought and temperature events associated with projected global climate change, indicating heightened risks for drought-induced die off for current tree populations. This figure was developed for tree mortality, but can apply to shrub or grass mortality, although the mortality threshold for these different life forms likely differs (Figs. 3-4) (reproduced from Allen et al.[5]).

More extreme droughts also may interact with other drivers of state transitions. Hotter and drier conditions can enable more intense wildfire, and also can alter the periods when fire might be most effectively prescribed as a management tool to maintain a given rangeland site. Pests and pathogens, especially those affecting woody plants, may become more pronounced during periods of drought. Protracted periods of drought leave soil conditions dry, which can, for example, result in increased wind erosion.[7] Additionally, such dry soil may be susceptible to erosion associated with post-drought flooding, which is expected to become more intense in some areas as a result of climate change. These varied consequences of drought under climate change need to be considered in the context of rangeland states and transitions.

Another important aspect to consider relative to alternate states and potential transitions as a result of more extreme drought is the relative abundance of different plant life forms, such as grasses, shrubs, and trees, and their relative vulnerabilities to drier and hotter conditions. These dominant life forms can