Climate Change Adaptation Library for the Western United States

Information in the Library is derived from climate change vulnerability assessments conducted by Adaptation Partners (http://adaptationpartners.org), which collaborates with a diversity of organizations and stakeholders to develop multi-resource assessments. A science-management partnership including research scientists and natural resource specialists provides a foundation for all projects. Adaptation options are intended to inform sustainable management of natural resources, reduce the negative effects of climate change, transition ecosystems to a warmer climate, and help integrate climate change in natural resource management, planning, and business operations of federal land management agencies.

Adaptation Partners has elicited expertise on management responses to climate change from land managers in the U.S. Forest Service, National Park Service, and other organizations throughout the western United States. Specifically, adaptation options in the Library were developed by resource specialists during workshops convened to examine climate change vulnerability assessments. During these workshops, land managers identified (1) the most important climate change sensitivities to natural resources, (2) general strategies for adapting to climate change, and (3) within each strategy, specific tactics that can be implemented in on-the-ground management.

Adaptation options in the Library have been documented (or are in press) in the following peer-reviewed publications:

Furniss, M.J., C.I. Millar, D.L. Peterson, L.A. Joyce, R.P. Neilson, J.E. Halofsky, and B.K. Kerns. 2009. Adapting to climate change: a short course for land managers. USDA Forest Service General Technical Report PNW-GTR-789. Pacific Northwest Research Station, Portland, OR. DVD, and online at http://www.fs.fed.us/ccrc/hjar.

Halofsky, J.E., D.L. Peterson, M.J. Furniss, L.A. Joyce, C.I. Millar, and R.P. Neilson. 2011. A workshop approach to the development of climate change adaptation strategies and actions for natural resource management agencies in the U.S. *Journal of Forestry* 109:219-225.

Halofsky, J.E., D.L. Peterson, and L. Hoang (eds.). 2016. Climate change vulnerability and adaptation in the Northern Rocky Mountains region. USDA Forest Service General Technical Report RMRS-GTR-xxx. Rocky Mountain Research Station, Fort Collins, CO. In press.

Halofsky, J.E., D.L. Peterson, L.A. Joyce, C.I. Millar, J.M. Rice, and C.W. Swanston. 2014. Implementing climate change adaptation in forested regions of the United States. Pages 229-243 in V.A. Sample and R.P. Bixler (eds.), Forest conservation and management in the Anthropocene: conference proceedings. USDA Forest Service Proceedings RMRS-P-71. Rocky Mountain Research Station, Fort Collins, CO.

Halofsky, J.E., D.L. Peterson, L.A. Joyce, C.I. Millar, J.M. Rice, and C.W. Swanston. 2015. Implementing climate change adaptation in forested regions of the western United States. In V.A. Sample and R.P. Bixler (eds.), Forest Conservation and Management in the Anthropocene. University Press of Colorado, Boulder. In press.

Halofsky, J.E., D.L. Peterson, K. O'Halloran, and C. Hawkins Hoffman. 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. USDA Forest Service General Technical Report PNW-GTR-844. Pacific Northwest Research Station, Portland, OR.

Littell, J.S., D.L. Peterson, C.I. Millar, and K. O'Halloran. 2012. U.S. national forests adapt to climate change through science-management partnerships. *Climatic Change* 110:269-296.

Peterson, D.L., C.I. Millar, L.A. Joyce, M.J. Furniss, J.E. Halofsky, R.P. Neilson, and T.L. Morelli. 2011. Responding to climate change in national forests: a guidebook for developing adaptation options. USDA Forest Service General Technical Report GTR-PNW-855.

Raymond, C.L., D.L. Peterson, and R.M. Rochefort. 2013. The North Cascadia Adaptation Partnership: a science-management collaboration for responding to climate change. *Sustainability* 5:136-159.

Raymond, C.L., D.L. Peterson, and R.M. Rochefort (eds.). 2014. Climate change vulnerability and adaptation in the North Cascades region. USDA Forest Service General Technical Report PNW-GTR-892. Pacific Northwest Research Station, Portland, OR.

ADAPTATION SYNTHESIS: FOREST VEGETATION

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
Increased opportunity for exotic species establishment with east-side habitats potentially more susceptible.	Increase exotic species control efforts	• Implement early detection/rapid response for exotic species treatment • Coordinate invasive species management, funding, and support between agencies
	Prevent invasive plants from establishing after disturbances	• Include invasive species prevention strategies in all projects • Inventory regularly to detect new populations and species • Coordinate invasive species management, funding, and support between agencies
	Prevent widespread outbreaks of invasive species or pathogens	• Plan for extreme events and events with low probability • Maintain permits for aggressive treatment of invasive species (e.g., burning and herbicide)
	Increase resilience by promoting native genotypes and adapted genotypes of native species	• Consider assisted migration • Emphasize use of plant species that will be robust to climate change in restoration projects • Plant genetically adapted species from appropriate seed zones
	Maintain integrity of native plant populations and prevent exotic species invasions	• Early detection, rapid response • Promote weed-free seed • Prevent nonnative plant introductions during projects • Ensure weed-free policies are included in planning documents • Coordinate with USDA FS and NPS weed-free seed standards and regulations • Expand weed-free feed list to include additional nonnative species

Potential for mortality events and regeneration failures, particularly after large disturbances	Mitigate consequences of large disturbances by planning ahead	• 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 range of species, particularly species that may do well in the future under hotter and drier conditions • Increase production of native plant materials for post-flooding plantings
	Increase regeneration in older trees to ensure adaptation of progeny to future conditions	• Thin older forests and support regeneration
	Use judicious managed relocation of genotypes where appropriate	• Relax seed zone guidelines to include genotypes from warmer locations; use a variety of genotypes rather than just one
	Protect genotypic and phenotypic diversity	• Protect trees that exhibit adaptation to water stress (e.g., trees with low leaf area:sapwood ratio); collect seed for future regeneration • Maintain variability in species and in tree architecture in some locations
	Use tree improvement programs to ensure availability of drought tolerant tree species and genotypes	• Develop seed orchards that contain a broader range of tree species and genotypes than in the past
Increased forest drought stress and decreased forest productivity at lower elevations	Increase resiliency in forests	• Increase the amount of thinning and possibly alter thinning prescriptions • Use girdling, falling and leaving trees, prescribed burns, and wildland fire to reduce stand densities and drought stress • Maximize early successional tree species diversity by retaining minor species

		during precommercial thinning activities to promote greater resilience to drier conditions • Consider including larger openings in thinning prescriptions and planting seedlings in the openings to create seed sources for native drought-tolerant species
	Protect genotypic and phenotypic diversity	• Protect trees that exhibit adaptation to water stress (e.g., trees with low leaf area:sapwood ratio); collect seed for future regeneration • Maintain variability in species and in tree architecture in some locations
	Maintain and enhance forest productivity regardless of tree species; focus on functional ecosystems and processes	• Manage species densities to maintain tree vigor and growth potential • Prepare for species migration by managing for multiple species across large landscapes • Maintain soil productivity through appropriate silvicultural practices
Increased warming, drought and wildfire will reduce tree vigor and increase susceptibility to insects and pathogens with increased potential for large and extensive insect and pathogen outbreaks, particularly of non-native insects and pathogens	Increase resilience of forest stands to disturbance by increasing tree vigor	• Thin to accelerate development of late-successional forest conditions • Harvest to variable densities • Thin to decrease stand density and increase tree vigor • Reduce density of post-disturbance artificial regeneration • Consider using genetically improved seedling stock • Plant resistant species or genotypes where species-specific insects or pathogens are a concern

		• Increase stand-scale biodiversity and minimize monocultures • Treat existing pathogen outbreaks with more aggressive management
	Increase forest landscape resilience to large and extensive insect or pathogen outbreaks	• Design forest gaps that create establishment opportunities • Increase diversity of patch sizes • Consider planting desired species (assisted migration) rather than relying on natural regeneration and migration
	Recognize natural role of insect disturbances, and identify areas at high risk	• Tolerate some natural mortality • Implement prescribed burning in areas affected by insect outbreaks • In dry forest, restore low-severity fire and early-successional species
	Promote diversity of forest age and size classes	• Diversify large contiguous areas of single age and size classes by “punching holes” in them
	Increase resistance to invasion by non-native insects	• Assertively apply early detection/rapid response to limit non-native insects
	Revegetate with native plant species	• Use seeding of native plant species in areas with non-native species • Plant seeds with biochar coating • Reduce grazing practices that encourage spread of non-native species • Apply herbicides and other direct eradication methods
More fire (larger aerial extent and more high-severity patches) and more area in recently burned or early-successional stages.	Plan and prepare for greater area burned	• Incorporate climate change into fire-management plans • Anticipate more opportunities to use wildfire for resource benefit • Plan postfire response for

		large fires • Consider using prescribed fire to facilitate transition to a new fire regime in drier forests • Consider planting fire-tolerant tree species post-fire in areas with increasing fire frequency • Manage forest restoration for future range of variability
	Increase resilience of existing vegetation by reducing hazardous fuels and forest density and maintain low densities	• Thin and prescribe burn to reduce hazardous fuels in the wildland-urban interface • Increase intentional use, management of reignition of lightning-ignited fires • Consider using more prescribed fire where scientific evidence supports change to more frequent fire regime • Use prescribed fire to maintain structure and promote fire-tolerant conifer species • Increase interagency coordination shared risk • Conduct thinning treatments (pre-commercial and commercial) • Use regeneration and planting to influence forest structure
	Increase resilience through postfire management	• Consider climate change in postfire rehabilitation • Determine where native seed may be needed for postfire planting • Anticipate greater need for seed sources and propagated plants • Experiment with planting native grass species to compete with cheatgrass postfire • Increase postfire monitoring

		in areas not currently monitored
	Manage forest vegetation to reduce severity and patch size; protect refugia (e.g., old trees)	• Map fire refugia • Use gaps in silvicultural prescriptions • Identify processes and conditions that create fire refugia
	Use high-severity wildfires as opportunities to "reset the clock"	• Use post-fire timber harvest to prevent uncharacteristic reburns • Allow some burned areas to regenerate naturally
	Manage forest landscapes to encourage fire to play a natural role	• Implement fuel breaks at strategic locations • Create incentives to encourage wildland fire use • Implement strategic density management through forest thinning • Incorporate climate change in Wildland Fire Decision Support System • Push boundaries of prescribed burning (e.g., burn earlier in spring, later in summer)
Higher temperatures may increase stress for some species in cold upland and subalpine forests	Protect rare and disjunct tree species	• Plant and encourage regeneration of rare and disjunct species in appropriate locations
	Protect cold upland and 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 and spread
	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
Higher temperatures may increase stress for some alpine plant communities including rare plants	Improve our understanding of the effects of climatic variability and change on alpine plant species	• Install GLORIA plots to monitor species distribution and abundance • Collaborate with other federal agencies to monitor

		alpine species
Higher temperatures and increasing drought will stress some species in moist mixed conifer forests, especially western larch	Maintain vigorous existing western larch and encourage its regeneration	• Create gaps in forests to reduce competition and increase larch vigor • Regenerate larch with appropriate site preparation (e.g., prescribed burning, followed by planting)
Increased hazard trees that threaten people and infrastructure	Prevent the development of and reduce risks associated with hazard trees	• Consider increasing use of pheromone treatments to protect trees in campgrounds, high-value habitats, and after floods • Coordinate with entomologists • Increase internal education about increasing hazard tree risk • Develop options, triggers, and methods for more aggressive management of hazard trees
Increased tree establishment at the treeline	Increase knowledge of rates and patterns of tree establishment and regeneration failures	• Detect and attribute historical changes in tree distribution at the tree line • Monitor tree establishment patterns • Use climate change information to project changes in recreation use patterns in the alpine environment • Expand geographic scope or enhanced site monitoring
Change in species composition, relative abundance, and species distribution patterns	Increase knowledge of patterns, characteristics, and rates of change in species distributions	• Expand long-term monitoring programs
The distribution of subalpine forests is likely to shift as a result of increasing temperatures with climate change	Monitor and detect change in seedling survival, species composition, and mortality of mature trees in subalpine forests	• Install and analyze additional plots to gather trend information over time, targeting areas where changes are expected • Use Forest Inventory and Analysis plot information to determine trends in subalpine forests

		• Expand reforestation monitoring and post-treatment monitoring
Loss of subalpine areas for traditional uses of plant species	Maintain or increase the extent of subalpine areas	• Maintain huckleberry production through tree removal and prescribed fire • Consult with tribes to understand historical patterns and current locations of huckleberry habitat
Increased tree mortality and loss of site conditions that support vulnerable species	Promote resiliency in communities with vulnerable species and increase resistance to mountain pine beetle	• Strategically use anti-aggregation pheromones • Continue to establish permanent monitoring plots and share data • Coordinate U.S. Department of Agriculture, forest Service and National Park Service efforts to collect cones and produce seedlings • Identify sites that are less likely to be affected by climate change (refugia), and focus on those sites for restoration • Implement fire management, planting at lower elevations, and removing other dominant species
Possible loss of relict or disjunct populations and rare species	Prevent loss of relict populations of vascular and nonvascular species	• Increase seed collection and seed banks (ex situ) • Identify areas where relict plants could be established

The frequency and scale of disturbance will likely increase with climate change	Promote disturbance-resilient species	• Thin to favor disturbance-resilient species • Plant disturbance resilient species • Promote disturbance-resilient species with prescribed fire and/or natural fire use
Areas with limited species and genetic diversity will likely be more susceptible to climate change stressors	Promote species and genetic diversity	• Plant potential microsites with a mix of species • Maintain species diversity during thinning • Interplant to supplement natural regeneration and genetic diversity
Climate change will lead to loss of large ponderosa pine individuals in ponderosa pine forests through increased risk of stand-replacing wildfire and mortality from drought	Decrease density within stands, and increase structural diversity across the landscape	• Reduce density by thinning, prescribed fire, and wildfire use, with density and structural goals based on past and predicted future conditions • Promote age class and structural diversity across the landscape, through regeneration harvest, thinning, prescribed fire and wildfire use • Monitor establishment, survival and development of ponderosa pine by age class and in different topoedaphic conditions using Forest Inventory and Analysis data and project-level stocking exams
Climate change stressors cross boundaries, forcing agencies to coordinate and work across boundaries	Work across jurisdictions at larger scales	• Align budgets and priorities for program of work with neighboring lands • Communicate about projects adjacent to other lands, and coordinate on the ground • Work across boundaries to preserve roads, trails, and access with increasing fire and flood events

ADAPTATION SYNTHESIS: NON-FOREST VEGETATION

Sensitivity to Climate Change	Adaptation Strategy	Adaptation Tactic
Increased opportunities for non-native species establishment	Increase non-native species control efforts	• Implement early detection/rapid response for non-native species treatment • Coordinate invasive species management, funding, and support between agencies
	Prevent invasive plants from establishing after disturbances	• Include invasive species prevention strategies in all projects • Inventory regularly to detect new populations and species • Coordinate invasive species management, funding, and support between agencies • Use seeding of native plant species in areas with non-native species • Plant seeds with biochar coating • Reduce grazing practices that encourage spread of non-native species
	Prevent widespread outbreaks of invasive species or pathogens	• Plan for extreme events and events with low probability • Maintain permits for aggressive treatment of invasive species (e.g., burning and herbicide)
	Maintain integrity of native plant populations	• Implement early detection/ rapid response • Promote weed-free seed • Prevent non-native plant introductions during projects • Ensure weed-free policies are included in planning documents • Coordinate with USFS and NPS weed-free seed standards and regulations • Expand weed-free feed list to include additional non-native species

	Mitigate consequences of large disturbances by planning ahead	• Develop a gene conservation plan for ex situ collections for long-term storage • Identify areas important for in situ gene conservation • Maintain a seed inventory with high-quality seed for a range of species, particularly species that may do well in the future under hotter and drier conditions • Increase production of native plant materials for post-flooding plantings
	Determine potential resilience of different locations, and actively restore less resilient sites	• Increase resilience of native species where intact or productive communities exist • Decrease resilience of existing non-native species with appropriate management practices or biotic path herbicides • Monitor soil stability and productivity to reduce low-fertility soils that promote non-natives • Identify and promote early-successional natives that may be able to compete with non-natives
Higher temperatures and increased fire frequency	Increase resilience of native sagebrush-grass ecosystems	• Promote the occurrence and growth of early-season native species • Reduce grazing in July and August to encourage perennial growth • Revise grazing policies, and review and evaluate grazing allotment plans
	Maintain vigorous growth of native shrub, perennial grass, and other perennial species	• Remove encroaching conifers • Plant seed of native species • Monitor successional patterns of vegetative communities • Apply prescribed burning in the spring

		• Focus grazing on non-native species in spring; do not graze natives in summer • Find locations where late-season grazing has minimal impacts
	Maintain reproducing populations of curl-leaf mountain-mahogany, so it can expand as needed	• Use fencing to protect shrubs from grazing by livestock and ungulates • Manage hunting seasons to reduce impacts of grazing by ungulates
	Manage for soil conditions to avoid increased runoff	• Ensure that vegetative ground cover is as high as possible for local conditions
Higher temperatures may increase stress for some alpine plant communities, including rare plants	Improve our understanding of the effects of climatic variability and change on alpine plant species	• Install plots to monitor species distribution and abundance • Collaborate with other federal agencies to monitor alpine species
Change in species composition, relative abundance, and species distribution patterns	Increase knowledge of patterns, characteristics, and rates of change in species distributions	• Expand long-term monitoring programs
Possible loss of relict or disjunct populations and rare species	Prevent loss of relict populations of vascular and nonvascular species	• Increase seed collection and seed banks (ex situ) • Identify areas where relict plants could be established
Loss of subalpine areas for traditional uses of plant species	Maintain or increase the extent of subalpine areas	• Maintain huckleberry production through tree removal and prescribed fire • Determine historical patterns and current locations of huckleberry habitat
Areas with limited species and genetic diversity will likely be more susceptible to climate change stressors	Promote species and genetic diversity	• Plant potential microsites with mix of species • Maintain species diversity during thinning • Interplant to supplement natural regeneration and genetic diversity
Climate change stressors cross boundaries, forcing agencies to coordinate and work across boundaries	Work across jurisdictions at larger scales	• Align budgets and priorities for program of work with neighboring lands • Communicate about projects

		adjacent to other lands, and coordinate on the ground • Work across boundaries to preserve roads, trails, and access with increasing fire and flood events
All of the above	• Conduct integrated and consistent inventory and monitoring of vegetation • Focus monitoring on sensitive locations such as wetlands and high elevations, on endemic or at-risk species, and on plant phenology • Use feedback from monitoring in implementation of adaptive management	

ADAPTATION SYNTHESIS: RIPARIAN/WETLAND

Sensitivity to Climate Change	Adaptation Strategy	Adaptation Tactic
Shift in hydrologic regime involving changes in timing and magnitude of flows. Anticipated changes include lower summer flows and higher, more frequent winter flows	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)
	Increase upland water storage by managing for greater beaver populations	• Accommodate and maintain higher beaver populations • Trap and relocate beavers that create dams that flood trails • Use riparian shrub planting and protection and riparian aspen restoration and management • Use valley form analysis to assess potential sites for beaver colonies and channel migrations

	Maintain or restore natural flow regime to buffer against future changes	• Use watershed analysis, watershed condition framework, etc. to develop integrated, interdisciplinary tactics associated with vegetation and hydrology • Protect groundwater and springs • Restore riparian areas and beaver populations to maintain summer base flows and raise water table • Address water loss at water diversions and ditches • Reconnect and increase off-channel habitat and refugia in side channels and channels fed by wetlands • Revegetate, use fencing to exclude livestock • Acquire water rights, use low-flow channel design • Disconnect roads from streams to reduce drainage efficiency
Reduction in size and hydroperiod of wetlands and changes in nutrient availability, productivity, and species compostion, including riparian obligates	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 regarding invasive species • Address water loss at water diversions and ditches
Increased prevalence of disease and fungal and bacterial infections with	Reduce riparian impacts by storing more water on the landscape	• Increase beaver populations to create more wetland habitat

associated mortality		• Use snow fences and reflective tarps to retain snow in critical areas
	Increase resilience to disease and pathogens	• Use devices to retain snowpack near sensitive areas • Educate the public about disease sensitivities • Manage or limit recreation and other use through closure or other means
Changes in phenology and species interactions (e.g., predation, competition) of wetland obligate species	Increase resilience by preserving biodiversity	• Identify important habitat manipulations based on monitoring • Protect critical areas
	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 priorities
	Increase population resilience by reducing non-climatic threats	• Manage road, trail, and recreation impacts • Maintain hydrology of critical habitats • Increase habitat connectivity and heterogeneity
Climate change stressors cross boundaries, forcing agencies to coordinate and work across boundaries	Work across jurisdictions at larger scales	• Align budgets and priorities for program of work with neighboring lands • Communicate about projects adjacent to other lands, and coordinate on the ground • Work across boundaries to preserve roads, trails, and access with increasing fire and flood events

All of the above	• Conduct integrated and consistent inventory and monitoring of vegetation • Focus monitoring on sensitive locations such as wetlands and high elevations, on endemic or at-risk species, and on plant phenology • Use feedback from monitoring in implementation of adaptive management

ADAPTATION SYNTHESIS: WATER RESOURCES

Sensitivity to Climate Change	Adaptation Strategy	Adaptation Tactic
Higher peak flows will lead to increased road damage at stream crossings	Increase resilience of stream crossings, culverts, and bridges to higher peak flows	• Continue to replace culverts with higher capacity culverts • Complete unit-wide inventory of culverts and bridges, including GPS locations of structures and accurate culvert data • Consider a process for replacing culverts based on projected future, rather than historical, peak flows • Consider prioritizing structure replacement in high-risk (mixed-rain-and-snow) watersheds • Reroute roads out of flood plains
	Increase resistance of road surfaces to higher peak flows at stream crossings	• Install hardened stream crossings • Perform a basin-wide assessment of current hydrological interactions with roads • Continue to use grade control structures, humps, and water bars to reduce velocity and redirect flow
	Facilitate the response to higher peak flows by reducing the road system and thus flooding of roads and stream crossings	• Continue to decommission roads with high risk and low access • Convert use to other modes of transportation (e.g., from vehicle to bicycle or foot) • Change user expectations with public education
Higher peak flows will lead to increased damage and disrupted access to facilities and cultural and historical resources	Increase resistance of infrastructure and cultural and historical resources	• Stabilize banks near resources with rip-rap or vegetation • Consider increased use of engineered logjams to redirect flows
	Increase resiliency of the floodplain	• Restore natural function of the floodplain allowing waterways to migrate • Remove or modify infrastructure allowing channels to migrate within the floodplain

Higher peak flows and flood frequency may increase damage to trails and bridges, requiring more maintenance, replacement or closures	Increase resilience of trail system to higher peak flows by repairing, replacing, and rerouting trails and trail bridges with high demand for access	• Continue to 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 reroute • Request additional funding to prepare fore more trail and bridge failures • Focus on acquiring funding for high-profile projects (based on co-benefits of public demand and safety) • Consider increasing the height of bridges above waterways • Collaborate with hydrologists to consider future peak flows in design of new trails and bridges
	Leverage partnerships with recreational user groups to increase awareness of threats to access, and adjust user expectations	• Improve outreach publically and internally • Increase efforts to collaborate with volunteers and build capacity for trail maintenance • Collaborate with user groups educate the public and increase political support and funding to maintain access • Coordinate between agencies for a consistent message on access and climate change
	Reduce the system of trails and trail bridges	• Abandon damaged trails with los use and high flood risk • Continue to reroute trails in locations that eliminate the need for trail bridges
Increased landslides will lead to more road closures, higher maintenance costs, and disrupted access	Increase resilience to landslides by protecting 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 • Compensate for landslides by

		reducing weight
	Allow for increased landslide frequency by relocating roads and structures	• Close and decommission roads in areas of high landslide risk • Locate new construction or reroute roads away from areas of high landslide risk • Collaborate with partners to compare data of current damage with data on soil moisture and landforms to identify sensitive areas
Increased trail failures will be associated with erosion and landslides	Increase resilience of trail system to erosion	• Increase restoration and erosion control with revegetation projects • Reduce erosion by building protection into trail design • Increase onitoring of ground water to assess risk of landslides and slope failures
Soil saturation will increase, which will increase the need for trail maintenance	Increase resilience of trail systems to saturated soils	• Inventory frequently saturated areas and prioritize changes in trail locations • Locate piezometer where the greatest impacts are expected (e.g., mixed rain and snow basins) • Reroute high-risk trails that experienced past problems with saturated soils
Trail and bridge failures will increase risk to public safety	Minimize risks to public safety	• Evaluate and monitor timing of visitor use relative to hydrologic dynamics • Limit visitor access when safety is a concern • Coordinate with recreational user groups to educate the public about safety concerns associated with increased bridge and trail damage
Increased flooding will lead to fewer campgrounds, greater use of alternative campgrounds, greater use of	Prevent flood damage to high-use campgrounds	• Protect campgrounds from initial increase in flood risk • Accept higher maintenance costs associated with more floods

fewer facilities, and reduced services	Increase resilience of facility and campground system to maintain access	• Abandon campsites in higher risk locations but add sites in other locations, conserving the total number of sites • Educate the public about how funds are allocated to relocate sites but the total number of sites is conserved • Redirect, but not require, changes in visitor use of facilities
	Accept loss of campgrounds and other recreational facilities	• Close and abandon sites • Change timing or route of access • Change the nature of the access mechanism
Increasing length of the snow-free season will cause increased demand for access	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 • Open trail, campgrounds, and facilities earlier in the season • Limit access when public safety is a concern • Implement adaptive management—alter management as the length of the recreation season changes
Increased flooding of roads and culverts will cause increased sedimentation in streams	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

Lower summer flows, higher winter peak flows, earlier peak flows, and lower groundwater recharge will cause higher demand and competition for water by municipalities and agriculture	Restore function of watersheds; connect floodplains; support groundwater dependent ecosystems; reduce drainage efficiency; maximize valley storage; reduce fire hazard	• Add wood to streams and increase beaver populations • Use a "climate change lens" during project analysis • Improve livestock management to reduce water use (e.g., shut-off valve on stock ponds) • Reduce surface fuels and stand densities in low-elevations forest • Restore meadows
	Address demands for water (including water rights); improve water conservation.	• Conduct integrated assessment of water and local effects of climate change • Implement vegetation treatments in high water retention areas (e.g., snow retention) • Improve efficiency of drainage and ditches • Encourage communication and full disclosure information • Conduct vulnerability assessments by community • Treat roads where needed to retain water and maintain high water quality
	Maintain sufficient water supply to meet demand	• Attribute causes of potable water loss to determine appropriate response • Investigate alternative water sources (e.g., ground water) • Consider constructing new wells, cisterns, and reservoirs • Increase water storage with artificial storage infrastructure (e.g., water towers) • Import water from other regions
	Increase resilience through water conservation	• Install waterless urinals and low-flow, solar, and composting toilets • Institute gray water recycling • Educate the public about water shortage and conservation • Reduce water provided in campgrounds and other facilities • Change user expectations of water availability • Reduce campground capacity to decrease water demand

		• Close facilities when water is not available

ADAPTATION SYNTHESIS: FISHERIES

Sensitivity to Climate Change	Adaptation Strategy	Adaptation Tactic
Increased flood frequency and higher peak flows may reduce egg-fry survival for fall spawners and yearling parr winter survival.	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 habitat resilience by reducing threats from roads and infrastructure in the floodplain	• Designate and restore natural flood plain boundaries • Increase floodplain habitat • Remove infrastructure from flood plains • Disconnect roads from streams • Reduce road density near streams • Increase culvert capacity • Reduce flashiness of peak flows
Lower low flows will reduce fish habitat quality	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
	Manage upland vegetation to retain water and snow in order to slow spring snowmelt and runoff	• Increase forest cover to retain snow and decrease snow melt • 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)
Lower low flows will increase pre-spawn mortality for summer run and stream-type salmon and steelhead	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
Warmer stream temperatures will reduce thermal heterogeneity in streams and increase thermal stress on many life stages of fish	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
	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 fish distributions • Re-evaluate and update water temperature standards (both values and indices)
	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

Warmer stream temperatures may favor non-native fish species	Increase resilience of native fish species by reducing barriers to native species and removing non-native species	• Survey and map non-native species • Combine non-native mapping with information on migration barriers • Consider information from surveys of warmer basins farther south as indicators of vulnerability • Remove or control non-native fish species • Assess migration barriers and potential habitat for native species • Remove barriers to fish passage where this will not increase threats from non-native species • Maintain or construct barriers to prevent spread of non-native species
Warmer stream temperatures may create more favorable conditions for diseases and parasites	Increase population resilience by increasing fish health	• Increase public education to eliminate disease vectors • Direct treatment or removal of infected fish • Survey fish health conditions • Collaborate and standardize health survey methods among agencies • Consider changes in hatchery practices
Warmer summer stream temperatures may alter aquatic food web dynamics	Monitor changes in aquatic food web dynamics	• Assess food webs for baseline data • Monitor food web dynamics for changes with warming
Increased sedimentation in streams will accompany increased flooding of roads and culverts	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

Sedimentation in streams will increase as fire area and fire severity increase	Reduce sedimentation associated with erosion and fire	• Include climate change projections in identification of potential areas for stream bank and upland erosion • Inventory disturbed areas for riparian and upland vegetation restoration • Manage fire and fuels 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
	Identify hillslope landslide hazard areas and at-risk roads prior to wildfires and as part of fire planning	• Link stream inventory with topographic, geomorphic, and vegetation layers to assess existing hazard and risk

ADAPTATION SYNTHESIS: WILDLIFE

Sensitivity to Climate Change	Adaptation Strategy	Adaptation Tactic	Potentially Sensitive Species
More insect outbreaks and fire will Increase loss of late-successional forest habitat and connectivity	Maintain current habitat, restore historical habitat, and promote potential future habitat	• Conserve current old-growth western redcedar and western larch, but reduce density to increase resilience to drought • Restore western white pine with a western redcedar understory to create future habitat • Maintain or create necessary structure in a modeled future fisher habitat	• American marten • Barred owl • Black bear • Bushy-tailed woodrat • Canada lynx • Coyote • Ensatina • Marbled murrelet • Mountain beaver • Northern alligator lizard • Northern flying squirrel • Northern spotted owl • Opossum • Pacific fisher • Porcupine • Roosevelt elk • Snowshoe hare • Van Dyke's salamander • Warty jumping slug
	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 patch mosaic • Accelerate development of additional late-successional habitat in matrix • Increase protection of critical habitat structure (e.g., snags and nest trees) • Consider policy changes to allow more management and adaptive management in late-successional reserves • Consider more use of prescribed fire • Increase monitoring of insects to anticipate and prevent outbreaks • Allow shifts in native	

		species ranges • Collaborate with neighbors about priority areas for treatments, and increase extent of protected areas	
	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 attribute population changes to climate change vs. other threats	
Higher temperture and increased disturbance will cause shifts in species ranges and loss of species functional types	Increase habitat connectivity and permeability	• Increase use of conservation easements • Increase road closures and restrictions on access in critical habitats • Accept loss of some facets of ecosystem to protect others	• American beaver • Birds • Carnivorous mammals and their prey • Insect pollinators
Higher temperature and increasing drought will stress some species in moist mixed conifer forests, especially western larch	Maintain vigorous existing western larch and encourage its regeneration	• Create gaps in forest to reduce competition and increase larch vigor • Regenerate larch with appropriate site preparation (e.g., prescribed burning, followed by planting	• American marten • Black bear • Bushy-tailed woodrat • Coyote • Roosevelt elk

A warmer climate will potentially convert drier ponderosa pine stands to grassland or Douglas-fir stands	Promote ponderosa pine resilience	• Reduce competition from Douglas-fir and grand fir (thin, burn) in current mature ponderosa pine stands • Increase understory burning • Retain current mature and older ponderosa pine stands • Plant ponderosa pine where it has been lost	• Black bear • Bobcat • Mountain goat • Yellow-pine chipmunk
Higher temperature may increase stress for some species in cold upland and subalpine forests	Protect rare and disjunct tree species (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	• American Pika • Cascade red fox • Clark's nutcracker • Coyote • Hoary marmot • Mountain goat • Roosevelt elk • White-tailed ptarmigan • Wolverine
	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 and spread	
	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 where appropriate	
	Increase population resilience of subalpine-dependent species	• Increase education and regulatory enforcement to prevent adverse human-wildlife interactions • Augment currently stressed populations of mountain goats from populations that are large and more robust	

Tree establishment in subalpine meadows decreases forage for American pika and marmot species	Maintain and protect summer alpine habitat for pika and marmot	• Monitor tree establishment in meadows • Remove trees from meadows using fire and mechanical treatments • Monitor soil development, cryptobiotic crust, and herbaceous plant establishment in previously snow-covered and glaciated areas • Decrease visitor use in alpine and subalpine habitats	
Area of summer range for ungulate species will decrease	Conserve winter range for ungulate species	• Identify critical winter habitat for ungulate species • Increase collaboration with partners to conserve critical winter habitat	• Bighorn sheep • Deer (multiple species) • Moose • Mountain goat • Rocky mountain elk • Roosevelt elk
Increased flooding will alter riparian habitats	Increase upland water storage by managing for larger beaver populations	• Accommodate and maintain higher beaver populations • Trap and relocate beavers that create dams that flood trails	• American dipper • Cascades frog • Chorus frog • Garter snake • Hairy woodpecker • Harlequin duck • Hooded merganser • Long-toed salamander • Makah copper butterfly • Northwestern salamander • Pacific fisher • Red-breasted sapsucker • Red-legged frog • Van Dyke's salamander • Warty jumping slug • Western toad • Wood duck
Decreased stream flow reduces riparian vegetation, affects food supply and habitat structure for riparian obligate species	Reduce riparian impacts by storing more water on the landscape	• Inventory current and potential habitat • Increase beaver populations with translocation and trapping to create more wetland habitat • Restore riparian habitat by planting willows, managing grazing, and raising water level • Use snow fences and reflective tarps to retain snow in critical areas	

Higher temperature will Increase prevalence of disease and fungal and bacterial infections, causing increased animal mortality	Increase resilience to disease and pathogens	• Use devices to retain snowpack near sensitive habitat • Educate the public about disease sensitivities • Manage or limit recreation and other uses through closures or other means	
Higher temperature will alter phenology and species interactions (e.g., predation, competition) of wetland obligate species	Increase resilience by preserving biodiversity	• Identify important habitat manipulations based on monitoring • Protect critical areas • Control spread of non-native 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 non-native 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 • Increase microhabitat structures (e.g., woody	

		debris) for microclimate refugia, nesting habitat, and egg deposition	
Increased temperature will cause fluctuating nutrient levels, episodic acidification, more disease, and decreased prey for the western toad	Maintain and enhance habitat quality to boost survival of all life stages	• Use decontamination procedures and consider microbial treatments • Provide dispersal cover between aquatic and upland habitats • Maintain burrowing mammal habitats • Manage for toadlet migration • Increase vertebrate prey resources	
Higher wildfire frequency will cause increased mortality of shrub species and native grasses and increase dominance of non-native species	Increase resilience of native sagebrush-grass ecosystems	• Promote the occurrence and growth of early-season native species • Reduce grazing in July and August to encourage perennial growth • Revise grazing policies, and review and evaluate grazing allotment plans • Manage fire to maintain desired habitat • Apply prescribed burning in the spring • Prevent fragmentation of native habitat	• Greater sage grouse • Pygmy rabbit • Sage thrasher • Other sagebrush obligates
	Maintain vigorous growth of native shrub, perennial grass, and other perennial species, 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 ungulates to reduce impacts on perennial	• Focus grazing on non-native species in spring; do not graze natives in summer	

	grasses	• Find locations where late-season grazing has minimal impacts	
	Manage for soil conditions to avoid increased runoff	• Ensure that vegetative ground cover is as high as possible for local conditions	

ADAPTATION SYNTHESIS: RECREATION

Sensitivity to Climate Change	Adaptation Strategy	Adaptation Tactic
Increased trail failures will be associated with erosion and landslides	Increase resilience of trail system to erosion	• Increase restoration and erosion control with revegetation projects • Reduce erosion by building protection into trail design • Increase monitoring of ground water to assess risk of landslides and slope failures
Increased soil saturation will increase the need for trail maintenance	Increase resilience of trail systems to saturated soils	• Inventory frequently saturated areas and prioritize changes in trail locations • Locate piezometers where the greatest impacts are expected (e.g., mixed rain and snow basins) • Reroute high-risk trails that experienced past problems with saturated soils
Increased risk to public safety will be associated with trail and bridge failures	Minimize risks to public safety	• Evaluate and monitor timing of visitor use relative to hydrologic dynamics • Limit visitor access when safety is a concern • Coordinate with recreational user groups to educate the public about safety concerns associated with increased bridge and trail damage
Increased flooding will result in fewer campgrounds, more use of alternative campgrounds, reduced services, and increased use of fewer facilities	Prevent flood damage in high-use campgrounds	• Protect campgrounds from initial increase in flood risk • Accept higher maintenance costs associated with more floods
	Increase resiliency of facility and campground system to maintain access	• Abandon campsites in high-risk locations, but add sites in other locations, conserving the

		total number of sites • Educate the public about how funds are allocated to relocate sites but the total number of sites is conserved • Redirect, but do not require, changes in visitor use of facilities
	Accept loss of campgrounds and other recreational facilities	• Close and abandon sites • Change timing or route of access • Change the nature of the access mechanism
Road design and maintenance are sensitive to increasing flood risk; 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 are compromised by more extreme events (e.g., landslides and debris flows)	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
Increases in flooding, fire, and other natural disturbances damage infrastructure	Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities	• Determine which recreation sites and infrastructure are at risk from increased flooding and other natural hazards • Prioritize post-disturbance treatments, including relocation, arming, and other mitigation measures • Invest strategically in developed recreation facilities, prioritizing those that will be viable in the future and accommodate changing use patterns

Ice- and snow-based recreation is highly sensitive to variations in temperature and the amount and timing of precipitation	Transition recreation management to address shorter average winter recreation seasons and changing use patterns	• Maintain current infrastructure and expand facilities in areas where concentrated use increases • Develop options for diversifying snow-based recreation, including cat-skiing, helicopter skiing, additional ski lifts, higher elevation runs, toboggan runs, snow making, and backcountry yurts • Conduct safety education to make the public aware of increased risk of avalanche and thin ice
Increasing length of snow-free season will increase demand for summer recreation access	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 • Open trails, campgrounds, and facilities earlier in the season • Limit access when public safety is a concern • Implement adaptive management—alter management as the length of the recreation season changes
	Provide sustainable recreation opportunities in response to changing demand	• Assess changes in use patterns and identify demand shifts • Adjust capacity of recreation sites (e.g., enlarge campgrounds, collect additional fees, and install infrastructure such as fences, signs, and gates) • Adjust timing of actions such as road and trail closures, food storage orders, and special use permits

The seasonality of whitewater rafting will shift with increasing temperatures and shifts in the timing of peak streamflows	Increase management flexibility and facilitate transitions to meet user demand and expectation	• Vary permit season to adapt to changes in peak flow and duration • Educate the public about changing river conditions