Ecological Responses and Interactions with Drought in the Southwestern United States

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Introduction

In the southwestern United States, water availability is a key limiting resource for ecosystem functioning. Potential evaporation is much larger than precipitation throughout this region during most months of the year. Southern California is generally classified as a Mediterranean ecosystem with the majority of precipitation inputs associated with large winter frontal storms originating from the Pacific. As an example of human appropriation of water in this region, the Los Angeles system uses extensive amounts of water, with large fluxes associated with irrigation of agricultural lands and recreational landscaping activities.

Arizona has a bimodal precipitation regime. This region is strongly limited by water, and precipitation is generated by widespread and long-duration frontal systems in winter and more localized and high-intensity convective storms in summer associated with the North American Monsoon (NAM). In comparison to winter rains, summer rains generally exhibit larger spatial variability, larger frequency of events, larger event intensity, more surface run-off, and higher evaporative demand. These summer-winter contrasts are common features of summer and winter rains globally and across the southwestern United States. Further inland towards New Mexico, precipitation is again mostly associated with a single season in which the majority of precipitation arrives as part of the NAM.

Ecohydrology is a rapidly growing integration of ecosystem and hydrologic sciences, which emphasizes the coupling between hydrologic cycles and ecological functioning to understand how life depends on and affects the partitioning and chemical constituency of water on the continental surfaces. The ecohydrologic perspective can be a useful bridge between engineering approaches for managing water flows and ecological approaches to understand the biological, physical, and societal system encompassing the dynamics of water flows and in particular drought. The ecohydrologic perspective allows an explicit recognition of how water fluxes respond to processes and decision making at scales ranging from individuals to international treaties.

In the context of pulsed ecosystem dynamics, meteorological droughts can be translated into ecological droughts through altered amounts, timing, and distributions of precipitation. For the same amount of precipitation, a distribution among five large events will induce a different ecological response than a distribution among 20 small events. The many small events may each be sufficient to generate physiological pulses in the soil but insufficient for plant pulses of activity. However, if the timing of the 20 small events occur in close proximity, for example over the course of a single month, these water inputs may instead be sufficient to generate an initiation of plant growing season. This interaction between amount, timing, and distribution suggests ecological droughts occur in the absence of meteorological droughts given sufficient societal activity.
Connections between ecological and social drought

Ecological drought, where functioning is curtailed and altered, can lead to social drought through the reduction in ecosystem services. This may occur for example when drought leads large agricultural failures that impact society. Similarly, social drought can lead to ecological drought with the management of water deliveries and land cover. If societal water supplies are perceived to be limited, water can be diverted from other ecosystems to direct human consumption, thus leading to negative ecological impacts. As the southwestern United States has some of the most extensive hydraulic engineering, these connections can occur in areas highly disconnected from their source origins.

Responses and adaptations of ecosystems to drought

Droughts are a regular occurrence in the recent history of the southwestern United States as water inputs are associated with two dominant ocean-atmospheric cycles, the patterns of El Niño/La Niña and the Pacific Decadal Oscillation (PDO). El Niño/La Niña status is characterized by the surface water temperatures in the tropical eastern Pacific Ocean. El Niño events, periods of unusually warm surface temperature, tend to bring more winter precipitation and warmer summer temperatures to the southwestern United States. La Niña events tend to have opposite effects. The PDO is characterized by surface temperatures of the northern Pacific Ocean, with contrasting warm and cool phases. PDO signals have been reconstructed as far back as millennia using tree-ring analyses. The effect of these decadal scale changes in moisture conditions can strongly impact ecosystems in the southwestern United States.

The 2000s drought, which in some parts of the southwestern United States has lasted the entire decade, has been overlayed with an exponential expansion of urbanization. This has put additional demands on water deliveries and expected ecosystem services.

Along with these annual-scale droughts, perturbations to seasonal precipitation distributions can lead to seasonal droughts that may have longer-term consequences. During the past decade, the contributions of winter precipitation has been reduced throughout the southwestern region with less changes associated with summer rainfall and is associated with changes in jet streams and projected to continue in the future. Mitigation strategies for maintaining ecosystem services are currently being evaluated, and the maintenance of intact ecosystems with sufficient water resources is becoming more publicly acceptable. Extensive research is being conducted on developing more drought-resistant crop plants and farming practices that maintain biological functioning. Planners in California are implementing new restrictions and are quickly moving to develop additional management practices to reduce outdoor water use. Concepts of ecosystem service water use efficiency seem to have some potential to help decision-making for water allocations.

Conclusions

Evaluating ecological droughts as one aspect of multiple types of drought provides a consistent framework for understanding biological responses and interactions with society and meteorology. Ecohydrology, with an emphasis on pulse responses to precipitation variability, provides an initial theoretical approach to understanding ecological droughts. An ecohydrological approach suggests a water use efficiency of the ecosystem services required for societal sustainability could be a useful analysis to evaluate water diversion strategies. Meteorological and hydrological droughts are likely expected to increase in frequency, severity, and duration throughout the southwestern United States. These will likely cause increases in ecological droughts directly and lead to societal changes that will have indirect causes on ecological drought. Likely, these changes are happening throughout the world and an integration across ecosystems globally will improve understanding and be a source for multiple management options.