Climate Risk Management Practices

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Abstract

Climate change is a major challenge for resource management decision making because of the uncertainties of how future conditions may unfold. Past techniques for responding to environmental challenges may not be as effective in the future. Adaptation options generated through a series of climate change vulnerability assessments and adaptation workshops in the Western United States were synthesized and are presented here as key climate change sensitivities and risk management practices for: forest vegetation, non-forest vegetation, water and infrastructure, fisheries and fish habitat, wetlands and riparian areas, wildlife, and recreation. These practices can be applied in resource management planning and on-the-ground projects.

Climate Risk Management Practices -- Introduction

Climate change is a major challenge in natural resource management, both because of the magnitude of potential effects and because of the uncertainty associated with climate change projections and effects. Adapting resource management to changing conditions is critical to reduce the vulnerability of key natural and human systems to negative climate change effects, and to ensure continued functionality of terrestrial and aquatic ecosystems in the future. Significant progress has been made in climate change vulnerability assessment and adaptation in natural resource management over the last decade, and key sensitivities and adaptation practices have emerged from these efforts. *Here, we synthesize key climate change sensitivities and risk management practices for forest vegetation, non-forest vegetation, water and infrastructure, fisheries and fish habitat, wetlands and riparian areas, wildlife, and recreation.*

How were these practices developed?

Climate Risk Management Practices are a distillation of information in the Climate Change Adaptation Library for the Western United States (http://adaptationpartners.org/library.php). The Library provides sensitivities to climate change and related adaptation strategies and tactics for different resource areas. It was derived from climate change vulnerability assessment and adaptation efforts conducted by Adaptation Partners (http://adaptationpartners.org), primarily in the Pacific Northwest, Northern Rocky Mountains, and Intermountain West regions. Science-management partnerships, including research scientists and natural resource specialists, are the foundation of all Adaptation Partners projects. Science-based climate change vulnerability assessments were conducted by teams of research scientists and managers, and adaptation options in the Library were developed by resource specialists during workshops convened to examine the vulnerability assessments. Adaptation Partners has elicited expertise on management responses to climate change from more than 1,300 land managers in the U.S. Forest Service, National Park Service, and other organizations throughout the western United States.

To develop Climate Risk Management Practices, a team of scientists compiled the most commonly suggested and scientifically-supported climate change sensitivities and practices (i.e., strategies and tactics) from the Library and its supporting literature (link to individual docs or list; see separate doc for list). The sensitivities and practices for each resource area were then reviewed by a minimum of two resource managers from federal and state land management agencies in the western United States. Review comments were incorporated into the final Climate Risk Management Practices.

What is climate risk?

Generally speaking, risk is the chance (probability) of harmful consequences or expected losses resulting from the interaction between existing hazardous conditions triggered by an adverse event. Such an event often leads to disruptions to the normal functioning of communities, including adverse human, material, economic, and/or environmental effects that require emergency response to address immediate critical human needs, followed by external support for recovery. Climate change often leads to greater exposure to risks because of changing, unexpected or unpredictable natural conditions that may lead to dire outcomes. For example, uncharacteristic extreme heat and lack of precipitation may leave forests susceptible to insect infestation and wildfires where trees are not adapted to such conditions. This creates a vulnerability to climate effects. Climate risk management practices are designed to minimize the exposure to such risks by managing hazards, and thereby reducing the vulnerability of communities and landscapes and increasing their resilience.

How can these practices be used and applied?

Climate Risk Management Practices are intended to provide natural resource managers with ideas for concrete actions to minimize the risks associated with climate change. They are not an exhaustive list of possible climate-smart practices; rather, they can be used as a tool to help identify potential issues (sensitivities) and mitigating actions for particular locations and landscapes. They also identify where monitoring may be useful to inform management.

<u>*The sensitivities and practices are not applicable in all places and situations. Managers will need to carefully consider specific site characteristics and landscape context, as well as policies and regulatory requirements, in determining whether practices are appropriate.*</u> Some of these practices are already utilized (e.g., invasive plant practices are already required in all Pacific Northwest Region National Forests), but we list them here to support their use in a changing climate. Managers may also want to consider expanding their application or reprioritizing the locations where they are implemented using other tools and frameworks (e.g., National Watershed Condition Framework, legacy roads and trails program). Adequate funding and capacity will be required for implementation.

The effectiveness of these practices depends on many factors, including site conditions, timing, and climatic conditions at the time of and following implementation. Monitoring will help to determine effectiveness for varied conditions and settings. In some cases, pilot projects could test the practices and demonstrate the results on a small scale. If they are implemented at a large scale or as new operational procedures, effectiveness should be tracked and monitored consistent with an adaptive management strategy.

How are the practices organized?

Climate Risk Management Practices are organized by resource area (i.e., water and infrastructure, forest vegetation, non-forest vegetation, fisheries and fish habitat, wetlands and riparian areas, wildlife, and recreation). Within each resource area, key climate change sensitivities describe resource susceptibility to harm. Under each sensitivity, general practices are listed, followed by specific practices.

Climate Risk Management Practices for Hydrology, Water Uses, and Infrastructure

Sensitivity: Higher winter peak flows will lead to increased damage of roads, bridges, trails, campgrounds, and other infrastructure.

Explanation: Warming will affect the amount, timing, and type of precipitation, and timing and rate of snowmelt (Luce et al. 2012, Luce et al. 2013, Safeeq et al. 2013), which will reduce snowpack volumes (Hamlet et al. 2005), and lead to higher winter peak streamflows (Hamlet and Lettenmaier 2007, Hamlet et al. 2013). Higher peak streamflows will lead to increased likelihood of damage to infrastructure, requiring more maintenance and replacement of infrastructure, and road and trail closures (Strauch et al. 2015).

Practices:

- Increase resilience of roads, stream crossings, culverts, and bridges to higher peak flows
    - Conduct inventory of culverts and bridges
    - Replace culverts with higher capacity culverts that can accommodate future peak flows
    - Consider prioritizing structure replacement in high-risk (mixed-rain-and-snow) watersheds
    - Reduce hydrologic connectivity of roads to the stream system by outsloping, increasing rolling dips and cross culverts
    - Improve road surfacing, especially at approaches to crossings
    - Increase size of drainage structures
    - Install more bridges and open bottom culverts
- Increase resistance of road surfaces to higher peak flows at stream crossings
    - Install hardened stream crossings
    - Use grade control structures, humps, and water bars to reduce stream velocity and redirect flow
- Reduce the road system to reduce flood damage and sedimentation to streams
    - Decommission roads with high risk and low access
    - Reroute roads out of floodplains
    - Convert use of roads to other modes of transportation (e.g., from vehicle to bicycle or foot)
- Increase the ability to protect recreation facilities, historic and cultural sites and points of diversion from flood damage
    - Restore watershed function by reconnecting stream channels to floodplains, dispersing flow and reducing the intensity of flood events in campgrounds and other facilities
    - Relocate recreation facilities (e.g., bathrooms, picnic tables) to locations that are not likely to flood frequently
    - Increase capacity to evaluate and respond to increased hazard trees and to mitigate risk in a timely manner
- Increase resilience of trail system to higher peak flows
    - Upgrade trail bridges with stronger parent material, if possible
    - Reroute trails above waterways with the highest flood risk
    - Increase long-range planning to prioritize trail and bridge repair, replacement, and rerouting
    - Consider increasing the height of bridges above waterways
    - Consider future peak flows in design of new trails and bridges
    - Abandon damaged trails with low use and high flood risk
    - Reroute trails in locations that eliminate the need for trail bridges
    - Increase capacity for trained staff to rapidly conduct hazard tree assessments after disturbances and for the management units to rapidly implement their recommendations

Sensitivity: Increased winter soil saturation will lead to higher risk of landslides and tree failure, affecting road and trail systems, access, human safety, and water quality.

Explanation: Climate change projections suggest that winter precipitation may increase in the Pacific Northwest and more winter precipitation will occur in intense storms (Salathé et al. 2014), leading to higher soil saturation. Furthermore, reduced snowpack is expected to increase antecedent soil moisture in winter (Hamlet et al. 2013). Elevated soil moisture and rapid changes in soil moisture can affect the stability of a slope and are responsible for triggering more landslides than any other factor (Crozier 1986).

Practice:

- Protect roads and structures from higher landslide frequency
    - Increase maintenance frequency
    - Stabilize slopes mechanically or with vegetation
    - Improve drainage
    - Alter road surface type and grade
    - Elevate roads to allow landslides to pass underneath
    - Locate/relocate roads in areas less vulnerable to landslides
    - Redesign roads to avoid over-steep cut and fills, and to improve water drainage; design debris catches on major access roads
    - Utilize seasonal road closures during most hazardous times of year
    - Develop thresholds for forecasted precipitation and wind that will trigger closures, and train staff to understand and implement them.
- Increase resilience of the trail system to erosion and landslides
    - Increase erosion control with revegetation projects
    - Reduce erosion by building protection into trail design
    - Reroute high-risk trails
- Increase the capacity of staff to rapidly respond and evaluate hazard tree situations
    - Increase the capacity to provide staff training and raise awareness of hazard tree policy and practices
    - Increase the number of qualified hazard tree assessment specialists.
    - Increase the capacity to rapidly communicate and implement the recommendations of the specialists in order to restore safe access and conditions

Sensitivity: Increasing length of the snow-free season will cause increased demand for access.

Explanation: Warming temperatures will reduce snowpack (Hamlet et al. 2005) and increase public demand for access to recreation during times when, historically, snow prevented warm-weather recreation activities (Strauch et al. 2015).

Practices:

- Maintain safe access at the beginning and end of the summer recreation season
    - Educate the public about risks associated with early- and late- season access
    - Establish new (or ensure compliance with) existing procedures, thresholds or checklists to safely open trails, campgrounds, and facilities earlier in the season
    - Alter seasonal staffing schedules to ensure additional recreation workload is covered
    - Ensure that adequate resources are available (e.g., seasonal crews that perform pre-season maintenance, teams of sawyers to remove hazard trees) to accomplish necessary tasks
    - Limit access when public safety is a concern

Sensitivity: Lower summer streamflows will cause higher demand and competition for water by municipalities and agriculture.

Explanation: Lower snowpack and earlier runoff with warming will lead to lower summer streamflows and less available water during peak demand in summer (Stewart et al. 2005, Luce and Holden 2009, Safeeq et al. 2013).

Practices:

- Restore function of watersheds to maximize water storage
    - Reconnect floodplains and side channels to improve hyporheic and baseflow conditions
    - Protect groundwater-dependent ecosystems
    - Maintain large wood in forested riparian areas for shade and recruitment to streams
    - Promote and increase beaver populations where appropriate
    - Promote appropriate livestock grazing management and proper use standards
    - Improve water diversions, delivery systems, and livestock distribution; minimize impact to spring sources (e.g., use shut off valves and splitters, locate troughs away from water sources, and locate head boxes away from spring sources)
    - Restore meadows
    - Manage for highly functioning riparian areas that can absorb and slowly release the flow of water off the landscape
    - Conduct vegetation management (e.g., mechanical treatments, prescribed fire, and managed wildfire) to develop appropriate vegetation density, arrangement (clumps, openings, gaps), and composition for optimal water balance and healthy watersheds
- Increase water conservation
    - Promote facilities with drought tolerant plants (xeriscape)
    - Install low-flow, solar, and composting toilets
    - Institute gray-water recycling
    - Educate the public about water shortage and conservation
    - Change user expectations for water availability
    - Reduce campground capacity to decrease water demand
    - Close facilities when water is not available

Climate Risk Management Practices for Forest Vegetation

Sensitivity: Warming temperatures will lead to longer fire seasons, increased wildfire frequency, and increased area burned across the western U.S.

Explanation: Increasing temperatures will result in more fire (larger spatial extent and potentially more high-severity patches) (McKenzie et al. 2004, Westerling et al. 2006) and more area in recently burned or early-successional stages (Chmura et al. 2011).

Practices:

- Plan and prepare for greater area burned and longer fire seasons
    - Continuously improve interagency coordination on fire management
    - Create fuel breaks to protect communities and high-value habitats
    - Anticipate more opportunities to use managed wildfire for resource benefit; in wilderness, permit fire to play a natural ecological role
    - Identify processes and conditions that create durable fire refugia, and promote these processes and conditions to protect high-value habitats
- Increase resilience of dry forest vegetation to fire by reducing forest density and hazardous fuels
    - Conduct thinning to reduce high fuel concentrations, particularly in the wildland-urban interface
    - Reduce fuel continuity and abundance of dwarf mistletoe fuel ladders
    - Increase use of managed wildfire for resource benefit
    - Use prescribed fire to maintain fire-resilient forest structure and promote fire-tolerant conifer species
- Focus post-fire management on forest resilience
    - Plan post-fire management response to large fires
    - Conduct prompt post-disturbance regeneration assessments to accurately report reforestation needs and prescribe reforestation treatments and monitoring
    - Update seed use plans to reflect increased reforestation needs at a regional scale with greater area burned
    - Anticipate greater need for propagated plants for post-fire reforestation
    - When planting trees post-disturbance, promote resilience to future conditions by considering fire tolerance and drought tolerance in planted species and genotypes
    - Consider switching to autumn planting to increase survival and to take advantage of earlier soil warming in the spring
    - Maintain key reforestation skills or arrange for training as needed on post-disturbance reforestation assessments (e.g., on seedling handling, cone and seed collection and handling, monitoring seedlings in storage, tree cooler maintenance and monitoring, microsite planting, reforestation contract administration)
    - Understand past management history on reforestation sites and how it has influenced tree species composition (e.g., through selective logging) and may influence response to climate change
    - Increase capacity to conduct tree survival assessments, and use findings to develop guidance for post-fire management
    - Identify areas that were historically non-forested to eliminate areas for reforestation that are not likely to support forests in the future
    - Increase post-fire monitoring to identify where regeneration failures are occurring and how vegetation trajectories may be changing
- Maintain and restore species and structural diversity to increase ecosystem resilience to fire and increasing temperatures
    - Manage for diversity of structure and patch size with fire and mechanical treatments to reduce fuel continuity and create more variation in fire behavior under average burning conditions

    - Manage for late-successional forest conditions, as area of late-successional forest may decrease with increased area burned
    - Use natural regeneration and planting of native species to promote diversity
    - Plant and encourage regeneration of rare and disjunct species in appropriate locations

Sensitivity: There will be increased opportunity for invasive species establishment with increased disturbance and shifting plant species composition in a changing climate.

Explanation: Stand mortality following wildfire and insect outbreaks will increase open space, light, and nutrient availability that facilitate regeneration of both native and nonnative species (Hellmann et al. 2008), creating the potential for long-term change in species distribution and abundance that may or may not be consistent with land management objectives.

Practices:
- Increase invasive species control and prevention efforts
    - Inventory regularly to detect new populations and species
    - Implement early detection/rapid response for invasive species treatment
    - Include invasive species prevention strategies in all projects
    - Promote weed-free seed, straw, and hay
    - Implement existing recommended management practices, such as restrictions on equipment and water use, when working in areas with root disease or other waterborne pathogens to prevent new infections and reduce spread
    - Implement guidelines and restrictions on the movement of plant material to reduce the risk of introducing invasive species
    - Educate employees, crews, and the public about invasive species and their detrimental effects on ecosystems
    - Coordinate invasive species management, funding, and support among agencies and staff areas

Sensitivity: The potential for mortality events and regeneration failures will increase in a warming climate with increased fire, drought, insect outbreaks, and interactions among disturbances.

Explanation: Permanently warmer temperatures and more frequent droughts create stress in mature trees, making them more susceptible to other stresses (e.g., insects). These conditions also make it difficult for newly germinated (or planted) trees to survive harsh conditions near the soil surface (Chmura et al. 2011, Clark et al. 2016).

Practices:
- Promote native species and genetic diversity appropriate to ecosystem and site constraints
    - Maintain species diversity during thinning
    - Work with geneticists to improve genetic diversity of regenerating trees where trees are being planted or where natural regeneration is prescribed
    - Cautiously relax seed zone guidelines to include genotypes from warmer locations, develop monitoring protocols, and track their performance (unless empirical data from long-term provenance tests indicate otherwise, or negative effects on wildlife habitat may occur)
    - Match species and seed sources to soil conditions
    - Reduce competition (including herbicide use where appropriate) and promote desired species
    - Develop systems to reliably track rare components of operational planting efforts over time (e.g., devise and implement systems to track trees from different seed zones)

- Plan for large disturbances and mortality events
    - Develop reforestation guidelines to ensure conservation of genetic, species, stand, and landscape diversity.
    - Develop a gene conservation plan for *ex situ* collections for long-term storage
    - Identify areas important for *in situ* gene conservation
    - Maintain a tree-seed inventory with high-quality seed for a wide range of species, seed zones, and elevation bands
    - Increase seed and propagule production of a wide variety of native plant species for post-disturbance restoration work
    - Monitor reforestation success

Sensitivity: Warming temperatures will result in increased forest drought stress and decreased productivity, particularly at lower elevations.

Explanation: Even short drought periods can create stress and reduce growth, making trees more susceptible to other stressors (Clark et al. 2016).

Practices:
- Manage stand density to maintain tree vigor and increase resilience to drought
    - Conduct thinning in dense forests to increase individual tree health and make trees more resilient to drought and more resistant to insect outbreaks
    - Manage stands to reduce prevalence and impacts of dwarf mistletoe
    - Use appropriately-timed girdling, cutting and leaving trees, prescribed burns, and managed wildfire to reduce stand densities and drought stress, yet provide standing dead trees to support beneficial microclimate and insect predators
    - Maximize early-successional tree species diversity by retaining minor species during thinning activities to promote resilience to drier conditions
    - Promote tree size and age diversity in stands and across large landscapes to increase resilience to insect outbreaks, fire, and drought; consider uneven-aged management
    - Promote drought-tolerant species (e.g., in thinning prescriptions and planting), but not to the detriment of species diversity and habitat
    - Use prescribed fire to reduce stand densities, increase landscape heterogeneity, and increase resilience to drought
    - Monitor tree survival and growth under different management prescriptions
- Develop capacity and guidance for drought preparedness and response
    - Develop indicators for a “drought early warning system” for forests
    - Leverage partnerships to increase capacity for mitigating and responding to drought
    - Look for synergies that accomplish multiple objectives (e.g., use prescribed fire and thinning to increase drought resilience and achieve broader restoration goals)
    - Institutionalize drought as a factor to be considered in existing guidance

Sensitivity: Warmer conditions, and more fire, drought, and extreme events with climate change will increase tree susceptibility to and the potential for extensive insect outbreaks and possible spread of pathogens.

Explanation: Insects and pathogens have high biological potential to reproduce and spread rapidly during periods of favorable environmental conditions (Weed et al. 2013). Many insect species, especially bark beetles, increase their populations rapidly in areas with stressed trees, potentially leading to outbreak conditions; some fungal pathogens also take advantage of stressed trees (Weed et al. 2013).

Practices:

- Increase resistance and resilience of forest stands to insects and pathogens
  - Thin to decrease stand density and increase tree vigor
  - Reduce density of post-disturbance planting
  - Plant resistant species or genotypes where species-specific insects or pathogens are a concern
  - Increase stand-scale biodiversity and prevent stand failure by planting multiple genotypes and multiple species (where appropriate)
  - Promote age, size class, and structural diversity to increase resilience to insects and disease outbreaks
  - Treat existing pathogen occurrence (e.g., dwarf mistletoe, root disease) more aggressively
  - Strategically use anti-aggregation pheromones and protective pesticides to protect high-value trees and stands
  - Increase the capacity to evaluate, recommend, and implement innovative forest protection strategies, and monitor effectiveness

Sensitivity: Higher temperatures will lead to changing vegetation dynamics in cold upland and subalpine forests.

Explanation: A warmer climate may alter species distribution and abundance in the long term, especially if large disturbances become more common; tree species and associated insects and pathogens that are energy limited may grow faster in some locations if they have a longer growing season (Halofsky and Peterson 2016).

Practices:
- Manage stem density and fuels in forests at lower elevations, thus reducing spread of large crown fires and dispersal of insect populations from lower-elevation forests
  - Create targeted fuel breaks at strategic landscape locations
  - Thin low-elevation dry forests to reduce fire intensity and spread into subalpine forest
  - Thin low-elevation dry forest to reduce insect population pressure and spread into subalpine forests
- Accelerate restoration of cold upland and subalpine forests, where appropriate
  - Increase the availability of nursery stock and seed for tree species in cold upland and subalpine forests
  - Plant and encourage regeneration of rare and disjunct species in appropriate locations
- Monitor and detect change in survival, species composition, and mortality in subalpine forests
  - Install and analyze additional monitoring plots to gather trend information over time, targeting areas where changes are expected
  - Use existing monitoring information (e.g., Forest Inventory and Analysis plot information) to determine trends in subalpine forests
- Identify and protect potential climate change refugia in cold upland and subalpine forests
  - Map refugia
  - Protect refugia from high-intensity fire by excluding fire, thinning, and using prescribed fire
  - Control invasive plant species in high-elevation areas and potential refugia
  - Monitor to determine where refugia are likely to exist under future conditions

Sensitivity: Foliage fungi can cause more damage in warmer winter and warmer/wetter spring conditions.

Explanation: Needle diseases are favored by warmer and wetter winters and springs, which may be more common with climate change (Sturrock et al. 2011). Needle casts, rusts, and needle blights in pines, Douglas-fir, and true fir usually cause loss of needles in the year following a season favorable for infection. Their occurrence at epidemic levels depends on favorable weather conditions and presence of an adequate host population (Sturrock et al. 2011).

Practices:

- Increase the capacity for evaluation and communication about rapidly-developing foliage symptoms.
    - Improve access to foliage disease taxonomic identification
    - Monitor foliage disease activity to assess whether long-term impacts are occurring
- Use silvicultural techniques to reduce vulnerability
    - Plant species that are compatible with local soils and climate
    - Closely monitor diseases in trees planted for assisted migration (managed relocation)
    - Increase species diversity in stands where possible
    - Use techniques such as pruning to improve air circulation and reduce humidity in susceptible stands

Sensitivity: Multiple factors, including white pine blister rust, bark beetles, and fire, will stress whitebark pine in a changing climate.

Explanation: Whitebark pine populations are already reduced from white pine blister rust and bark beetles, and a warmer climate will promote the occurrence of mountain pine beetle at high elevation, as well as higher wildfire frequency, which may further stress whitebark pine (Keane et al. 2012).

Practices:

- Increase the competitive ability and resilience of whitebark pine to changing disturbance regimes
    - Actively monitor and protect individual high-value whitebark pine trees (especially those with genetic resistance to white pine blister rust) with pesticides, pheromones, and other techniques
    - Thin to reduce tree competition (e.g., remove whitebark pine or other species like subalpine fir)
    - Regenerate rust-resistant strains and increase seed sources
    - Create fuel breaks around whitebark pine individuals and stands
    - Improve structural and age class diversity of whitebark communities at multiple scales
    - Manage lower-elevation vegetation to reduce susceptibility to bark beetles and prevent outbreaks in whitebark pine stands
    - Use the Minimum Requirements Decision Guide and the Evaluation Framework for Proposed Ecological Intervention and Restoration in Wilderness to evaluate site-specific proposals for actions in wilderness to support restoration of whitebark pine

Climate Risk Management Practices for Non-Forest Vegetation

Sensitivity: There will be increased opportunity for invasive species establishment with increased disturbance and shifting plant species composition under changing climate.

Explanation: Rapid removal of vegetation following wildfire will create open space and light that facilitate regeneration of both native and nonnative species, creating the potential for long-term change in species distribution and abundance (Hellmann et al. 2008).

Practices:

- Increase invasive species control and prevention efforts
    - Inventory regularly to detect new populations and species; map new and existing infestations of invasive weeds
    - Implement early detection/rapid response for invasive species treatment
    - Include invasive species prevention strategies in all projects
    - Expand promotion of weed-free seed especially in non-wilderness areas
    - Educate employees and the public about invasive species and their detrimental effects on ecosystems
    - Coordinate invasive species management, funding, and support among agencies
- Maintain or restore ecological integrity of native rangeland ecosystems to prevent spread of invasive species
    - Apply ecologically-based invasive plant management (EBIPM) principles
    - Identify areas more susceptible to wind erosion post-fire, and pre-plan activities to reduce wind erosion risks
    - Increase resilience of native species where intact or productive communities exist
    - Treat invasive species with appropriate management practices or biotic-path herbicides
    - Monitor soil stability and productivity to reduce low-fertility soils that promote invasives
    - Identify and promote early-successional natives that may be able to compete with invasives (e.g., seeding of native plant species)
    - Reduce grazing practices that encourage spread of non-native species
    - Periodically reevaluate sustainable animal unit months (AUM) and appropriate management levels (AML) to account for changes in rangeland productivity as annual and seasonal temperatures increase

Sensitivity: Climate change may lead to loss of climatically suitable habitat for persistent pinyon-juniper ecosystems.

Explanation: Prolonged droughts, which will be more common in a warmer climate, can stress low-elevation pinyon pine, leading to mortality from beetles in some locations (Clark et al. 2016).

Practices:

- Maintain and restore ecological integrity of persistent pinyon-juniper communities.
    - Identify and map persistent pinyon-juniper communities and assess current conditions
    - Reduce invasive species; maintain or restore native understory composition
    - Maintain or restore structural diversity to promote natural disturbance regimes
    - Reduce stand density where appropriate
    - Actively protect high-value trees and stands from beetles, if necessary

Sensitivity: Many sagebrush ecosystems are in poor ecological condition because of past overgrazing, invasives, and other factors; climate change may increase stress on these ecosystems by shifting species composition, providing opportunities for invasive species establishment, and allowing for emergence of new invasive species.

Explanation: Increasing frequency of prolonged droughts in a warmer climate can increase stress in sagebrush and other native shrubs, killing them or reducing canopy cover, making it easier for some nonnative species (e.g., cheatgrass) to become established (Finch et al. 2016).

Practices:

- Improve resilience and resistance of sagebrush-grass ecosystems to changing climatic conditions
    - Maintain vigorous growth of native shrub, grass, and forb species
    - Develop a flexible grazing management plan
    - Adapt grazing management practices and policies to improve ecological resilience and resistance
    - Monitor successional patterns and long-term effects of fire on sagebrush ecosystems to inform management actions
    - Control invasive species affecting the ecology of sagebrush ecosystems
    - Actively manage conifer encroachment to maintain sagebrush ecosystems
    - Utilize native seed sources for restoration (planting) that will be adapted to future climate conditions
    - Develop seed zones and promote propagation of native seed sources for sagebrush ecosystems
    - Protect existing sagebrush communities from high-intensity wildfire (but consider prescribed fire)
    - Protect locations where invasive species are absent
- Manage for soil conditions to avoid increased runoff
    - Protect and promote cryptobiotic soil crust

Sensitivity: Conifers are likely to continue expanding into sagebrush and grassland ecosystems under changing climate.

Explanation: With warming, juniper encroachment is expected to increase at higher elevations that are currently too cold (Weisberg et al. 2007). Juniper encroachment will be favored where climate change increases winter precipitation and reduces summer precipitation (Miller and Rose 1999).

Practices:

- Control expansion of juniper
    - Identify current and future critical areas to optimize the benefits of control measures
    - Prioritize Phase I and Phase II juniper (lower juniper density), and Phase III juniper (high juniper density) where deep soils have allowed retention of native grasses
    - Use mechanical control
    - Use prescribed fire and managed wildfire to kill younger trees

Sensitivity: Drought increases the amount of bare ground in rangelands, increasing potential for wind and water erosion.

Explanation: Increased frequency of prolonged drought in a warmer climate will weaken and kill some plant species, thus reducing plant cover and exposing bare ground. This can promote establishment and production of nonnative species (Finch et al. 2016).

Practices:

- Increase or maintain ground cover with drought
    - Manage the amount, timing, and distribution of domestic ungulate herbivory and removal of plant cover and impacts on cryptobiotic soil crust; develop proactive, flexible, and adaptive allotment management plans
    - Consider utilization of forage in allotments by native ungulates and adapt authorized AUMs accordingly
    - Provide rest or defer grazing on lands in an unhealthy condition
    - Reduce or eliminate conifer encroachment and reduce sagebrush density to no more than 25% in warm-dry sagebrush and no more than 30% in cool-moist sagebrush to maintain native herbaceous cover and composition
    - Reseed after disturbance with drought-resistant native plants
    - Promote healthy soil and biodiversity (both above and belowground) to increase drought resilience (e.g., increase organic matter to increase soil water holding capacity and improve retention and recovery of cryptobiotic soil crust)
    - Better manage wild horse and burro populations to reduce impacts during drought and promote vegetation recovery after drought; include population reduction or elimination and exclusion among the management options
- Increase communication, education, and collaboration with range users and public users during drought
    - Clearly define thresholds that will trigger alternative management strategies
    - Ensure ongoing collaboration focused on drought conditions and possible mitigation
    - Implement local stewardship programs that include multiple participants
    - Ensure that employees are familiar with and sensitive to local ranch and range culture
- Develop integrated drought management plans for allotments and base properties with willing permittees and leasees

Climate Risk Management Practices for Riparian Areas, Wetlands, and Groundwater-Dependent Ecosystems

Sensitivity: Reduced snowpack, shifts in hydrologic regime involving changes in timing and magnitude of streamflows, and changing groundwater recharge and discharge will likely lead to shifts in plant species composition and reduced habitat quality in riparian areas, wetlands, and groundwater-dependent ecosystems.

Explanation: Anticipated changes include lower summer flows (Stewart et al. 2005, Luce and Holden 2009, Safeeq et al. 2013), higher and more variable winter flows (Hamlet and Lettenmaier 2007, Hamlet et al. 2013), and potential shifts in vegetation composition and abundance (Dwire and Mellmann-Brown 2017).

Practices:

- Maintain and promote riparian processes and functions
    - Manage upland vegetation to reduce risk from large-scale, high-severity fire in riparian areas (e.g., with thinning and prescribed fire)
    - Restore riparian obligate species
    - Promote appropriate livestock grazing management and proper use standards
    - Reconnect floodplains and side channels to improve hyporheic and baseflow conditions
    - Manage for highly functioning riparian areas that can mitigate high flows
- Implement management strategies that retain soil moisture in riparian areas, wetlands, and GDEs
    - Maintain and improve soil function and health
    - Improve stream channel function
    - Manage upland forest vegetation
- Increase floodplain and channel water storage by managing for American beaver populations
    - Plant shrubs in riparian areas for beaver use
    - Trap and relocate beavers to selected watersheds; use valley form analysis to assess potential sites for beaver colonies and channel migrations
    - Consider beaver dam analogues to improve habitat quality for beaver
    - Work with appropriate agencies to reduce trapping rates in vulnerable watersheds
    - If populations are low in a watershed, trap and relocate beavers to create dams
- Plan and prepare for more frequent and severe flood events
    - Restore native plant species in riparian areas
    - Control invasive plant species in flood-prone reaches
    - Expand current restoration projects to mitigate increasing flood risk
    - Avoid committing resources for restoration projects in areas with high flood risk; prioritize areas with low flood risk
    - Use natural flood protection (e.g., vegetation or engineered logjams)
    - Refine and revise stream health protocol to integrate flow regime change
- Maintain or restore natural flow regime to buffer against future changes
    - Protect groundwater and springs
    - Address water loss at water diversions and ditches
    - Consider float valves for watering troughs and disconnect diversions during off seasons
    - Reconnect and increase off-channel habitat and refugia in side channels and channels supported by wetlands
    - Revegetate and use fencing to exclude livestock
    - Acquire water rights where possible
    - Disconnect roads from streams to reduce drainage efficiency
- Increase floodplain water storage
    - Plant appropriate trees and shrubs in riparian areas
    - Maintain or restore channel form
    - Manage to adjust livestock season of use, use numbers, and duration of use

    - Manage to adjust recreation season of use, use numbers, and duration of use
- Conduct education and outreach with involved parties to promote riparian and wetland function
    - Collaborate with watershed councils
    - Collaborate with recreation specialists and managers
    - Increase communication networks for safety and awareness
- Maintain resilience of high-elevation wetlands
    - Monitor functionality of existing wetlands
    - Reduce direct human impact on sensitive wetland habitats
    - Monitor changes in plant distribution, especially invasive species
    - Address water loss at water diversions and ditches
- Monitor and prioritize regions for wetlands management
    - Prioritize habitats for active management and protection across jurisdictional boundaries
    - Focus monitoring on sensitive habitats and species in priority regions
    - Periodically review and revise management priorities
- Increase riparian and wetland plant population resilience by reducing non-climatic threats
    - Manage road, trail, and recreation impacts
    - Maintain hydrology of critical habitats
    - Increase habitat connectivity and heterogeneity
    - Mitigate road impacts; eliminate unnecessary roads and impacts to wetlands and riparian areas
    - Redesign road drainage to reduce runoff and increase water infiltration and retention
    - Control invasive species; use early detection, rapid response (EDRR)
- Manage water to maintain springs and wetlands; improve soil quality and stability
    - Monitor recreation usage in/near springs and wetlands and manage impacts
    - Reduce ungulate trampling in/near springs and wetlands with fencing and livestock use changes; place watering troughs outside riparian/wetland zones
    - Maintain water on-site through water conservation techniques such as float valves, diversion valves, and hose pumps
    - Encourage spring development project designs that will ensure water flows for native species and habitat
    - Develop a national groundwater protection program

Climate Risk Management Practices for Fish Habitat and Fisheries

Sensitivity: Increased flood frequency and higher peak flows may reduce egg-fry survival for fall spawners and yearling parr winter survival.

Explanation: A warmer climate is expected to reduce snowpack and increase rain:snow ratios, thus leading to more flooding, especially in late autumn and winter when eggs and young fish of some species are especially vulnerable to damage by turbulent water and abrasion by sediments (Mantua et al. 2010, Goode et al. 2013).

Practices:

- Increase spawning habitat resilience by restoring stream and floodplain structure and processes
  - Restore stream and floodplain complexity
  - Increase protection of alternate spawning habitat
  - Consider removing natural barriers to increase spawning habitat
  - Increase use of logjams where feasible
  - Increase bank and channel stability
- Increase habitat resilience by reducing threats from roads and infrastructure in floodplains
  - Designate and restore natural floodplain boundaries
  - Increase floodplain habitat
  - Remove infrastructure from floodplains
  - Disconnect roads from streams
  - Reduce road density near streams
  - Increase culvert capacity
  - Reduce flashiness of peak flows
  - Increase side-channel habitat and increase large wood for parr winter survival

Sensitivity: Increased sedimentation in streams will accompany increased flooding and wildfire.

Explanation: Increased flooding will expose streambanks and accelerate subsequent erosion into streams (Goode et al. 2013). Increased wildfire will expose soils to overland flow and channeling in the absence of live vegetation, thus accelerating sediment removal and erosion into streams, especially near roads (Goode et al. 2012).

Practices:

- Manage and reduce sediment generated by roads
  - Evaluate road system for sediment input
  - Reduce sediment input to streams by replacing culverts, and relocating and decommissioning roads
- Reduce sedimentation associated with erosion and wildfire
  - Include climate change projections in identification of potential areas for streambank and upland erosion
  - Inventory disturbed areas for riparian and upland vegetation restoration
  - Manage fire and fuels in dry forests with thinning and prescribed fire to reduce fire severity and extent
  - Restore and revegetate burned areas to store sediment and maintain channel geomorphology
  - Develop a geospatial layer of debris flow potential for pre-fire planning

Sensitivity: Lower low flows in summer will reduce fish habitat quality.

Explanation: In a warmer climate with less snowpack, streamflows will be even lower in summer, at a time when sufficient flows of cool water are needed for various life stages of fish (Mantua et al. 2010, Isaak et al. 2017).

Practices:

- Increase aquatic habitat resilience to low summer flows
    - Increase off-channel habitat and protect refugia in side channels and channels fed by wetlands
    - Protect wetland-fed streams that maintain higher summer flows
    - Design channels at stream crossings to provide a deep thalweg for fish passage during low-flow periods
    - Increase deep-water habitat and channel morphology
    - Reduce width:depth ratios to reduce solar radiation in stream
- Manage upland vegetation to retain water and snow in order to slow spring snowmelt and runoff
    - Manage forest cover to retain snow and decrease snowmelt
    - Restore mid-and high-elevation wetlands that have been altered by land use
- Decrease fragmentation of stream network so fish can access similar habitats
    - Identify stream crossings that impede fish movements and prioritize culvert replacement
    - Use stream simulation design (e.g., bottomless arches, bridges), adjusting designs to provide low-flow thalweg
    - Rebuild stream bottoms by increasing floodplain connectivity, riparian vegetation, and water tables; decrease road connectivity
    - Restore beaver habitat and beaver colonies
    - Maintain minimum streamflows (buy and lease water rights, install modern flow structures, monitor water use)
- Manage riparian vegetation to optimize shade to streams
    - Plant trees in riparian areas
    - Maintain or enhance shade to streams
    - Increase sinuosity in channels
    - Eliminate human disturbances affecting width:depth ratio
- Protect existing hyporheic flows
    - Avoid activities that disrupt flows
    - Identify locations of hyporheic flows
- Increase residence time; store water on landscape
    - Restore fluvial processes
    - Promote beaver populations
    - Protect springs
    - Improve efficiencies in regulated water use; promote water conservation
    - Identify where reservoir management can improve species conservation
- Reduce intensity of use in areas of concentrated fish populations, particularly during drought
    - Stop fishing and curtail uses (in important cold-water habitat or other important habitat) during drought
    - Curtail season of use or shut down recreation season (rafting, camping) during drought
    - Shift recreation to more stable, resilient areas
    - Fence off areas to keep livestock out of sensitive areas
    - Bring in alternative sources of water for livestock to remove them from or reduce use of critical areas
    - Educate the public so that they can change their behavior and activities
    - Use signs to help inform the public about sensitive areas

Sensitivity: Lower low flows in summer will increase pre-spawn mortality for summer run and stream-type salmon and steelhead (Mantua et al. 2010, Isaak et al. 2017).

Explanation: In a warmer climate with less snowpack, streamflows will be even lower in summer, at a time when sufficient flows of cool water are needed for various life stages of fish.

Practices:

- Increase in-stream flows with dry-season water conservation to reduce withdrawals
    - Increase efficiency of irrigation techniques
    - Reduce summer withdrawals on federal lands
    - Consider alternative water supplies for federal lands to retain in-stream flows
    - Coordinate with downstream partners on water conservation education
    - Restore beaver habitat and populations
    - Investigate and quantify connectivity between groundwater and streamflows

Sensitivity: Warmer stream temperatures will reduce thermal heterogeneity in streams and increase thermal stress on many life stages of fish (Mantua et al. 2010, Goode et al. 2013, Isaak et al. 2017).

Explanation: In a warmer climate with less snowpack, streamflows will be lower in summer in addition to being affected by higher air temperatures, at a time when sufficient flows of cool water are needed for fish.

Practices:

- Increase habitat resilience for cold-water fish by restoring structure and function of streams
    - Increase habitat and refugia in side channels
    - Protect wetland-fed streams that maintain higher summer flows
    - Restore structure and heterogeneity of stream channels
    - Reconnect floodplains to improve hyporheic and base flow conditions
    - Remove dikes and levees
    - Restore and protect riparian vegetation.
    - Manage livestock grazing to restore ecological function of riparian vegetation and maintain streambank conditions
    - Reduce high road densities that are intercepting subsurface stream flows
- Increase understanding of thermal tolerance of fish species
    - Conduct field experiments of fish-temperature relationships for multiple species and regions
    - Monitor changes in stream temperature and fish distributions
    - Re-evaluate and update water temperature standards (both values and indices)
    - Manage fishing to reduce stress to fish during critical times
- Increase understanding of thermal heterogeneity in streams and cold-water refugia
    - Identify and inventory cold water refugia, springs, and groundwater input to springs
    - Identify seasonal refugia (winter and summer)
    - Research the influences of lakes, reservoirs, and groundwater on stream temperatures
    - Research fish use of thermal refugia

Sensitivity: Warmer stream temperatures may favor nonnative fish species.

Explanation: Increased stream temperature in summer is expected to create thermal stress for cold-water fish species, making them less competitive with nonnative species that are more tolerant of warm water (Mantua et al. 2011).

Practices:

- Increase resilience of native fish species by reducing barriers to native species and removing non-native species
    - Survey and map nonnative species
    - Combine mapping of nonnative fish species with information on migration barriers
    - Consider information from surveys of warmer basins farther south as indicators of vulnerability
    - Assess migration barriers and potential habitat for native species
    - Remove barriers to fish passage where this will not increase threats from nonnative species
    - Tailor restoration actions to benefit native species
    - Maintain or construct barriers to prevent spread of nonnative species
    - Manage livestock grazing to restore ecological function of riparian vegetation and maintain streambank conditions.
    - Remove or control nonnative fish species
    - Reduce habitat fragmentation of native trout habitat through barrier removal (e.g., culverts and water diversions)
    - Restore native trout to high elevation, cold-water refugia
- Monitor for invasive species and control or eliminate populations
    - Use environmental DNA (eDNA) monitoring for early detection of river and stream invasions
    - Reduce or suppress brook trout populations
    - Construct barriers that prevent access/invasion to conserve native populations in headwaters
    - Implement monitoring and boat inspection programs to detect invasive mussel and aquatic plants species in lakes before populations are established
    - Use early detection/rapid response

Sensitivity: Warmer stream temperatures may create more favorable conditions for diseases and parasites (Mantua et al. 2011).

Explanation: Increased stream temperature in summer facilitates development and spread of some types of diseases and parasites, which adds to the thermal stress experienced by cold-water fish species, making them even more vulnerable to a warmer climate.

Practices:

- Increase population resilience by increasing fish health
    - Increase public education to eliminate disease vectors
    - Use direct treatment or removal of infected fish
    - Survey fish health conditions
    - Collaborate and standardize health survey methods among agencies
    - Consider changes in hatchery practices to decrease infection rates

Sensitivity: Climate change will likely result in shifts in native species distributions and community realignments.

Explanation: In most cases, decreased cold-water habitat, progressively confined to higher elevations and other locations with less exposure to high temperature, will restrict the range of fish species that require cool water, rearranging the distribution and abundance of both native and nonnative species (Isaak et al. 2017).

Practices:

- Conduct biodiversity surveys to describe current baseline conditions and manage distribution shifts
    - Formalize, expand and standardize biological monitoring programs (e.g., management indicator species)
    - Use modern, low-cost technologies (e.g., environmental DNA [eDNA] and digital photo points)
    - Consider managed relocation
    - Use digital technology in data collection and for database uploads
    - Streamline field crew data collection protocols
    - Fully utilize existing corporate databases and legacy datasets
    - Develop and improve understanding, adaptive actions, and models related to non-game aquatic species (e.g., mussels, dace, sculpin, spring snails, and amphibians)
    - Continue to refine and improve understanding, adaptive actions, and models related to cold-water salmonids

Climate Risk Management Practices for Wildlife

Sensitivity: More wildfire and insect outbreaks will increase loss of late-successional forest habitat and connectivity.

Explanation: In a warmer climate, dense forests with high fuel loads will be more susceptible to crown fires and insect damage, which can kill old trees and eliminate multi-level canopy structure, thus reducing habitat for some animal species that need old forests (Chmura et al. 2011, Halofsky et al. 2015).

Practices:

- Maintain current habitat, restore historical habitat, and promote potential future habitat
    - Conserve current old-growth habitat
    - Strategically place fuel breaks to minimize risk to important habitat areas
    - Protect, maintain and recruit legacy structures (e.g., large trees, snags, down wood)
    - Restore understory to create future habitat
    - Identify and protect areas on the landscape that are more likely to maintain late-successional habitat
- Increase resilience of late-successional habitat and surrounding habitat
    - Increase landscape biodiversity and heterogeneity by modifying species composition
    - Increase diversity of age classes and restore a patch mosaic
    - Accelerate development of additional late-successional habitat
    - Increase protection of critical habitat structure (e.g., snags and nest trees)
    - Consider policy changes and/or amendments to existing management plans to allow for adaptive management within late-successional reserves to promote stand resilience
    - Increase capacity for monitoring insects to forecast and anticipate outbreaks
    - Manage insect outbreaks in early stages or as necessary to reduce damage
    - Collaborate with neighbors on priority areas for treatments, and increase extent of protected areas
    - In dry forest types, consider thinning and prescribed fire to prevent stand-replacement fire, but prevent loss of old trees by reducing fuels prior to burning (e.g., reduce fine fuels at the base of trees and reduce ladder fuels)
    - Maintain spatial patterns that are resilient to disturbance and maintain landscape permeability
- Increase monitoring of specialist species that are expected to be sensitive to climate change
    - Identify climate refugia
    - Adjust monitoring protocols to detect species responses to climate change
    - Increase monitoring to determine if population trends are associated with climate change versus other stressors

Sensitivity: Loss of habitat structure and spatial heterogeneity will increase species vulnerability to changing climate.

Explanation: If disturbances increase in a warmer climate, forests will tend to be in younger age classes, without as much (vertical and horizontal) structural diversity (Chmura et al. 2011), reducing the number of animal species for which suitable habitat is available.

Practices:

- Develop prescriptions for stands and large landscapes to maintain heterogeneity
    - Maintain high quality early-, mid-, and late-successional habitats
- Develop prescriptions to monitor and protect high-value, large, old trees

Sensitivity: Higher temperature and increased disturbance will cause shifts in ranges of plant and animal species.

Explanation: If disturbances increase in a warmer climate, plant species composition will shift, thus causing a significant change in habitat availability and connectivity for animal species (Parmesan 2006).

Practices:

- Increase habitat connectivity and permeability
    - Increase, prioritize, and support the purchase and management of land transactions such as acquisitions and easements, especially in critical areas where connectivity may be of concern
    - Consider transportation infrastructure management tools (including encumbrances) to address concerns regarding access in critical habitats
    - Develop landscape connectivity and permeability patterns for animal movement at multiple scales

Sensitivity: A warmer climate will potentially convert drier forest types (e.g., ponderosa pine) to shrubland or grassland

Explanation: Increased crown fires in dense stands, prolonged droughts, and bark beetles may eliminate some older ponderosa pine stands and make regeneration difficult, allowing other species to become dominant in some locations (Halofsky et al. 2015). This will eliminate habitat for animals that use mature ponderosa pine forest.

Practices:

- Promote ponderosa pine resilience
    - Reduce competition from Douglas-fir and grand fir (thin, burn) in current mature ponderosa pine stands
    - Utilize understory burning when possible and during historic burning windows in order to provide for understory forb, grass, shrub, and overstory resilience
    - Protect current mature and older ponderosa pine stands
    - Plant ponderosa pine where it has become less common within its natural range
- Identify sites that will no longer sustain ponderosa pine and promote high-quality grassland and shrubland habitat in those locations

Sensitivity: Higher temperatures, loss of snowpack, and vegetation changes may increase stress for some species in cold upland and subalpine forests

Explanation: A warmer climate may affect the mosaic of forest and meadows in subalpine ecosystems by altering species composition in response to less snow and a longer growing season (Cansler et al. 2016). This would affect animals that require persistent snowpacks and mountain meadows.

Practices:

- Protect rare and disjunct tree species (e.g., Alaska cedar, limber pine, whitebark pine)
    - Plant and encourage regeneration of rare and disjunct species in appropriate locations
    - Plant whitebark pine genotypes that are resistant to white pine blister rust
- Protect cold upland subalpine forests by restoring forests at lower elevations, thus reducing spread of large crown fires
    - Create targeted fuel breaks at strategic landscape locations
    - Thin dry forests to densities low enough to reduce fire intensity
- Accelerate restoration of cold upland and subalpine forests where appropriate

    - Increase the availability of nursery stock and seed for tree species in cold upland and subalpine forests
- Increase population resilience of subalpine-dependent species
    - Increase education and regulatory enforcement to prevent adverse human-wildlife interactions
- Maintain and protect summer alpine habitat for species such as pikas and marmots
    - Monitor tree establishment in meadows
    - Remove trees from meadows using fire and mechanical treatments
    - Monitor soil development, cryptobiotic soil crust, and herbaceous plant establishment in previously snow-covered and glaciated areas
    - Assess visitor use in alpine and subalpine habitats; incorporate management strategies that may include education, awareness, use designations, and other recreation management tools
- Develop mitigation measures and strategies to compensate for loss of snowpack location and duration
    - Reduce impacts from winter recreation as ice- and snow-based recreation is concentrated into smaller areas
    - Maintain habitat for thermal cover and security
    - Utilize methods that retain snowpack and associated moisture (e.g., utilize tree retention to slow the loss of snow and retain snowmelt through meadow and wetland restoration)

Sensitivity: Decreased streamflow will reduce riparian vegetation and affect food supply and habitat structure for riparian-obligate species.

Explanation: Riparian habitat is relatively uncommon across most landscapes, but will be disproportionately affected by a warmer climate (Dwire and Mellmann-Brown 2017), quickly altering habitat quality for a large number of animal species that need this habitat for water, food, and cover.

Practices:
- Reduce riparian impacts by storing more water on the landscape and raising the water table where possible
    - Inventory current and potential habitat
    - Increase beaver populations with translocation and trapping to create more wetland habitat in strategic locations where they can be most successful
    - Plant native riparian vegetation, manage domestic and ungulate grazing, and manage recreational use including special uses in order to restore riparian habitat
    - Use snow fences and reflective tarps to retain snow in critical areas where effective and appropriate

Sensitivity: Increased duration and periodicity of drought and reduced soil moisture stress will lead to changes in wetland habitat quantity and quality; higher temperature will alter phenology and species interactions (e.g., predation, competition) of wetland obligate species.

Explanation: Wetland habitat is relatively uncommon across most landscapes, but will be disproportionately affected by a warmer climate (Lee et al. 2015), quickly altering habitat quality for a large number of animal species that need this habitat for water, food, and cover.

Practices:
- Identify, retain, and restore riparian and wetland habitat for wildlife
    - Actively maintain and protect functioning wetlands
    - Expand or restore habitat where appropriate

    - Deepen wetlands to retain water later
    - Restore floodplain function
    - Increase beaver populations with translocation and trapping to create more wetland habitat in strategic and coordinated areas where they can be the most successful
    - Manage grazing, recreation, special uses, and other stressors in sensitive areas to maintain wildlife habitat
    - Maintain riparian vegetation to provide wildlife habitat and stream shading
- Increase resilience of wetland obligate species by preserving biodiversity
    - Identify important habitat manipulations based on monitoring
    - Protect critical areas
    - Control spread of nonnative species
- Monitor and prioritize areas that would benefit from wetlands management
    - Prioritize areas for active management and protection across jurisdictional boundaries
    - Focus monitoring on sensitive habitats and species in priority locations
    - Periodically review and revise priorities
- Increase population resilience by reducing non-climatic threats
    - Manage road, trail, and recreation impacts
    - Maintain functional hydrology in critical habitats
    - Increase habitat connectivity and heterogeneity
    - Control spread of nonnative species
- Increase resilience to changes in temperature and hydroperiod by enhancing breeding sites
    - Use vegetation to increase shading of wetlands and microhabitats
    - Retain water levels in wetlands when controlled by reservoir systems and special use permits
    - Increase microhabitat structures (e.g., woody debris) for microclimate refugia, nesting habitat, and egg deposition

Sensitivity: Higher wildfire frequency in sagebrush-grass ecosystems will cause increased mortality of shrub species and increase dominance of nonnative species.

Explanation: Increased fire frequency is expected to cause high mortality of large expanses of mature sagebrush (Creutzburg et al. 2015), thus quickly reducing habitat for greater sage-grouse, sage sparrow, and other species, requiring decades for recovery of high-quality sagebrush systems.

Practices:

- Increase resilience of native sagebrush-grass ecosystems
    - Promote the occurrence and growth of early-season native species
    - When reviewing and evaluating grazing management plans and policies, promote, monitor, and manage perennial growth and native species structure and diversity
    - Manage fire to maintain desired habitat
    - Apply prescribed burning during historic burning period; actively monitor to continually support local knowledge base
    - Prevent fragmentation of native habitat
- Determine most appropriate management strategies to reduce conifer encroachment in mid- and late-successional sagebrush
    - Use mechanical means and prescribed fire to reduce conifer encroachment
    - Reconsider active management to maintain sagebrush where it is unlikely to persist in the future
- Maintain growth of native shrub, grasses and forbs, while minimizing the spread of non-native species
    - Remove encroaching conifers
    - Plant seed of native species

    - Monitor successional patterns of vegetative communities
- Manage grazing by livestock and native ungulates to reduce negative and cumulative impacts to native grasses, forbs, and shrubs
- Manage for soil conditions to avoid increased runoff
    - Ensure that vegetative ground cover is as high as possible for local conditions
- Reduce disturbances that can result in a habitat type/species conversion
    - Reduce fuel continuity to decrease the likelihood of widespread fire
    - Use methods that reduce adverse impact of treatments (e.g., invasion by annual grasses following prescribed fire or wildfire)
    - Control invasive plants
    - Manage motorized and mechanical recreation, grazing, and other stressors
    - Maintain and restore a diversity of vegetation types and successional stages across the landscape

Sensitivity: Higher temperatures will alter wildlife phenology, or timing of life history events (e.g., breeding, dispersal, pelage change).

Explanation: Mismatches in phenological characteristics between animals and their environment (vegetation, snowpack, etc.) can result in lower fitness for some animal species through altered reproduction, predation, and vigor (Parmesan 2006).

Practices:
- Identify species where phenology mismatches are relevant, and prioritize those areas for protection; protect and restore large enough areas to be relevant to the population.
    - Maximize habitat quality and availability so populations are more resilient (potentially helping to minimize impacts of phenology mismatches)
    - In areas that remain phenologically matched, prioritize those areas for protection and manage for habitat resilience
    - Identify areas that will become matched in the future and maintain and promote connectivity so animals can migrate to new habitats
    - Consider assisted migration (managed relocation) where appropriate

Sensitivity: Increasing temperatures may exceed physiological thresholds of some animal species.

Explanation: A warmer climate will cause stress in animals with low or narrow ranges of thermal tolerance if adequate habitat to buffer this stress is unavailable, potentially lowering fitness through altered reproduction, predation, and vigor (Root and Hughes 2005).

Practices:
- Provide thermal refugia and opportunities for movement
    - Maintain sufficient habitat for thermal cover and security
    - Maintain landscape permeability for animal movement (e.g., provide passage structures across major highways, close roads, maintain elevational connectivity)

Sensitivity: Altered disturbance regimes, altered water availability and increasing temperatures will likely enhance the spread of nonnative invasive species.

Explanation: Establishment of nonnative invasive species will likely result in loss and/or alteration of native aquatic and terrestrial habitats (Hellmann et al. 2008).

Practices:

- Use an integrated approach to prevent the spread and establishment of nonnative invasive species
  - Use early detection/rapid response to treat and restore newly invaded areas to prevent establishment
  - Enhance the resistance and resilience of native plant communities by maintaining vigorous growth of native species
  - Use integrated pest management to control established infestations, including biological controls, herbicides, and ecological competition
  - Increase surveillance for nonnative invasive species (e.g., white nose syndrome, zebra and quagga mussels, avian diseases such as West Nile virus and endoparasites) to identify and control outbreaks
  - Conduct public education and outreach to reduce spread of nonnative invasive species

Sensitivity: Warming temperatures may alter human-use patterns in some habitats (especially low and high elevation), including longer periods of use, altered seasonal-use patterns, and increased concentrations of use in particular habitats, which can affect habitat resilience.

Explanation: In a warmer climate, recreation and visitor use is expected to increase in areas with cooler temperatures and water, including more and earlier recreation in high-elevation habitats as snow decreases, and more recreation in low-elevation lakes and rivers (Hand and Lawson 2017).

Practices:

- Improve habitat resilience from increased human pressure
  - Address high-elevation snow sports and recreation with travel management, seasonal restrictions, and area designations
  - Address increased recreation use within riparian areas, such as dispersed camping and concentrated day use, with strategic, long-term recreation planning
  - Address disturbance from extended human use in low- and mid-elevation habitats with travel management, strategic recreation planning, and improving effectiveness of physical barriers for road and trail closures

Climate Risk Management Practices for Recreation

Sensitivity: Higher winter streamflows will lead to increased damage of roads, trails, campgrounds, and other infrastructure.

Explanation: In a warmer climate, more precipitation will fall as rain rather than snow, and snowpack will be reduced, leading to higher winter streamflows (Hamlet et al. 2005, Hamlet and Lettenmaier 2007). This will lead to increased likelihood of damage to infrastructure, requiring more maintenance and replacement of infrastructure, and road and trail closures (Strauch et al. 2015). In particular, higher peak flows lead to increased road damage at stream crossings (because of insufficient culvert capacity, more culvert blockage, and low bridges). Access and safety will be compromised by more extreme flood events (Strauch et al. 2015).

Practices:

- Increase resilience and protect recreation facilities, historic and cultural sites, and points of diversion from flood damage
    - Restore watershed function by reconnecting stream channels to floodplains, dispersing flow and reducing the intensity of flood events in campgrounds and other facilities
    - Identify and relocate recreation facilities (e.g., campgrounds, picnic areas, specific campsites) to locations that are less likely to flood frequently
- Increase resilience of trail systems to higher peak flows
    - Identify high-priority trails and bridges to be repaired, replaced, rerouted, or decommissioned based on flood risk, amount of use, and other factors. Consider future peak flows in design of new trails and bridges. For existing trails, consider rerouting trails in locations that eliminate the need for trail bridges, increasing the height of bridges above waterways, or upgrading trail bridges with stronger parent material, if possible.
- Increase resilience of stream crossings, culverts, and bridges to higher peak flows
    - Replace culverts with higher-capacity culverts or other appropriate drainage (e.g., fords or dips) in high-risk locations
    - Complete geospatial database of culverts and bridges
- Facilitate response to higher peak flows by reducing the road system and thus flooding of roads and stream crossings; disconnect roads from streams
    - Continue to decommission roads with high risk and low access
    - Convert use to other transportation modes (e.g., from vehicle to bicycle or foot)
    - Use drains, gravel, and outsloping of roads to disperse surface water
- Minimize risks to public safety
    - Evaluate and monitor timing of visitor use relative to hydrologic dynamics.
    - Limit visitor access when safety is a concern
    - Post educational signs about potential danger of flood events due to changing weather conditions (e.g., rain-on-snow events, thunderstorms) and escape routes.
- Increase capacity of trained people to evaluate and respond to hazard-tree situations
    - Continue to provide staff training and raise awareness of hazard-tree policy and practices
    - Increase the number of qualified hazard tree inspectors, and provide contact information to efficiently dispatch qualified inspectors.
    - Increase the capacity to rapidly communicate and implement recommendations of inspectors in order to restore safe access and conditions

Sensitivity: Increased flooding will reduce the number of operational and functional campgrounds, possibly shifting visitor use to campgrounds that are less equipped to handle regular high volumes of visitations, as well as reduced services, and higher concentration of use to fewer facilities

Explanation: A warmer climate with lower snowpack and more rain on snow is expected to cause more frequent and higher magnitude floods (Hamlet et al. 2005, Hamlet and Lettenmaier 2007). Because many campgrounds are in and near floodplains of large streams, access may be limited, and safety risks for recreationists could increase (Strauch et al. 2015).

Practices:
- Analyze climate change effects to existing campgrounds will affect visitor-use patterns and identify locally appropriate sustainable recreation practices
- Identify campgrounds prone to flooding and prevent flood damage such as relocating recreation facilities (e.g., picnic areas, specific campsites) and structures (e.g., bathrooms, picnic tables) to locations with lower flood frequency; implement communication strategies to educate public on the importance of relocating sites out of potential flood areas
- Plan for higher maintenance costs associated with more flooding
- Identify campgrounds and other recreational facilities that will likely to be costly or unrealistic to be maintained based on future climate projections; accept the loss of those sites to optimize funding allocation and to mitigate risks to public safety

Sensitivity: Increases in flooding, wildfire, and other natural disturbances are expected to increase infrastructure damage.

Explanation: A warmer climate with lower snowpack and more rain on snow is expected to cause more frequent and higher magnitude floods (Hamlet et al. 2005, Hamlet and Lettenmaier 2007), and increasing drought is expected to cause more frequent and larger wildfires (Littell et al. 2016). Recreation facilities can be severely damaged or completely destroyed if the disturbance is severe.

Practices:
- Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities
    - Determine which recreation facilities, infrastructure, and campsites are at risk from increased flooding and other natural hazards
    - Increase capacity for rapid post-disturbance evaluations and planning
    - Prioritize post-disturbance treatments, such as relocation, arming, and other mitigation measures to mitigate risks to public safety and infrastructure
    - Invest strategically in developed recreation facilities, prioritizing those that will be viable in the future and accommodate changing use patterns

Sensitivity: Ice- and snow-based recreation is highly sensitive to increases in temperature and the amount and timing of precipitation.

Explanation: With warming temperatures, snowpack will decrease, particularly at low to mid elevations (Hamlet et al. 2005). Snow- based recreation will no longer be possible in these locations in some years. The length of the winter recreation season will also likely decrease (Hand et al. 2017).

Practices:
- Transition recreation management to address shorter average winter recreation seasons and changing use patterns
    - Invest strategically in infrastructure that supports winter recreation, prioritizing those that will be viable in the future and accommodate changing use patterns
    - Consider options for diversifying snow-based recreation (e.g., cat-skiing, helicopter skiing, additional ski lifts, higher-elevation runs, toboggan runs, snow making, and backcountry yurts)

    - Invest in temporary or mobile structures to adapt to higher variability in seasonal changes (e.g. adjustable snow park system based on snow levels, portable toilets in lieu of permanent toilets)
    - Invest strategically in infrastructure that supports winter recreation, prioritizing those that will be viable in the future and accommodate changing use patterns
    - Engineer road and trail systems for travel during wet weather
    - Increase capacity to conduct hazard-tree assessments and implement recommended actions

Sensitivity: Increasing length of snow-free season will increase demand for shoulder recreation access.

Explanation: A warmer climate with less snowpack will increase opportunities for warm-weather recreation, especially in the spring and autumn shoulder seasons (Hand and Lawson 2017). This will increase access at low to mid elevations, and earlier access to high elevations at times when facilities may not be open and seasonal employees are not on staff to assist with management of sites and trails (Hand and Lawson 2017).

Practices:
- Maintain safe access for recreation
    - Educate the public about risks associated with early- and late-season access
    - Consider opening recreation facilities and performing trail logout and maintenance earlier in the season when budgets allow
    - Limit access when public safety is a concern
    - Conduct risk management at developed sites prior to opening developed recreation facilities.
    - Plan for fire, flood, and geohazard evacuation and safety
    - Develop hazard tree management strategies in coordination with ecosystem restoration efforts
    - Educate the public about changing conditions (e.g., avalanche hazard, river flows)
- Increase flexibility and capacity for managing recreation resources, and provide sustainable recreation opportunities in response to changing demand
    - Assess changes in use patterns and identify demand shifts; consider the need to identify use thresholds and site capacity in relation to both visitor experience (e.g., potential for user conflicts) and the need to protect other resources
    - Identify where the timing of actions (e.g., opening and closing roads and recreation facilities, performing trail maintenance) should be adjusted to protect resources and provide sustainable recreation opportunities
    - Evaluate concessionaire contracts, special-use permits, personnel actions (e.g., timing of hiring seasonal workers), budget practices, fee programs, and grant opportunities to identify actions that could allow for more recreation opportunities during the shoulder season
    - Identify actions that would increase flexibility for year-round use of facilities (e.g., integrate summer uses into ski area operations)
    - Evaluate existing recreation sites and identify opportunities to accommodate longer use seasons; prioritize strategic investments in developed recreation sites that will be sustainable and accommodate changing use patterns
    - Where permits are required for boating, consult with stakeholders and the public about varying the permit season to adapt to changes in river peak flow and duration
    - Leverage partnerships to assist with management of recreation facilities (develop partnerships with local government, agencies, tribes, user groups, non-governmental organizations); identify recreation corridors where coordinating management across jurisdictions could result in more recreation opportunities

Sensitivity: Higher temperatures and lower summer streamflows will decrease suitable sites for water-based recreation, but demand will likely increase.

Explanation: In a warmer climate, demand for recreation in lakes and streams is expected to increase as recreationists seek relief from the heat. At the same time, some of those locations may have lower quality recreation opportunities if water levels are low, water is warm, and density of users is high (Hand et al. 2017).

Practices:

- Increase flexibility in water-based recreation site management and facility design
    - Increase length of boat ramps
    - Adjust management of shoreline areas as needed
    - Maintain flexibility in opening and closing facilities based on water conditions
    - Add language to concessionaire contracts to allow
    - efficient methods of communication to users about closures, conditions, hazards, and parking limitations well before arrival to recreation sites in order to facilitate trip planning and preparation (e.g., use a phone app)
    - Manage lake and river access capacity

Sensitivity: There will be uncertainty about the seasonality and availability of non-commercial forest products (e.g. berries, mushrooms, Christmas trees, boughs, firewood) with climate change.

Explanation: If climate is warmer or more variable, the “normal” time at which product gathering is conducted may be less consistent, disrupting schedules for users of public lands and creating less certainty about the availability of resources (Hand et al. 2017).

Practices:

- Adjust management of non-commercial forest products to changing conditions
    - Coordinate with other resource managers to look for non-commercial forest product habitat enhancement and restoration opportunities
    - Work with partners to collect information about status and trends of forest products

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Definitions

Adaptation is the adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects (Fourth National Climate Assessment [NCA4]).

Adaptive capacity is the potential of a system to adjust to climate change (including climatic variability and extremes) to moderate potential damage, take advantage of opportunities, and cope with the consequences (NCA4).

Adaptive management is the structured process of flexible decision making that incorporates learning from outcomes and new scientific information. The process facilitates decision making by resource managers to manage and respond to climate change effects (NCA4).

Climate change is altered average weather conditions that persist over multiple decades or longer. Climate change encompasses both increases and decreases in temperature, as well as shifts in precipitation, changing risk of certain types of severe weather events, and changes to other features of the climate system (NCA4).

Exposure is employed to refer to the presence (location) of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage (IPCC Ch. 1, p. 32).

Extreme events are weather events that are rare at a particular place and time of year, including heat waves, cold waves, heavy rains, periods of drought and flooding, and severe storms (NCA4). They comprise a facet of climatic variability under both stable and changing climate conditions.

Hazard refers to conditions that have the potential for a natural or human-caused event to cause damage. Natural hazard refers to the natural event causing the damage, such as extreme events originating from the atmosphere that pose a potential threat to humans and their welfare. For the purpose of managing forested lands, hazardous events of primary concern include wildfires, flooding, drought, extreme cold or heat leading to undue stress to vegetation and wildlife, insect or disease outbreak, or a combination of these events occurring sequentially. Many hazardous events may also be considered as disturbances, although the term disturbance generally refers to the ecological consequences of such an event.

Phenology is the pattern of seasonal life cycle events in plants and animals, such as timing of blooming, hibernation, and migration (NCA4).

Resilience is the capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.

Risk (insurance) is the probability of harmful consequences or expected losses resulting from the interaction between hazards and vulnerable conditions (Risk = Hazard x Vulnerability). The Fourth National Climate Assessment defines risk in terms of the threats to life, health and safety, the environment, economic well-being, and other things of value (Risk = Probability x Consequence). The IPCC defines **disaster risk** as the likelihood over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery (IPCC Ch. 1, p. 32).

Snow water equivalent (SWE) The amount of water held in a volume of snow, which depends on the density of the snow and other factors (NCA4).

Snowpack Snow that accumulates over the winter, and slowly melts to release water in spring and summer (NCA4).

Stressor Something that has a (typically negative) effect on people and on natural, managed, and socioeconomic systems. Multiple stressors can have compounded effects, such as when economic or market stress combines with drought to negatively impact farmers.

Value Belief or ideal held by individuals or society about what is important or desirable.

Value (economic) The benefit, usually expressed in monetary terms, gained from use or enjoyment from a good or service.

Vulnerability (**insurance**) The conditions determined by physical, economic, environmental factors or processes that increase the susceptibility of a landscape or community to the impact of realized hazards. The Fourth National Climate Assessment defines **vulnerability** as the degree to which physical, biological, and socio-economic systems are susceptible to and unable to cope with adverse impacts of climate change. The IPCC report defines **vulnerability** as the propensity or predisposition to be adversely affected. Such predisposition constitutes an internal characteristic of the affected element. In the field of disaster risk, this includes the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist, and recover from the adverse effects of physical events (Wisner et al. 2004).

Water stress Water stress occurs when demand for water by people and ecosystems exceeds available supply.

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