CHAPTER 6

Managing Effects of Drought in the Interior West

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BIOGEOGRAPHIC AND CLIMATIC CONTEXT

The biogeography of the Interior West region (Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico) is diverse, with terrestrial ecosystems varying greatly both from north to south and from high elevation to low elevation. Subalpine forests are dominated by species adapted to cold, snowy environments at high elevation: subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), Rocky Mountain bristlecone pine (*Pinus aristata*), limber pine (*Pinus flexilis*), and whitebark pine (*Pinus albicaulis*). Mixed-conifer forests are the most common forest vegetation throughout the region, in which Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) are often the dominant overstory species, with variable species composition and density in the understory. Ponderosa pine is found in nearly pure stands in many low-elevation, dry sites.

Woodlands dominated by various species of juniper (*Juniperus* spp.), pinyon pine (*Pinus edulis*, *P. monophylla*), and Gambel oak (*Quercus gambelii*) are common in drier portions of the southern half of the region, typically at lower elevations than mixed-conifer or ponderosa pine forests. A diversity of shrublands is found below woodlands and mixed-conifer forest in most of the region; several sagebrush species (*Artemisia* spp.) are dominant, along with mountain mahogany (*Cercocarpus* spp.) and antelope bitterbrush (*Purshia tridentata*). Perennial grasslands, often including nonnative annual grasses, are widespread at the lowest elevations in dry locations, intergrading with shrublands and woodlands. Riparian systems comprise a small but important component in all vegetation types and are often hotspots of biodiversity in arid to semiarid environments.

The topography and climate of the Interior West are highly varied; the region is home to some of the driest, hottest, and coldest locations in the conterminous United States. The Interior West is characterized by numerous mountain ranges, high-elevation basins and valleys, and low-elevation mesas and canyons, and climate is influenced by this complex terrain. Moisture comes predominantly from the Pacific Ocean, resulting in orographic precipitation in the mountains. Central Idaho and the Greater Yellowstone Area are some of the coldest portions of the region, and climate in these areas is strongly influenced by mountains and interactions among topography, elevation, and aspect. The southern portion of the region is the hottest and driest in the United States.

Drought is a familiar phenomenon throughout the Interior West, as evidenced by significant periods of drought in the 1930s to early 1940s (Dust Bowl), 1950s, mid-1960s, late 1970s, and 1990s (Weiss et al. 2009). Drought was also widespread in 2002–2007 and 2012–2015. Severity is generally greater in the southern portion of the region, for which arid climate is normal. The paleo record indicates that droughts in earlier centuries were more frequent and longer, in some cases lasting for multiple decades (Allen et al. 2013, Cook et al. 2014, DeRose et al. 2015, Meko et al. 1995).

Average annual temperatures in the region have risen by 1.6 °F (Vose et al. 2017) since the beginning of the 20th century. In most areas, warming has been greatest and most widespread in winter. In some cases, temperature increase has accelerated during recent centuries; for example, average annual temperatures in Colorado have increased 2 °F since 1977 (Lukas et al. 2014). Across the United States, the rate of increase in average annual temperature has been greater over the last several decades, and several of the warmest years on record have occurred since 2010 (Vose et al. 2017). Precipitation trends have been highly variable across the region, with some areas increasing and some decreasing (at both annual and seasonal time scales).

Global climate models project increases in mean annual temperature of 2–6 °F by mid-century (2036–2065) and 4–10 °F by late century (2070–2099) compared to 1976–2005 (Mote et al. 2014, Wuebbles et al. 2017). Warming is expected to occur during all seasons. Most models project the largest temperature increases in summer, ranging from 3.4 °F to 9.4 °F (under the Representative Concentration Pathway 8.5 scenario). All models suggest that heat extremes will increase.

Changes in precipitation are more uncertain. Annual average precipitation is projected to increase by about 3 percent, with general climate model (GCM) projections ranging from -4.7 percent to +13.5 percent (Mote et al. 2014, Wuebbles et al. 2017). Most models project decreases in summer precipitation, but model projections for precipitation vary for the other seasons, with some models projecting increases and others decreases. However, GCMs agree that extreme precipitation events will likely increase in the future.

Warming temperatures, regardless of precipitation changes, will affect hydrological processes in the Interior West, including the amount, timing, and type

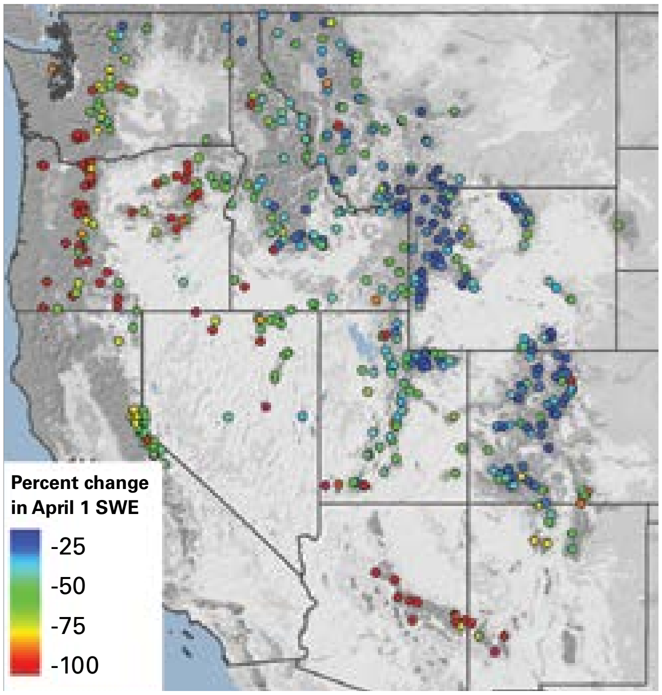


Figure 6.1—Estimated April 1 snow-water equivalent (SWE) sensitivity (percentage change) for a 5.5 °F increase in winter average temperature at each snowpack telemetry station. From Muir et al. (2018), modified from Luce et al. (2014a).

of precipitation, as well as timing and rate of snowmelt (Luce et al. 2012, 2013; Mote et al. 2018; Safeeq et al. 2013), which will affect snowpack volumes (Hamlet et al. 2005), streamflows (Hidalgo et al. 2009), and stream temperatures (Isaak et al. 2012, Luce et al. 2014b). In response to warming, shifts are already occurring from snowmelt-dominant to mixed rain-and-snow watersheds, and from mixed rain-and-snow to rain-dominant watersheds (Mote et al. 2018). These shifts are resulting in earlier and reduced spring peak flow, increased winter flow, and reduced late-summer flow (Raymondi et al. 2014). With future increases in temperature and altered hydrological dynamics, evapotranspiration is likely to increase, and soil moisture availability is likely to decrease during the summer, leading to more frequent, more intense, and longer droughts (Gershunov et al. 2013) (fig. 6.1).

SOCIAL AND REGULATORY CONTEXT

Water has enormous social, economic, and biological importance in the Interior West because most of the region is semiarid, and even under "average" weather conditions water is in short supply for much of the year. Surface water and groundwater contribute to municipal water supplies for major metropolitan areas, hydropower, habitat for fish and other aquatic species, and recreation (Warziniack et al. 2018a, 2018b). In some parts of the region, water (typically supplied from snowmelt and groundwater) is used for irrigation of a wide range of perennial (e.g., tree fruits) and annual (e.g., potatoes, hay) crops. Water supply in the southern part of the region is a concern in years when precipitation is average and becomes more acute during drought years. Water for agriculture and municipal use during drought periods is often supplemented by additional pumping of groundwater, in some cases depleting sources that are already declining.

Streams and riparian areas contribute greatly to aquatic and terrestrial biodiversity, especially in semiarid to arid landscapes. Water provides critical habitat for salmon and trout species throughout the northern and central portions of the region, and for fragmented fish populations (often threatened or endangered) associated with ephemeral aquatic habitat in desert ecosystems. Several salmon stocks are listed as threatened or endangered, and nearly all populations are much lower than they were prior to 1900; dams are a major impediment to recovery of many populations, especially on the Columbia and Snake Rivers and their tributaries. High temperatures and drought reduce habitat quality for cold-water fish species across all spatial and temporal scales, facilitating expansion of nonnative fish species that tolerate higher water temperature (Isaak et al. 2012). Declines in native fish and other traditional food sources will have detrimental effects on economic and cultural values for Native Americans and other rural residents in the region.

Grazing by domestic livestock is an important enterprise in rangelands in the Interior West (Reeves et al. 2018). These rangelands also provide habitat for elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), and many other animal species. Grazing occurs on both public and private lands, requiring frequent (and sometimes contentious) interactions between public land managers and ranchers focused on sustainable management of rangelands, especially during drought (Hawkes et al. 2018). Management of greater sage-grouse (*Centrocercus urophasianus*) habitat is a major conservation issue in sagebrush-steppe throughout the Interior West, further complicating these interactions in terms of public policy, grazing access on public lands, and local decision making.

Although timber production is still an important component of some local economies in the Interior

West, it has declined significantly since the 1990s (Halofsky et al. 2017). Changing social perspectives on resource management priorities, accompanied by a shift in timber production to locations that are more productive and have lower labor costs (e.g., the Southern United States), resulted in the closure of many timber mills. In response to social demands, most forest management in the Interior West now focuses on restoring native vegetation, creating mature forest structure, and improving wildlife habitat and various aspects of biological diversity.

Recreationists participate in a wide range of outdoor activities throughout the Interior West, including hiking, camping, sightseeing, skiing, hunting, fishing, and water-based activities. These recreational activities generate far more economic activity than traditional resource sectors such as timber, representing the New West in which human values and experiences represent an area of increasing demand (Halofsky et al. 2017). However, recreational activities can also generate significant demands for access to infrastructure and facilities, which in some cases can damage resources. Most recreation activities are affected in some way by a warmer climate and drought, some positively and some negatively (Hand and Lawson 2018, Hand et al. 2018).

Natural resources, social issues, human values, and ecosystem services are interwoven with the economy, lifeways, and culture of Native Americans. This has always been true for salmon and other "first foods" that have been used by Native Americans for millennia, and Federal land managers are becoming more aware of the need to involve Tribal partners in developing conservation plans. As a result, Tribes are increasingly influential in decision making and planning on lands where their interests may be affected. Including Tribes as partners when developing conservation plans and projects is now a common element of Federal land management.

Water availability is expected to decrease in the future because of shortages arising from decreased water supplies and increased water demand. Ninety percent of water consumption in the Western United States is used for irrigated agriculture, so competition with usage by municipalities, industry, and natural resources (e.g., fish habitat) can become intense during droughts (Warziniack et al. 2018a, 2018b). As a result, it will be necessary to minimize vulnerability of water-related infrastructure and water-dependent resources on public lands and to maximize efficiency of water uses where possible (Furniss et al. 2018). An integrated perspective on physical, biological, social, and economic processes and values will be necessary to ensure long-term sustainability of water and other resources.

ASSESSING THE EFFECTS OF DROUGHT

As noted above and in chapter 2, GCMs project that temperature will increase significantly in future decades, and the magnitude of temperature changes will likely decrease summer water availability, regardless of precipitation trends. Although we have considerable confidence in long-term projections (decades) of decreasing water availability and increasing frequency and magnitude of droughts, the actual occurrence of drought will be difficult to forecast at short time scales (months to years).

Water Resources and Aquatic Systems

Water is the most widely valued resource provided by public lands. During times of drought, decisions about allocation of limited water often involve tradeoffs among fish habitat, municipal and agricultural use, hydroelectric power, recreational use, and livestock grazing. Drought affects not only the quantity of water available but also water quality (higher temperature, turbidity) (Goode et al. 2012). Along with limited water availability, higher water temperature increases the likelihood of algal blooms that degrade aquatic habitat and can be harmful to people, pets, and livestock (Hand and Lawson 2018, Paerl and Huisman 2008). Droughts that cause low summer streamflows and high water temperature can have multiple consequences to cold-water fish populations, including significant mortality (Matthews and Marsh-Matthews 2003).

Surficial geology and soils determine both drainage properties and the severity of drought effects across mountainous landscapes in the Interior West. For example, in areas with highly permeable subsurface rocks and well-drained soils, water rapidly infiltrates down hundreds of feet, reducing both water storage for human uses and water availability for vegetation (Konrad 2006). Projected declines in snowpack and earlier snowmelt (chapter 2) will reduce the magnitude and duration of both surface and subsurface water (Luce 2018, Muir et al. 2018) (fig. 6.2), especially during years with low snowpack. Warmer winters will lead to earlier peak flows and lower, warmer base flows (Kormos et al. 2016, Mote et al. 2018), as well as very low summer flows in some streams (Luce 2018) (fig. 6.3).

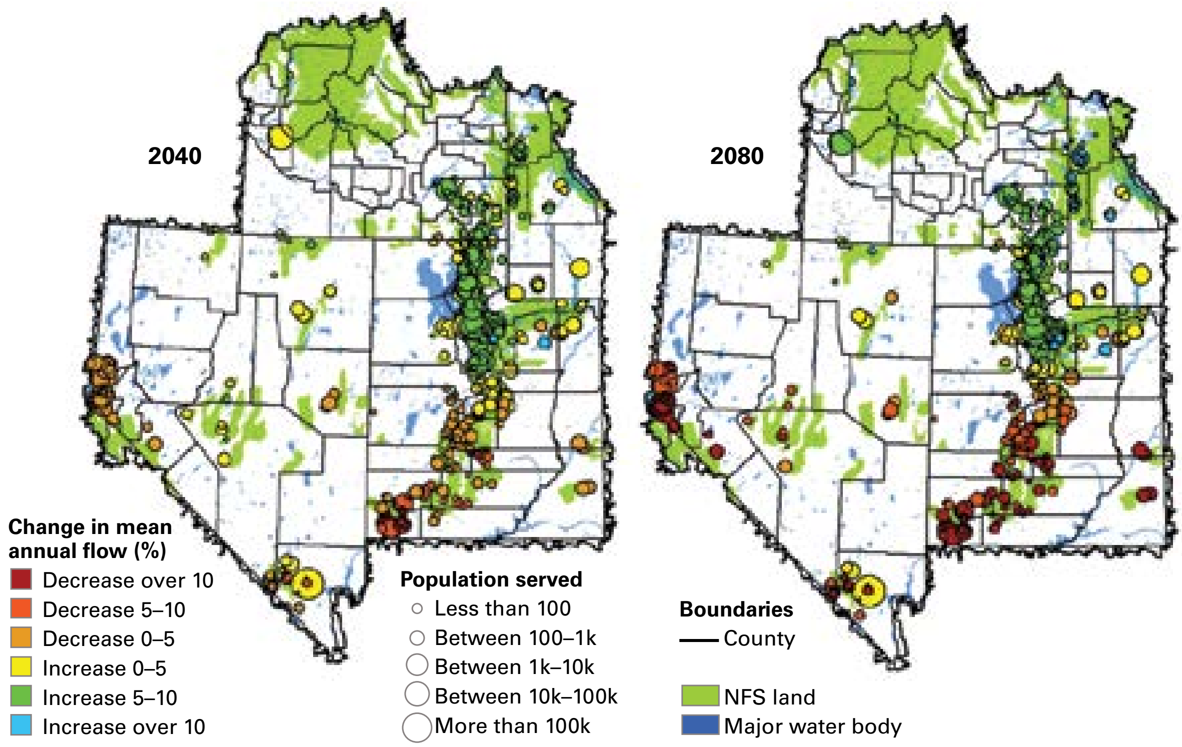


Figure 6.2—Projected changes in mean annual flow for municipal water systems in Nevada, Utah, and southern Idaho. Projections are based on streamflows generated from the Variable Infiltration Capacity (VIC) model (Liang et al. 1994) using an ensemble of Coupled Model Intercomparison Project Phase 3 models under the A1B emission scenario (similar to the RCP 6.0 emission scenario) (see Muir et al. [2018] for details on methods). The center of each circle is the central location of each drinking water system relative to intake locations. Mean summer flow (compared to historical flow) across this geographic area is -21 percent for 2040 and -26 percent for 2080. From Warziniack et al. (2018a).

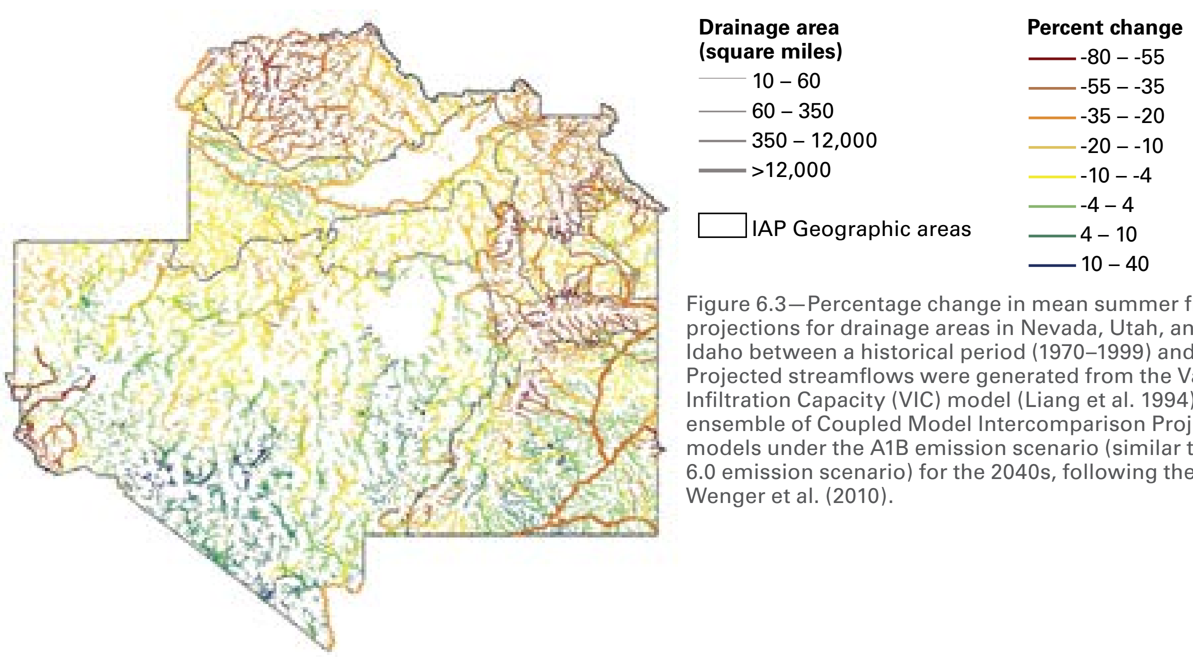


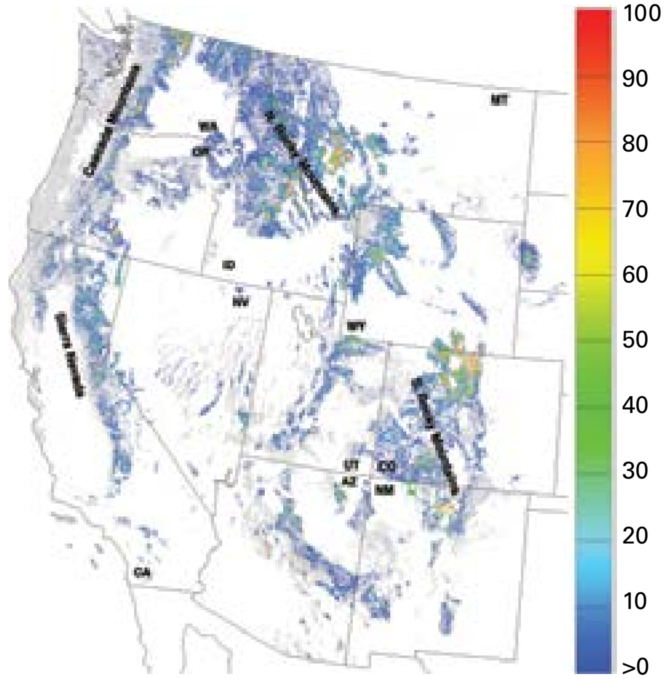
Figure 6.3—Percentage change in mean summer flow projections for drainage areas in Nevada, Utah, and southern Idaho between a historical period (1970–1999) and the 2040s. Projected streamflows were generated from the Variable Infiltration Capacity (VIC) model (Liang et al. 1994) using an ensemble of Coupled Model Intercomparison Project Phase 3 models under the A1B emission scenario (similar to the RCP 6.0 emission scenario) for the 2040s, following the methods of Wenger et al. (2010).

Forest Ecosystems and Disturbances

Drought-related water limitations will likely decrease growth in most tree species in most locations in the Interior West, especially in low- to mid-elevation coniferous forests. Species such as Douglas-fir and ponderosa pine, which are important ecologically and economically, are expected to have lower growth throughout the region (Behrens et al. 2018, Keane et al. 2018, Restaino et al. 2016), even though they are considered relatively drought-tolerant. Some species in high-elevation coniferous forests may have higher growth during drought years because less snowpack means a longer growing season in areas where water limitations are uncommon (Peterson and Peterson 2001).

Drought-related tree mortality has been rare at large spatial scales in the Interior West, with the exception of two-needle pinyon (*Pinus edulis*), which experienced significant mortality at low-elevation locations in northern New Mexico after a 10-year drought in the early 2000s (Breshears et al. 2005). More tree mortality can be expected, especially in dense stands at the lower elevations where drought exacerbates water deficit. Dry soils and topographic positions that do not retain soil moisture are vulnerable, especially where they affect the establishment of seedlings which are near the ground and have small root mass (Joslin et al. 2000). Carbon storage in vegetation and soils will become more difficult to manage as wood growth decreases and disturbances increase, and early-seral forest structure may become more prevalent across the landscape (Kashian et al. 2006).

Dense forests are particularly susceptible to bark beetle attack. Although beetles typically focus on weak trees, they can also spread to nearby vigorous trees when beetle populations are high (Fettig et al. 2007, Lieutier 2004). Lodgepole pine (*Pinus contorta* var. *latifolia*) in particular has experienced significant mortality from mountain pine beetles (*Dendroctonus ponderosae*), at least partly accelerated by drought periods, as part of a much larger pattern of beetle-caused mortality in the Western United States and British Columbia (Hicke et al. 2016) (fig. 6.4). Drought frequency and duration also affect the extent and severity of wildfires because drought causes both fine surface fuels and live fuels to dry earlier and stay dry longer, increasing fire hazard and likely the duration of the fire season (McKenzie et al. 2004, Peterson et al. 2011).



Bark beetles: area of killed trees

Figure 6.4—Tree mortality caused by bark beetles, 1997–2012, indicating the pervasiveness of bark beetle damage throughout the Interior West. Colors show area and percentage of tree mortality. From Hicke et al. (2016).

Rangelands

Drought reduces growth in rangelands during the growing season, especially if large numbers of invasive annual grasses are present (Fehmi and Kong 2012, Finch et al. 2016, Hanberry et al. this volume, Runyon et al. 2012). Drought conditions favor the spread of annual grasses (especially cheatgrass [*Bromus tectorum*]) (Kindschy 1994, Tausch et al. 1994), which further limits the extent and productivity of native plant species (fig. 6.5). Excessive grazing by livestock and native ungulates during drought decreases aboveground and belowground biomass, creating growing space for invasive plant species (Biondini et al. 1998, Fuhlendorf et al. 2001). Although grazing typically occurs on perennial grasses, shrubs are also vulnerable to browsing when grasses are unproductive or dormant. In the summer, when conditions are hottest and grasses in the adjoining uplands are dormant, livestock are more likely to graze riparian areas (Padgett et al. 2018).

As drought intensity increases, rangeland productivity decreases (Hanberry et al. this volume, Padgett et al. 2018, Reeves et al. 2018), although the extent

Figure 6.5—Cheatgrass is common in grasslands throughout the Interior West. (Photo by Cassondra Skinner, USDA Natural Resources Conservation Service PLANTS Database)

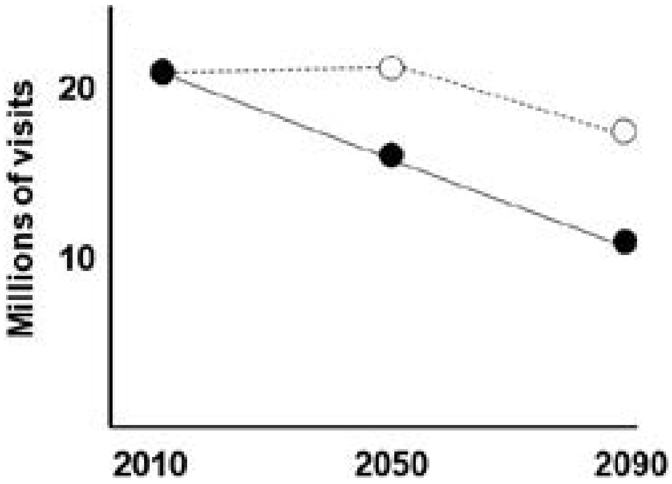


Figure 6.6—Projected effects of climate-altered snowpack on downhill skiing visits. The Rocky Mountain portion of the Interior West currently has by far the highest number of skiers of any region. By the end of the 21st century, visits are expected to decline by 50 percent for a constant population (closed circles), but only by 17 percent if the population increases according to recent demographic projections (open circles). From Wobus et al. (2017).

of decrease depends on dominant vegetation (e.g., sagebrush versus mountain meadows) and soils. In semiarid locations, annual grasses tend to increase fire frequency and spread (Balch et al. 2013), favoring further spread of annual grasses and less cover of native shrubs, grasses, and forbs (Link 2006, Melgoza and Nowak 1991). Although the quantity of fuel controls fire intensity, drought can extend the duration of conditions under which fuels will readily burn (Brown et al. 2005).

Socioeconomic Effects

More frequent, more intense, and longer drought will reduce surface water supply more often, leading to significant impacts on social and economic sectors that demand continuous, reliable water (Vose et al. 2016; Warziniack et al. 2018a, 2018b). In some cases, water is already allocated near or beyond the limit of its average availability, so access to water becomes even more limited during drought years, with tradeoffs occurring among sectors (e.g., among agriculture, hydroelectric power generation, and fish habitat). Recent projections of the effects of a warmer climate indicate that municipal watersheds will increasingly face water shortages in future decades (Warziniack et al. 2018a, 2018b), with periodic drought accentuating those shortages. Water supply in mountainous regions is often limited by reservoir capacity, and this can be depleted during years when snowpack is low and water demands are high (Harpold et al. 2017).

Any given drought period can affect multiple resource sectors (Halofsky et al. 2017). As noted, low water supply can cause stress and economic losses in agriculture and rural communities. "Snow droughts" can lead to low flows in rivers and streams (Harpold et al. 2017), reducing recreational opportunities for rafting and fishing (Hand and Lawson 2018, Hunt et al. 2016) and in some cases causing fish mortality. Snow droughts also affect winter recreation, with potential financial losses for downhill skiing operations and associated support businesses (Hand et al. 2018, Wobus et al. 2017) (fig. 6.6). Following widespread drought in 2017, wildfires burned 4.4 million acres in the eight Interior West States, incurring over $1 billion in suppression costs (National Interagency Fire Center data: https://www.nifc.gov), causing economic damage in many communities, reducing access to public lands, reducing forage for grazing, and in some locations, degrading air quality for several weeks.

MANAGING FOR DROUGHT, EXTREME EVENTS, AND DISTURBANCES

The 2016 Federal Action Plan of the National Drought Resilience Partnership (White House 2016) describes ways in which Federal departments and agencies can work with State, regional, Tribal, and local partners to respond to drought and increase long-term drought resilience. Drought-related guidance (in the form of guidebooks and manuals) (e.g., Hawkes et al. 2018) is rare in the Forest Service, U.S. Department of Agriculture (USFS) and other Federal agencies, although some USFS Regions have issued guidance to national forests during severe drought periods. The Bureau of Land Management (BLM) has used instruction memoranda to issue guidance on drought response.

Existing frameworks and tools used by the USFS and BLM can be used to address drought in the future (Vose et al. 2016). For example, many of the National Best Management Practices (BMPs) for water quality management on National Forest System lands (USDA FS 2012) can help mitigate drought. These BMPs address program activities such as water use, aquatic ecosystems, rangelands, and recreation. Specific drought references in the BMPs include designing projects to account for water availability, addressing drought-related shoreline degradation, and responding to water availability in range permit activities.

The USFS Watershed Condition Framework (Potyondy and Geier 2011) and regional aquatic restoration strategies guide forest watershed and aquatic restoration programs, and restoration activities can help increase ecosystem resilience to drought. Incorporating drought in restoration planning could help to further improve drought resilience in the future. For example, two strategies to help decrease future drought-related mortality are to plant drought-tolerant vegetation in restoration treatments and reduce forest stand density (Sohn et al. 2016).

All national forests in the USFS Northern and Intermountain Regions have completed climate change vulnerability assessments, including adaptation options (Halofsky et al. 2018a, 2018b). These assessments cover a significant portion of the Interior West. They incorporate potential effects of increased temperatures on water resources, fish and aquatic systems, vegetation, wildlife, recreation, infrastructure, cultural resources, and ecosystem services, thus providing insight on potential effects of drought. Climate change adaptation options in the assessments similarly provide information that will help facilitate drought planning and prioritize responses. Disaster management tools and systems are in place in Federal agencies (e.g., Incident Command System, Burned Area Emergency Response), and these could be applied to drought response and used as a template for drought planning.

Management Options for Responding to Drought

Lower snowpack and increased drought severity in a warmer climate will lead to lower streamflows and reduced soil moisture, especially in arid to semiarid landscapes in the Interior West (Luce et al. 2012, 2013; Mote et al. 2018; Safeeq et al. 2013). Inevitably, water supplies for agriculture, cities and towns, aquatic systems, and other uses will decrease during periods of drought (Prestemon et al. 2016; Warziniack et al. 2018a, 2018b). At a series of workshops during 2016–2017, resource managers throughout the Interior West discussed the potential effects of drought on natural resources and developed options to build resilience in ecosystems and organizations, thus reducing vulnerability to drought. Management options discussed below (tables 6.1–6.4) are drawn from the output of these workshops (USDA FS 2017a, 2017b, 2017c, 2017d).

Water resources—Water conservation practices will help sustain water supplies, especially during the summer when water availability is already low. Water systems will be more resilient to drought if they use water-smart technology and anticipate future storage needs (Luce 2018) (table 6.1). In some cases, water diversion structures may need to be improved to minimize impacts on groundwater-dependent ecosystems. Reconnecting floodplains and side channels will help restore hydrological function, retain water for longer periods (including recharging groundwater), and restore functional riparian systems (fig. 6.7).

Riparian and wetland restoration can be prioritized for both hydrological and ecological values, assisted by geospatial analysis to identify where restoration will be feasible and have maximum benefit. Two ways to improve functionality of riparian systems are to (1) reduce gullying and (2) reconnect channels and facilitate maintenance and establishment of American beaver (*Castor canadensis*) populations to increase water storage (Pollock et al. 2014). In addition, stand density management and hazardous fuel reduction in dry forests will help reduce the severity of future wildfires (Luce et al. 2012).

Federal land management agencies currently have limited capacity to respond to frequent, severe droughts. This limitation can be improved by incorporating drought in all relevant aspects of planning and management (see Conclusions chapter in this volume). Doing so includes specific actions, such as increasing instream flows through altered water rights and incentives, and developing or revising standards and practices to protect stream corridors and other water features. Education on drought awareness can be institutionalized both

Table 6.1—Drought vulnerabilities and management options for water resources in the Interior West

WATER RESOURCES	
VULNERABILITY TO DROUGHT	**DROUGHT MANAGEMENT OPTIONS**
Drought will reduce the availability of water for a variety of uses during the summer.	• Increase water conservation; prioritize maintenance and reconstruction. • Make water systems more resilient to drought (e.g., use water-smart technology) and prepare for future storage needs. • Improve existing water diversion structures or design new structures to divert only the water needed while retaining water in groundwater-dependent ecosystems. • Reconnect floodplains and side channels, and maintain and restore functioning riparian corridors (e.g., reestablish riparian vegetation). • Recharge groundwater by using restoration techniques for rewetting floodplains (e.g., reconnect channels with floodplains).
Drought will reduce the functionality of hydrological systems and associated riparian systems.	• Prioritize and target riparian and wetland restoration to provide shade over water and reduce quick flow from roads; use geospatial tools to identify restoration priorities. • Continue to manage landscapes to reduce fire severity and promote fire-adapted native vegetation. • Control water pollution. • Manage American beaver activity to increase water storage. • Identify a target for a healthy riparian system and start managing for that target. • Reduce gullying and reconnect channels to maintain functionality of riparian areas.
Federal land management agencies have limited capacity to respond to frequent, severe droughts.	• Incorporate drought planning in management considerations, decisions, and analyses. • Increase instream flows through change in water rights and incentives (e.g., reduce water allotments when water supply is low, and provide rewards to users for reducing consumption). • Develop or improve standards/guidelines, mitigation measures, and best management practices to protect stream corridors and more isolated water features. • Increase drought awareness with agency leadership and the public. • Build and maintain constructive relationships with State agencies and other organizations, and engage in collective problem solving to manage a wide range of hydrological conditions.

Figure 6.7—Riparian restoration on Susie Creek, NV, has greatly increased retention of water during summer, improving habitat for both vegetation and wildlife. (Photo courtesy of USDI Bureau of Land Management)

internally and externally, while collaborating with other agencies and organizations to address water resource issues of common interest.

Fish and aquatic systems—Drought years are typically associated with low snowpack, often resulting in high winter streamflows and low summer streamflows, creating stress for a wide range of fish species and other aquatic organisms. Most options for improving resilience in aquatic systems focus on retaining adequate amounts of cool water and riparian vegetation (Isaak et al. 2018, Young et al. 2018) (table 6.2). For example, reconnecting floodplains and side channels helps maintain and restore functional riparian corridors. Connectivity among fish habitats will be critical, aided by modifying infrastructure (e.g., aquatic organism passages) and removing barriers to fish movement. Stream temperature models (e.g., NorWeST stream temperature database, https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html) will be especially helpful to guide future management actions so that refugia for cold-water fish can be identified (Isaak et al. 2015). In arid locations, identifying refugia will be especially critical for desert fish species, whose habitat is often highly dispersed (Carveth et al. 2006).

Increased drought frequency will reduce water retention in high-elevation and riparian systems. Therefore, to increase resilience across large landscapes in the long term, it will be necessary to restore and maintain healthy stream, riparian, and aquatic ecosystems. Restoration will be especially important in places that are likely to be refugia during future droughts (e.g., high-elevation streams and locations with cold-water upwelling), accompanied by restoration of native species in viable habitats (Isaak et al. 2015). As noted earlier, populations of American beavers will help increase water storage, including cool water. Drought is expected to increase the occurrence of wildfire, especially crown fires in areas with high fuel loadings. Fuel reduction treatments,

Table 6.2—Drought vulnerabilities and management options for fish and aquatic habitat in the Interior West

FISH AND AQUATIC HABITAT	
VULNERABILITY TO DROUGHT	**DROUGHT MANAGEMENT OPTIONS**
During drought years, winter streamflows will generally increase and summer streamflows will decrease, creating stress for fish and other aquatic organisms.	• Reconnect floodplains and side channels, and maintain and restore functioning riparian corridors (e.g., reestablish riparian vegetation). • Increase fish habitat connectivity by modifying infrastructure (e.g., aquatic organism passages). • Use stream temperature models (e.g., NorWeST stream temperature database) to guide future management actions. • Remove barriers to fish movement where appropriate and for bull trout (*Salvelinus confluentus*) in particular (e.g., modify infrastructure to increase habitat connectivity). • Create refugia habitats (e.g., hatcheries and ponds) during fire or drought evacuations to hold high-value species.
Increased frequency and magnitude of droughts will reduce water retention in high-elevation and riparian systems, especially when accompanied by wildfire, thus reducing habit quality for many organisms.	• Restore and maintain healthy stream, riparian, and aquatic ecosystems that will be more resilient to drought cycles. • Conduct riparian and stream restoration in places that are likely to be refugia during future droughts (e.g., high-elevation streams and locations with cold-water upwelling). • Prioritize native species restoration in habitats that will persist through drought periods. • Reintroduce American beaver where appropriate to increase water storage. • Use prescribed burning in dry forests in order to reduce high-intensity wildfire.
Drought will make it more difficult to maintain the functionality of riparian systems and infrastructure.	• Use land management plan revisions as opportunities to encourage riparian vegetation treatments across the landscape to restore desired functions and processes. • Maintain the function of the transportation system without damaging riparian and aquatic ecosystems (e.g., develop engineered solutions for high-priority roads in floodplains). • Develop partnerships with departments of transportation, counties, and other organizations to mitigate negative impacts of the transportation system on water resources. • Coordinate with range managers to better manage riparian areas, focusing on how cattle move across the landscape.

including prescribed burning in dry forests, can reduce the likelihood of high-intensity wildfires (Luce et al. 2012).

Drought will make it more difficult to maintain the functionality of riparian systems and infrastructure, such as roads. Federal land managers can use land management plan revisions as opportunities to encourage riparian vegetation treatments across the landscape to restore desired functions and processes. It is especially important to maintain the function of transportation systems without damaging riparian and aquatic ecosystems (e.g., develop engineered solutions for high-priority roads in floodplains). Partnerships with other agencies and organizations will help mitigate negative impacts of roads on water resources, while facilitating access to public lands.

Forest ecosystems—If drought becomes more frequent or of longer duration, tree regeneration may decrease or be more variable in drier locations. Strategic planting can ensure adequate tree establishment, especially where large-scale mortality has occurred and natural regeneration is low (table 6.3). Where site conditions and management objectives allow, forest managers can diversify planting with drought-tolerant species and genotypes (Kilkenny et al. 2013). This will require managing seed inventories to maintain genetic diversity, as well as producing sufficient nursery stock to meet demands. In some cases, planting densities can be increased to compensate for potential seedling mortality.

Drought will cause a general loss of tree vigor, growth, and productivity in most locations. In some cases, these stresses will lead to more tree mortality, both directly and because of increased frequency of disturbances. Drought-stressed trees may also have weaker defenses to bark beetle attack, and drought can increase the likelihood that attacks by different beetle species will erupt simultaneously (Raffa et al. 2005). To reduce

Table 6.3—Drought vulnerabilities and management options for forest vegetation in the Interior West

FOREST VEGETATION	
VULNERABILITY TO DROUGHT	**DROUGHT MANAGEMENT OPTIONS**
Tree regeneration may be lower or more variable if drought is frequent or protracted.	• Use planting to ensure adequate tree establishment. Focus on areas of large-scale mortality that are not regenerating naturally. Plant seedlings in suitable microsites and provide artificial shading. • Diversify stands and landscapes where site conditions and management objectives allow; focus on drought-tolerant species and genotypes. • Manage seed inventories to maintain genetic diversity; update and maintain seed procurement inventories to increase genetic diversity. Collect seeds from multiple trees of the same species in seed transfer zones. Increase planting densities to compensate for potentially higher seedling mortality.
Drought will cause tree vigor to decrease and tree mortality to increase, both directly and because of more frequent disturbances.	• Promote tree size and age diversity within stands and across landscapes to increase resilience to drought, insect outbreaks, and fire. • Use thinning and prescribed fire in dry forests to reduce stand densities by removing smaller trees. Prioritize thinning in fire-prone areas within the wildland-urban interface where feasible. • Use prescribed burning and managed wildfire to reduce surface fuels and manage for diversity of ages, structure, and species.
Local survival of viable populations of some tree species may be threatened by increasing frequency and duration of drought.	• Identify sites where special species can be protected; designate refugia where appropriate. • Increase resilience of sensitive species, such as whitebark pine, by protecting them from high-severity fire (e.g., through prescribed fire and removal of competing species such as subalpine fir and Engelmann spruce). • Enhance opportunities for self-migration (e.g., establish seedlings in sites more resistant to drought); favor seed production and dispersal in current habitat and receptive seedbeds in nearby habitats.
Drought will create additional stress for management organizations, requiring new approaches and greater flexibility.	• Increase resources to implement landscape treatments; look for cost-sharing opportunities with other agencies and organizations. • Create a regional rapid-response fire and vegetation management team by formalizing multi-agency cooperation and sharing resources and responsibilities.

stand densities, thinning and prescribed fire can be implemented in dry forests, thereby removing smaller trees, promoting diversity of tree size and age and increasing vigor of residual trees within stands and across landscapes (Clark et al. 2016, Sohn et al. 2016) (fig. 6.8). Prescribed burning and managed wildfire can further reduce surface fuels and create diversity in stand ages, structure, and species (Johnson et al. 2007, Keeley et al. 2009, Peterson et al. 2011). Although silvicultural manipulations may increase the defensive capacity of a tree by ameliorating the effects of drought, they may be ineffective at reducing large-scale mortality in association with drought and bark beetle outbreaks (Fettig et al. 2007).

Viable populations of some tree species may be threatened by increasing frequency and duration of drought. Thus, it will be critical to identify sites where special species can be protected, maintaining habitat connectivity if possible. To ensure resilience, sensitive species (e.g., whitebark pine) may need to be protected from high-severity fire (e.g., through prescribed fire and removal of competing species) (Keane et al. 2017). Habitat connectivity will facilitate self-migration by favoring seed production and dispersal in current sites as well as suitable nearby regeneration sites. All responses to drought will benefit from collaboration and increased flexibility among management organizations to encourage treatments across large landscapes.

Rangelands—Drought will decrease vegetation productivity in many arid to semiarid locations, necessitating altered grazing practices for domestic livestock (Finch et al. 2016). One commonly used option to deal with drought is to alternate periods of disturbance (grazing) and rest (table 6.4). Monitoring tools, such as the Evaporative Demand Drought Index (EDDI) and U.S. Drought Portal (National Integrated Drought Information System) (USDA FS 2017b), can help inform decisions about grazing. Grazing management tools, such as PastureMap (PastureMap n.d.), The Grazing Manager (Ishmael 2013), and Grazekeeper (Ellis 2015), can inform specific decisions about herd composition, stocking rate, and timing. Grazing can also be targeted to control cheatgrass infestations (e.g., by grazing in early spring or late autumn) (Foster et al. 2015).

The long-term effects of drought on water availability can be addressed by reintroducing American beavers into areas where they are not presently thriving in order to retain more water in meadows and riparian areas (Pollock et al. 2014). Integrated pest management and early detection/rapid response strategies can be used to control invasive species, along with educating the public and agency personnel about invasive species. Resilience of vegetative cover to drought can be improved by managing the amount, timing, and distribution of ungulate (native animals plus livestock)

Figure 6.8—Reducing stem density (from left to right), shown here in a ponderosa pine stand in the Colorado Front Range, reduces both competition among trees and the propagation of wildfires into the canopy, thus increasing the resilience of dry conifer forests to drought. (Photo courtesy of U.S. Air Force)

Table 6.4—Drought vulnerabilities and management options for rangelands in the Interior West

RANGELANDS	
VULNERABILITY TO DROUGHT	**DROUGHT MANAGEMENT OPTIONS**
Drought will decrease vegetation productivity, thus affecting grazing practices.	• Use grazing methods that alternate periods of stress (grazing) and rest (reduced grazing). • Use drought-monitoring tools (e.g., Evaporative Demand Drought Index, U.S. Drought Portal) to provide information that will inform decisions about herd composition and numbers so that stocking rates match forage production. • Implement targeted grazing methods (e.g., use livestock to eat weeds) after disturbance events such as fire to restore vegetation cover.
Drought reduces water availability during the summer, which affects vegetation composition and productivity and favors invasive species.	• Increase watershed health and function by reintroducing American beavers into areas where they are not presently thriving as a way to retain more water in meadows and riparian areas. • Increase efforts to control invasive species through integrated pest management, targeted livestock grazing, and early detection/rapid response strategies. • Educate the public and agency personnel about invasive species, and co-monitor and manage with permittees to encourage collaborative learning. • Increase or maintain vegetative cover to be more resilient to drought by managing the amount, timing, and distribution of ungulate herbivory. Implement woody plant management to promote herbaceous groundcover.
Drought affects the ability of Federal land managers to manage rangelands in a sustainable manner.	• Establish an integrated monitoring plan that includes livestock management, drought, and climate. • Design permits based on future drought considerations rather than historical ranch production. • Consolidate monitoring data into a geospatial database across resources to help preserve knowledge and to aid resource managers in multiple disciplines.
Drought causes stress in the organizations and social systems that administer access to public rangelands.	• Maintain collaboration with private landowners; include partners and stakeholders in decision making. • Use conservation easements to avoid loss of open space if forage production on Federal lands cannot support livestock grazing. Create community-scale social networks to pool resources and exchange technology, labor, equipment, forage, and ideas. • Develop Coordinated Resource Management Plans with the USDA Natural Resources Conservation Service across all Federal, State, and private lands.

herbivory, and by promoting herbaceous groundcover through removal of encroaching woody plants (Hanberry et al. this volume).

In anticipation of future droughts and a warmer climate, it will be beneficial to establish monitoring plans that include livestock management, drought, and climate. Grazing permits can be based on drought considerations rather than just historical ranch production. Strong collaboration with private landowners and shared ownership of drought impacts across stakeholders will help to facilitate effective options for managing rangelands (e.g., Coordinated Resource Management Plans with the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service). Conservation easements can be used to avoid loss of open space if forage production on Federal lands cannot support livestock grazing (USDA FS 2017c). Pooling resources and sharing technology, labor, and equipment will maximize favorable outcomes for all parties. Finch et al. (2016) discussed additional options to adapt to drought in rangelands.

CONCLUSIONS

High temperatures, low snowpack, and low water availability in summer will affect both people and ecosystems in the Interior West more frequently in the future. Planning for and adapting to the likelihood of increasing frequency and duration of droughts are needed to minimize negative effects on species, ecosystems, and ecosystem services, and to facilitate a transition to different climatic conditions in the future. The diversity of the Interior West's climate, biogeography, and socioeconomics means that drought occurrence and effects will vary greatly from north to south and from year to year. Drought management options discussed here (tables 6.1–6.4) are a sample of potential responses and will need to be implemented in the context of local physical, biological, and social environments.

Generally, the first, best, and often least costly means of increasing resilience to drought are to reduce existing stressors and improve the current condition ("health") of ecosystems (Halofsky et al. 2017). Pre-emptive actions that create benefits for multiple resources are valuable, especially actions that increase the quantity and duration of water availability (Halofsky 2018). For example, reconnecting floodplains with side channels and restoring populations of American beaver both contribute to retaining water during the summer. This benefits water supply for agriculture and municipal watersheds, maintains productivity of riparian areas, and maintains high-quality fish habitat. In dry forests, the effects of past fire exclusion can be addressed by reducing stand densities and hazardous fuels to increase resilience to both drought and fire (Peterson et al. 2011). In rangelands, management responses to altered fire regimes, overgrazing, and invasive species will help maintain productivity and benefit livestock grazing, native ungulates, and many other species (Padgett et al. 2018, Reeves et al. 2018).

The organizational capacity of Federal agencies to respond effectively and quickly is the key to successful management of current and future drought conditions. Best management practices for water and climate change vulnerability assessments provide scientific information as the basis for decision making, as well as potential options to implement. Optimal responses can be developed by integrating existing policies and practices with new information and by timely reporting of current conditions. Coordination by Federal agencies with other agencies and stakeholders is needed for effective management of drought effects across large landscapes. If drought-informed thinking is institutionalized as part of agency operations, then planning and management will be more effective, and crisis management in response to drought can be avoided.

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