United States Department of Agriculture

EXECUTIVE SUMMARY

Effects of Drought on Forests and Rangelands in the United States:

A Comprehensive Science Synthesis

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Effects of Drought on Forests and Rangelands in the United States:
A Comprehensive Science Synthesis

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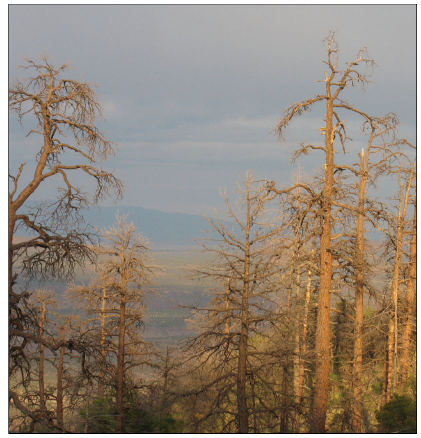
Overview and Purpose

This assessment provides input to the reauthorized National Integrated Drought Information System (NIDIS) and the National Climate Assessment (NCA); it also establishes the scientific foundation needed to manage for drought resilience and adaptation. The NIDIS Act[1] was signed into law in 2006 and reauthorized by Congress in 2014.[2] NIDIS will be implemented through a network of agencies and partners to integrate drought monitoring and forecasting systems at multiple levels (Federal, State, and local). It will support research that focuses on drought risk assessment, forecasting, and monitoring. Produced every 4 years, the NCA evaluates the effects of global climate change on forests, agriculture, rangelands, land and water resources, human health and welfare, and biological diversity, and it projects major trends. The NCA is based on technical information produced by public agencies and nongovernmental organizations.

As drought regimes change, the ability to quantify and predict the impacts on forests and rangelands is critical to developing and implementing management actions to increase resiliency and adaptation. The U.S. Department of Agriculture (USDA), Forest Service, Research and Development scientists in partnership with Duke University authored this assessment, entitled, *Effects of Drought on Forests and Rangelands in the United States: A Comprehensive Science Synthesis*. The assessment is a collaborative effort authored by 77 scientists from the Forest Service and other Federal agencies, research institutions, and various universities across the United States. The authors identified key issues from a series of virtual workshops involving scientists and stakeholders. Focal areas in the assessment include drought characterization; drought impacts on forest processes and disturbances such as insect outbreaks and wildfire; and the consequences on forest and rangeland values. The assessment closely follows the Intergovernmental Panel on Climate Change (IPCC) process, which is organized with convening authors, lead chapter authors, and contributing authors. The convening authors for the assessment had the chapters individually peer reviewed, and the lead and contributing authors revised the text in response to reviewer comments.



This assessment establishes the scientific foundation needed to manage forests and rangelands for resilience and adaption to drought.

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[1] National Integrated Drought Information System Act of 2006. P.L. 109-430 (December 20, 2006). 15 U.S.C. § 313d.

[2] National Integrated Drought Information System Act of 2014. P.L. 113-86 (March 6, 2014).

Topics Addressed in This Assessment

- Characterizing Drought for Forested Landscapes and Streams
- Physiological Responses of Forests to Future Drought
- Impacts of Drought on Forest Dynamics, Structure, Diversity, and Management
- Forest Biogeochemistry in Response to Drought
- Insect and Pathogen Responses to Drought
- Fire and Drought
- Rangeland Drought: Effects, Restoration, and Adaptation
- Detecting and Monitoring Large-Scale Drought Effects on Forests: Toward an Integrated Approach
- Ecohydrological Implications of Drought
- Economics and Societal Considerations of Drought in Forests and Rangelands

This assessment focuses on drought characterization, the impacts on forest processes and disturbances, and the consequences on forest and rangeland values.

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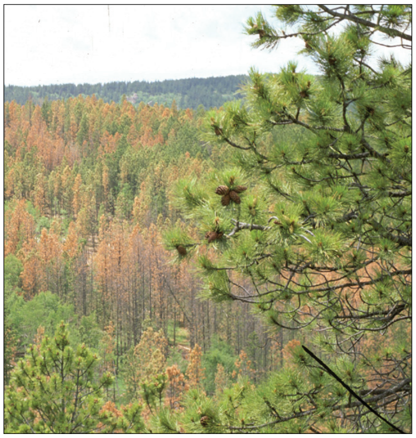
Key Messages from the Report

Characterizing and Predicting Future Drought

In simple terms, drought is a lack of water over a given temporal and spatial scale. Drought can be a severe natural disaster with substantial social and economic consequences. Drought becomes most obvious when large-scale changes are observed (i.e., insect outbreaks or wildfires) or when water requirements for human or agricultural needs are not met; however, even moderate drought can have long-lasting impacts on the structure and function of forests and rangelands without these obvious large-scale changes. Droughts are generally identified as one of four types: (1) meteorological, (2) hydrologic, (3) agricultural, or (4) socioeconomic. Meteorological and hydrologic droughts relate water availability to a reference condition (e.g., long-term mean); agricultural and socioeconomic droughts relate to impacts. In agricultural systems producing annual crops, characterizing and assessing drought impacts can be fairly straight forward; however, in systems with perennial vegetation (both natural and agricultural systems), characterizing and assessing drought impacts is much more complex, as responses can vary in space, time, and among species.

Historical and paleoclimatic evidence shows that drought has always impacted the physical environment and will continue to do so. The direction of trends in recent history varies from region to region, with the Western United States showing a trend toward dry conditions while trends in the East are more variable and complex. Much of the variability in how drought is characterized depends on definitions for terms, for reference conditions, and for methods of averaging short-term weather into climate statistics. Predicting future changes in drought frequency and severity has proven difficult using General Circulation Models (GCMs), but recent trends are a growing global concern. Uncertainty arises primarily from limited capacity to predict future precipitation changes, particularly long-term lapses in precipitation. Despite this uncertainty, there is growing consensus that extreme precipitation events (e.g., lapses in precipitation and more intense storms) will increase in frequency, and warmer temperatures will exacerbate the impacts of drought on forests and rangelands in the future (chapter 2).



Drought becomes obvious when large-scale changes such as insect outbreaks, (top) or wildfires (center) are observed and when water requirements for human or agricultural needs are not met (bottom).

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Ecosystem structure and processes are altered by drought. Cheatgrass (top) is a nonnative plant that invades burned sites. Dieback (bottom) can have global impacts on carbon cycles.

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Chris Evans, Illinois Wildlife Action Plan, Bugwood.org

Understanding the Effects of Drought on Forests and Rangelands

There is a critical need to understand how drought affects forests and rangelands, in part because drought severity and drought-associated forest disturbances are expected to increase with climatic change. Drought affects forest and rangeland systems both directly and indirectly. In regions where seasonal droughts are common, forest and rangeland ecosystems respond through various physiological and morphological adaptations. In regions where drought is less common, responses can be substantial because ecosystems are not well adapted to drought conditions.

High evaporative demand, the combination of high temperature and low humidity, combines with low soil moisture to induce stress through closure of stomata, which can lead to carbon stress, loss of hydraulic function, and mortality. Species vary in their vulnerability to drought due to differences in their allocation to roots, mycorrhizal associations, and xylem anatomy (chapter 3). Large stand-level impacts of drought are already underway in the West, but all U.S. forests are vulnerable to drought. Changes in climate will continue to stress forests and alter suitable habitat. Combined field evidence and models suggest that climate change is causing relocation of habitats at rates much faster than populations of trees can migrate. Reorganizations of stand structure and species composition are expected to lag behind shifts in habitat caused by increasing drought and temperature change (chapter 4).

Droughts are predicted to accelerate the pace of invasion by some nonnative plant species into rangelands and grasslands. Drought can also promote plant invasion indirectly by modifying the environment to favor nonnative species. For example, opportunities for invasion are created when drought kills native plants leaving open niches and bare ground (chapter 8). Drought is also an important contributor to the invasive annual grass-wildfire loop that threatens ecosystems not adapted to fire (e.g., cheatgrass' positive feedback with fire in parts of western North America's sagebrush biome). In this self-perpetuating cheatgrass-fire loop, drought increases the frequency of wildfires, and nonnative plants (especially annual grasses) are likely to invade burned sites.

Drought alters ecosystem processes such as nutrient, carbon, and water cycling in ways that are not yet well understood (chapter 5). Drought tends to slow nutrient uptake by plants and reduce re-translocation of foliar nutrients with premature leaf senescence. Dieback that results from combinations of drought and natural enemies can severely reduce carbon exchange between atmosphere and biosphere. Recent large diebacks have had global impacts on carbon cycles, including release from biomass and reductions in carbon uptake from the atmosphere, although impacts may be offset by vegetation regrowth in some regions. Multi-year or severe droughts can have substantial impacts on hydrological and stream biogeochemical processes.

Indirect effects of drought on forests can be widespread and devastating. Notable recent examples include insect and pathogen outbreaks (chapter 6) and increased wildfire risk (chapter 7). Available evidence suggests a nonlinear relationship between drought intensity and bark beetle outbreaks; moderate drought reduces outbreaks whereas long, intense drought can increase it. As a consequence of long-term drought and warming in the Western United States, bark beetles are currently the most important biotic agent of tree mortality. Multiple large outbreaks have killed hundreds of millions of trees in recent decades. Host trees weakened by drought allow beetle populations to build. Warming facilitates northward range expansion. In contrast, there is little current evidence for a role of drought in bark beetle outbreaks in coniferous forests of the Eastern United States. Fungal pathogens are poorly understood, but available evidence suggest reduced pathogen performance and host impacts in response to drought for primary pathogens and pathogens whose lifecycle depends directly on moisture. In comparison, secondary pathogens that depend on stressed hosts for colonization are anticipated to respond to drought with greater performance and host impacts.

Historical and pre-settlement relationships between drought and wildfire have been well documented in much of North America, with forest fire occurrence and area burned clearly increasing in response to drought. This body of evidence indicates that the role of drought in historical and likely future fire regimes is an important contingency that creates anomalously high potential for ignition, fire spread, and large fire events. However, drought is only one aspect of a broader set of controls on fire regimes, and by itself is insufficient to predict fire dynamics or effects. Whereas the relationships between fire occurrence or area burned and drought are well documented, the relationship between drought and fire severity can be complex. For example, north-facing slopes might offer some degree of local protection during mild droughts, but even they become dry under extreme conditions, reducing fine-scale heterogeneity in vegetation consequences.

Drought can increase the intensity of insect and pathogen outbreaks including bark beetles (top), Dothistroma needle blight (center), and hemlock woolly adelgid (bottom).

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Drought impacts streams (top) by concentrating sediments and nutrients. In rangelands, drought can reduce vegetative cover, leading to wind and water erosion (bottom).

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Seth Munson, U.S. Geological Survey

Streamflow and groundwater recharge respond directly to drought through reductions in precipitation (rain and/or snowfall), and they respond indirectly via evapotranspiration responses to changing evaporative energy and water availability. Hydrologic responses to drought can be either mitigated or exacerbated by forest vegetation, depending on vegetation water use and how drought affects forest population dynamics (chapter 10). Drought affects water quality both directly and indirectly. Direct impacts are primarily physical, as reduced streamflow concentrates nutrients and sediment, and warms more quickly. Indirect effects include a combination of terrestrial, riparian, and in-stream processes that impact sediment and nutrient concentrations and fluxes.

Detecting and Monitoring Future Droughts

The ability to detect drought effects on forest and rangelands over broad scales is limited, especially for episodic droughts of moderate severity. Compared to agricultural systems, detecting drought impacts on trees and other perennial vegetation may require a multi-year "memory" of antecedent conditions. With broad-scale monitoring, it is often not possible to detect drought effects, as moisture stress is not expressed uniformly across vegetation types.

Remote sensing approaches attempt to observe direct, secondary, and longer term effects of drought on vegetation (chapter 9). Remote sensing methods integrate across entire mixed-vegetation pixels and rarely distinguish the effects of drought on a single species, nor can they disentangle drought effects from those caused by various other disturbance agents. An integrated data-mining approach may hold the most promise for enhancing our ability to resolve drought impacts to forests. Efforts to integrate meteorological and remotely sensed data streams, together with other ancillary datasets such as vegetation type, wildfire occurrence, and pest activity, may help to identify and characterize drought effects.

Economic and Social Consequences of Drought

Drought has direct consequences to forest and rangeland production (chapter 11). Droughts can negatively impact forest inventories by increasing mortality and reducing growth. Drought in rangelands reduces forage and water available for livestock grazing. Reduced vegetative cover can lead to wind and water erosion. Drought-related disturbance, such as wildfire, can have protracted effects that include significant timber market losses.

Reduced water yield from forests and rangelands during extended meteorological drought can have substantial impacts on domestic and agricultural water supplies, which often results in water markets implementing quantity controls. Drought can also have nonmarket effects on forests and rangelands. For example, drought affects outdoor recreation, where low reservoir levels can reduce availability of fishing, recreational boating, swimming, and camping (although some net benefit can result from fewer precipitation free days). Low winter snow cover reduces economic benefits from skiing and related activities.

Ongoing drought in the Western United States, where most tribal lands exist, is expected to continue to affect tribal health, culture, economies, and infrastructure. Competing demands for dwindling water resources challenge Federal trust responsibilities. Complicating factors, including warming streams and hydrologic cycle changes, affect fish populations important to tribal diets and ceremonies. Because of their natural resource dependence for income, employment, and cultural practices, many tribes are also vulnerable to higher rates of forest and rangeland disturbances, including invasive species spread, increased occurrences of epidemic pest populations and their associated damages, and wildfires.

Drought in rangelands reduces forage and water available for livestock grazing (top). Lower reservoir and winter snow levels impact outdoor recreation activities (bottom).

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Managing Forests and Rangelands To Increase Resiliency and Drought Adaptation

How can forest and rangeland practices adapt to changing drought regimes? Frequent low-severity drought may selectively favor more drought-tolerant species and create forests and rangelands better adapted to future conditions without the need for management intervention. By contrast, severe drought (especially in combination with insect outbreaks or fire), may threaten large-scale changes that warrant substantial management responses. Actions could range from reducing vulnerability, facilitating post-drought recovery, or facilitating a transition to a new condition.

Management actions can either mitigate or exacerbate the effects of drought. A first principal for increasing resilience and adaptation would be to avoid management actions that exacerbate the effects of current or future drought. Options can include altering structural or functional components of vegetation, minimizing drought-mediated disturbance such as wildfire or insect outbreaks, and managing for reliable flow

Management strategies, such as thinning (top) and riparian buffer zone conservation (bottom), may help to mitigate the effects of drought.

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of water. Managers can implement structural changes by thinning or density management of planted forests. Thinned stands require less water and may be less vulnerable to water stress and insect outbreaks. Reduced fuel loads in thinned stands can also reduce wildfire risk.

Managers can also implement functional changes by favoring or planting more drought-adapted species. Management for a diversity of species can reduce stand vulnerability to drought, as uncertainty in future climate can encourage management for mixtures of drought-tolerant species and genotypes. Species diversity can also reduce intensity of insect attacks. In some regions of the United States, planting or favoring more drought-tolerant species may conflict with management objectives that favor rapid accumulation of biomass, as fast-growing woody species often use more water and exacerbate drought impacts.

While harvesting increases annual water yield in some forest ecosystems, a large reduction of forest cover is needed to have an appreciable effect on water yield. Hence, potential increases in streamflow through forest cutting are limited by the amount of land that managers can harvest. In addition, streamflow responses are often short term due to rapid forest regrowth, and the aggrading post-cut forest may actually have lower streamflow than the uncut forest. In contrast to management actions that are intended to augment streamflow, increasing drought stress in some forest ecosystems may warrant management strategies that retain water (and hence reduce streamflow) on the landscape in order to keep trees alive. Land managers may need to plan the timing of some management activities to ensure that ecosystems have optimal growing conditions and that these activities do not disturb streams during low-flow periods. Removal and alteration of riparian vegetation increases stream temperatures; therefore, maintaining or increasing shading from solar radiation through riparian buffer zone conservation and restoration may mitigate any changes in stream temperatures caused by drought.

In summary, this assessment synthesizes information from the published literature to better understand the impacts of drought on forests and rangelands in the United States. Our expectation is that this assessment will provide researchers, land managers, policymakers, and other stakeholders a set of realistic inferences of drought effects that can be applied to help predict future impacts and evaluate management options for adaptation and mitigation.

Acknowledgments

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Photograph: U.S. Geological Survey

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Abstract

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Keywords: Climate change, drought, forest disturbances, natural disasters, water quantity and quality.