Sierra Nevada Individual Species Vulnerability Assessment Briefing: Aspen

Populus tremuloides

Background and Key Terminology

This document summarizes the primary factors that influence the vulnerability of a focal resource to climate change over the next century. In this context, vulnerability is a function of the sensitivity of the resource to climate change, its anticipated exposure to those changes, and its capacity to adapt to changes. Specifically, sensitivity is defined as a measure of whether and how a resource is likely to be affected by a given change in climate, or factors driven by climate; exposure is defined as the degree of change in climate or climate-driven factors a resource is likely to experience; and adaptive capacity is defined as the ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011). The purpose of this assessment is to inform forest planning by government, non-profit, and private sector partners in the Sierra Nevada region as they work to integrate climate change into their planning documents.

Executive Summary

The overall vulnerability of aspen is influenced by their sensitivity and future exposure to increased temperature, decreased soil moisture, and predation pressure, but may be tempered by their capacity to cope with fire and other disturbances.

Aspen is sensitive to climate-driven changes such as:
- temperature,
- decreased soil moisture, and
- fire.

Increased temperatures and increased moisture stress can be detrimental to aspen growth, regeneration, and persistence, and could contribute to habitat conversion to more drought-tolerant vegetation types, while fire may help maintain aspen stands by limiting conifer regeneration and succession.

Aspen are also sensitive to several non-climate stressors including:
- herbivory, and
- fire suppression practices.

These non-climate stressors can amplify the effects of climate-driven changes. For example, herbivory can exacerbate drought effects leading to further regeneration losses and limited distribution. The capacity of aspen to adapt to changes in climate, however, will likely be facilitated by their wide distribution and ability to tolerate fire and other disturbances.

Recommended Citation

Hauptfeld, R.S. and J.M. Kershner. 2014. Sierra Nevada Individual Species Vulnerability Assessment Briefing: Aspen. Version 1.0. EcoAdapt, Bainbridge Island, WA.

This document is available online at EcoAdapt (http://ecoadapt.org/programs/adaptation-consultations/calcc).

Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

Climate and climate-driven changes that influence aspen sensitivity include increases in temperature, decreased moisture availability, and altered fire regimes. Aspen communities display vital differences in physical and biological processes and interactions that influence the responses of 'seral' and 'stable' stand types to climate changes (Rogers et al. 2014). In general, aspen is a water-limited, drought-intolerant species (Niinemets and Valladares 2006 cited in Morelli and Carr 2011) and functions poorly in hot, dry conditions (Jones et al. 1985b cited in Morelli and Carr 2011). Higher temperatures and available moisture can affect aspen mortality, growth, regeneration (Worrall et al. 2008), and potentially stand type (Rogers et al. 2014). 'Stable' aspen stands are often found on drier sites (Rogers et al. 2014), and aspen distribution is limited by the interaction of moisture and temperature (Worrall et al. 2013), with distribution limits dictated mostly by moisture stress (Rehfeldt et al. 2009). Extreme moisture stress conditions may result in shortened lifespan, and/or deterioration of aspen clones (Worrall et al. 2013), decline or death of aspen (Morelli and Carr 2011), and conversion to grasslands (Zoltai et al. 1991, Hogg et al. 2008 cited in Morelli and Carr 2011). Drought stress resulting in mortality has been linked to hydraulic failure of roots and branches in aspen (Anderegg et al. 2012). Recent declines in aspen extent may be partially explained by the trend of increased temperature and reduced moisture over the last several decades in North America (Hogg et al. 2008; Worrall et al. 2008; Morelli and Carr 2011).

Variations in temperature and precipitation can also affect aspen reproduction. For example, seedling (sexual) establishment was positively correlated with summers with cooler average maximum temperatures (21 - 22˚C) and wetter springs (5 to 6 cm) (2 to 2.4 in), while asexual reproduction was positively correlated with drier springs (3 to 4 cm) (1.2 to 1.6 in) and summers with warmer average maximum temperatures (23 - 24˚C) (Morelli and Carr 2011).

Alternately, aspen sensitivity to climate change may be moderated by its tolerance of fire and other disturbances such as high wind and floods, although response to disturbance frequency and intensity varies by functional type and stand size (Rogers et al. 2014). Interactions between multiple disturbance factors (e.g. fires, insect outbreaks, wind storms) appear to favor aspen expansion (Kulakowski et al. 2013) as they negatively impact competitor species, such as conifers. Aspen forests are relatively inflammable (Krawchuk and Cummings 2011) and fire helps maintain some aspen stands by limiting conifer regeneration and succession (Loope and Gruell 1973, and Jones and DeByle 1985 cited in Brown et al. 2006; Worrall et al. 2013).

Furthermore, fires may benefit aspen reproduction, as moist, bare mineral soil found after some stand-replacing fire events is important for sexual production (Baker and Veblen 1990, Veblen et al. 1991, Peet 2000, and Kulakowski and Veblen 2002 cited in Elliott and Baker 2004). However, Shinneman et al. (2013) classify aspen communities within five fire regime types, from highly-dependent seral communities, to fire-independent stable communities. In general, disturbances in seral stands occur at larger scales and higher intensities than those in stable types, although mixed-severity fires may result in mosaics of age-class patches in the landscape (Shinneman et al. 2013).

Future climate exposure

Climate and climate-driven changes important to consider for aspen forests include increased temperature, decreased precipitation and reduced soil moisture, and altered wildfire regimes. As conditions warm and dry in the Sierra Nevada an expansion of aspen stands associated with increased fires is expected within this century (2080-2089) (Rogers et al. 2007; Krawchuk and Cumming 2011). However, expansion may be offset by hydraulic failure during drought (Anderegg et al. 2012).

Temperature: Over the next century, annual temperatures in the Sierra Nevada are expected to rise between 2.4-3.4˚C varying by season, geographic region, and elevation (Das et al. 2011; Geos Institute 2013). On average, summer temperatures are expected to rise more than winter temperatures throughout the Sierra Nevada region (Hayhoe et al. 2004; Cayan et al. 2008), with changes of least magnitude during both seasons anticipated in the central bioregion (Geos Institute 2013). Associated with rising temperatures will be an increase in potential evaporation (Seager et al. 2007).

Precipitation: Precipitation has increased slightly (~2%) in the Sierra Nevada over the past 30 years compared with a mid-twentieth century baseline (1951-1980) (Flint et al. 2013). Projections for future precipitation in the Sierra Nevada vary among models; in general, annual precipitation is projected to exhibit only modest changes by the end of the century (Hayhoe et al. 2004; Dettinger 2005; Maurer 2007; Cayan et al. 2008), with decreases in summer and fall (Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 18-55% by the end of the century (Das et al. 2011).

Snow volume and timing: Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009) and earlier timing of runoff center of mass (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Maurer et al. 2007; Young et al. 2009), as a consequence of early snowmelt events and a greater percentage of precipitation falling as rain rather than snow (Dettinger et al. 2004a, 2004b; Young et al. 2009; Null et al. 2010). Annual snowpack in the Sierra Nevada is projected to decrease between 64-87% by late century (Thorne et al. 2012; Flint et al. 2013), with declines of 10-25% above 3750 m (12303 ft), and 70-90% below 2000 m (6562 ft) (Young et al. 2009). The greatest losses in snowmelt volume are projected between 1750 m to 2750 m (5741 ft to 9022 ft) (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009). Snow provides an important contribution to spring and summer soil moisture in the western U.S. (Sheffield et al. 2004), and earlier snowmelt can lead to an earlier, longer dry season (Westerling et al. 2006).

Climatic water deficit: Climatic water deficit, which combines the effects of temperature and rainfall to estimate site-specific soil moisture, is a function of actual evapotranspiration and potential evapotranspiration. Increases in potential evapotranspiration will likely be the dominant influence in future hydrologic cycles in the Sierra Nevada, decreasing runoff even under forecasts of increased precipitation, and driving increased climatic water deficits (Thorne et al. 2012). In the Sierra Nevada, climatic water deficit has increased slightly (~4%) in the past 30 years compared with the 1951-1980 baseline (Flint et al. 2013). Future downscaled water deficit modeling using the Basin Characterization Model predicts increased water deficits (i.e., decreased soil moisture) by up to 44%, with the greatest increases in the northern Sierra Nevada (Thorne et al. 2012; Flint et al. 2013; Geos Institute 2013).

Wildfire: Both the frequency and annual area burned by wildfires in the western U.S. have increased strongly over the last several decades (Westerling et al. 2006). Fire severity in the Sierra Nevada also rose from 17% to 34% high-severity (i.e. stand replacing) fire, especially in middle elevation conifer forests (Miller et al. 2009). In the Sierra Nevada, increases in large fire extent have been correlated with increasing temperatures and earlier snowmelt (Westerling and Bryant 2006), as well as current year drought combined with antecedent wet years (Taylor and Beaty 2005). Occurrence of large fire and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing by up to 74% by 2085 (Westerling et al. 2011). The area burned by wildfire in the Sierra Nevada is projected to increase between 35-169% by the end of the century, varying by bioregion, with the greatest increases projected at mid-elevation sites along the west side of the range (Westerling et al. 2011; Geos Institute 2013).

More information on downscaled projected climate changes for the Sierra Nevada region is available in a separate report entitled *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy process* (Geos Institute 2013). Additional material on climate trends for the system may be found through the TACCIMO website (http://www.sgcp.ncsu.edu:8090/). Downscaled climate projections available through the Data Basin website (http://databasin.org/galleries/602b58f9bbd44dffb487a04a1c5c0f52).

Sensitivity to non-climate stressors

Aspen are also sensitive to several non-climate stressors that may interact with climate-driven stressors to increase species vulnerability, including fire suppression practices and herbivory. As a result of fire suppression, aspen stands in the Sierra Nevada today are often of advanced age and in the process of succession to conifers (Potter 1998 cited in Krasnow et al. 2012). Fire suppression combined with climate-driven decreases in soil moisture could accelerate habitat conversion. Mammal herbivory can also be a key limiting factor in aspen recruitment and persistence at the local scale (Baker et al. 1997, Suzuki et al. 1999, Kay and Bartos 2000, and

Bailey and Witham 2002 cited in Seager et al. 2013) and can degrade aspen community structure and diversity (Leopold 1943, White et al. 2003, Hebblewhite et al. 2005, and Eisenberg 2012 cited in Seager et al. 2013). Herbivory can also exacerbate climate-driven drought effects on aspen growth and distribution (Romme et al. 2001 cited in Morelli and Carr 2011; Rogers and Mittanck 2013).

Adaptive Capacity

The capacity of the aspen species to adapt to changes in climate will likely be influenced by its wide distribution, ability to tolerate environmental disturbances, and genetic diversity. Aspen are distributed along a wide latitudinal and elevational gradient (4000 ft - 9000 ft) (1219 m - 2743 m) in the Sierra Nevada and southern Cascades, although in the Sierra Nevada aspen stands are often rare with small average stand size and occupy a relatively narrow ecological niche between wetlands and uplands with seasonal streams, seeps and springs, and snow pockets (Potter 1998). In the southern extent of their distribution, aspen are restricted to higher elevations and northerly aspects (Morelli and Carr 2011), which could indicate potential future trends in aspen distribution due to warming climate conditions.

Aspen is the most widespread tree species in North America, adapted to a broad range of environmental conditions including temperature, topographic position, annual precipitation, soil type, growing season length, and disturbance type, among others (Rehfeldt et al 2009; Rogers et al. 2014). Further, different aspen functional types (e.g. seral vs. stable) can be expected to react differently to changing climate conditions (Rogers et al. 2014). Identifying key ecological differences in these communities may be important to understanding the potential climate impacts across the Sierra Nevada and developing appropriate management strategies.

The potential for aspen to adapt to a changing climate may also be facilitated by its evolutionary potential. The primary reproductive strategy of aspen is asexual root sprouting, and recent research indicates great continental and localized genetic diversity in aspen clones (Mock et al. 2008; Callahan et al. 2013). Aspen can also reproduce sexually (i.e. by seeds). While widespread aspen germination from seeds may not have occurred in the western United States in the last 10,000 years (McDounough 1985 cited in Elliott and Baker 2004), the establishment of new genotypes (seedlings) is an important source of genetic variation that contributes to aspen resilience (Leiffers et al. 2001, Frey et al. 2003, and Mock et al. 2008 cited in Seager et al. 2013; Worrall et al. 2008). These characteristics also make aspen a good candidate for restoration programs.

Literature Cited

Anderegg, W. R., J. A. Berry, D. D. Smith, J. S. Sperry, L. D. Anderegg and C. B. Field (2012). "The roles of hydraulic and carbon stress in a widespread climate-induced forest die-off." Proceedings of the National Academy of Sciences USA **109**(1): 233-237.

Brown, K., A. J. Hansen, R. E. Keane and L. J. Graumlich (2006). "Complex interactions shaping aspen dynamics in the Greater Yellowstone Ecosystem." Landscape Ecology **21**(6): 933-951.

Callahan, C. M., C. A. Rowe, R. J. Ryel, J. D. Shaw and M. D. Madritch (2013). "Continental-scale assessment of genetic diversity and population structure in quaking aspen (Populus tremuloides)." Journal of Biogeography **40**(9).

Cayan, D., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio and D. H. Peterson (2001). "Changes in the Onset of Spring in the Western United States." Bulletin of the American Meteorological Society **82**(3): 399-145.

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree and K. Hayhoe (2008). "Climate change scenarios for the California region." Climatic Change **87**(S1): 21-42.

Das, T., M. D. Dettinger, D. R. Cayan and H. G. Hidalgo (2011). "Potential increase in floods in California's Sierra Nevada under future climate projections." Climatic Change **109**(S1): 71-94.

Dettinger, M. D. (2005). "From climate-change spaghetti to climate-change distributions for 21st Century California." San Francisco Estuary and Watershed Science **3**(1): Article 4.

Dettinger, M. D., D. R. Cayan, N. Knowles, A. Westerling and M. K. Tyree (2004a). Recent Projections of 21st-Century Climate Change and Watershed Responses in the Sierra Nevada, USDA Forest Service. **Gen. Tech. Report PSW-GTR-193**.

Dettinger, M. D., D. R. Cayan, M. K. Meyer and A. E. Jeton (2004b). "Simulated Hydrologic Responses to Climate Variations and Change in the Merced, Carson, and American River Basins, Sierra Nevada, California, 1900–2099." Climate Change **62**: 283-317.

Elliott, G. P. and W. L. Baker (2004). "Quaking aspen (Populus tremuloides Michx.) at treeline: a century of change in the San Juan Mountains, Colorado, USA." Journal of Biogeography **31**: 733-745.

Flint, L. E., A. L. Flint, J. H. Thorne and R. Boynton (2013). "Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance." Ecological Processes ***2***: 25.

Geos Institute (2013). Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy (VAAS) process, Available online at: http://www.geosinstitute.org/climatewiseservices/completed-climatewise-projects.html.

Glick, P., B. A. Stein and N. A. Edelson (2011). Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. Washington, D.C., National Wildlife Federation.

Hayhoe, K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J.

Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan and J. H. Verville (2004). "Emissions pathways, climate change, and impacts on California." Proceedings of the National Academy of Sciences **101**(34): 12422-12427.

Hogg, E. H., J. P. Brandt and M. Michaelian (2008). "Impacts of a regional drought on the productivity, dieback, and biomass of western Canadian aspen forests." Canadian Journal of Forest Research **38**(6): 1373-1384.

Knowles, N. and D. Cayan (2004). "Elevational dependence of projected hydrologic changes in the San Francisco Estuary and Watershed." Climate Change **62**: 319-336.

Krasnow, K. D., A. S. Halford and S. L. Stephens (2012). "Aspen restoration in the eastern Sierra Nevada: Effectiveness of prescribed fire and conifer removal." Fire Ecology **8**: 104-118.

Krawchuk, M. A. and S. G. Cumming (2011). "Effects of biotic feedback and harvest management on boreal forest fire activity under climate change." Ecological Applications **21**(1): 122-136.

Kulakowski, D., C. Matthews, D. Jarvis and T. T. Veblen (2013). "Compounded disturbances in sub-alpine forests in western Colorado favour future dominance by quaking aspen (*Populus tremuloides*)." Journal of Vegetation Science: 1-9.

Maurer, E. P. (2007). "Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California, under two emissions scenarios." Climatic Change **82**(3-4): 309-325.

Maurer, E. P., I. T. Stewart, C. Bonfils, P. B. Duffy and D. Cayan (2007). "Detection, attribution, and sensitivity of trends toward earlier streamflow in the Sierra Nevada." Journal of Geophysical Research **112**(D11).

Miller, J. D., H. D. Safford, M. Crimmins and A. E. Thode (2009). "Quantitative Evidence for Increasing Forest Fire Severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA." Ecosystems **12**: 16-32.

Miller, N. L., K. E. Bashford and E. Strem (2003). "Potential impacts of climate change on California hydrology." Journal of American Water Resources Association **39**(4): 771-784.

Mock, K. E., C. A. Rowe, M. B. Hooten, J. Dewoody and V. D. Hipkins (2008). "Clonal dynamics in western North American aspen (Populus tremuloides)." Mol Ecol **17**(22): 4827-4844.

Morelli, T. L. and S. C. Carr (2011). A Review of the Potential Effects of Climate Change on Quaking Aspen (Populus tremuloides) in the Western United States and a New Tool for Surveying Aspen Decline. Albany, CA, USDA, Forest Service, Pacific Southwest Research Station. **PSW-GTR-235:** 31.

Null, S. E., J. H. Viers and J. F. Mount (2010). "Hydrologic response and watershed sensitivity to climate warming in California's Sierra Nevada." PLoS One **5**(4).

Potter, D. A. (1998). Forested communities of the upper montane in the central and southern Sierra Nevada. F. S. Pacific Southwest Research Station, U.S. Department of Agriculture. Albany, CA. **PSW-GTR-169:** 319.

Rehfeldt, G. E., N. L. Crookston, C. Sáenz-Romero and E. M. Campbell (2012). "North American vegetation model for land-use planning in a changing climate: a solution to large classification problems." Ecological applications **22**: 119-141.

Rehfeldt, G. E., D. E. Ferguson and N. L. Crookston (2009). "Aspen, climate, and sudden decline in western USA." Forest Ecology and Management **258**(11): 2353-2364.

Rogers, P. C., S. M. Landhausser, B. D. Pinno and R. J. Ryel (2014). "A Functional Framework for Improved Management of Western North American Aspen (Populus tremuloides Michx.)." Forest Science **In press**.

Rogers, P. C. and C. M. Mittanck (2013). "Herbivory strains resilience in drought-prone aspen landscapes of the western United States." Journal of Vegetation Science **In Press**.

Rogers, P. C., W. D. Shepperd and D. L. Bartos (2007). "Aspen in the Sierra Nevada: Regional Conservation of a Continental Species." Natural Areas Journal **27**(2): 183-193.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. P. Huang, N. Harnik, A. Leetmaa, N. C. Lau, C. Li, J. Velez and N. Naik (2007). "Model projections of an imminent transition to a more arid climate in southwestern North America." Science **316**(5828): 1181-1184.

Seager, S. T., C. Eisenberg and S. B. St. Clair (2013). "Patterns and consequences of ungulate herbivory on aspen in western North America." Forest Ecology and Management ***In Press***.

Sheffield, J., G. Goteti, F. Wen and E. F. Wood (2004). "A simulated soil moisture based drought analysis for the United States." Journal of Geophysical Research: Atmospheres (1984-2012) **109(D24)**.

Shinneman, D. J., W. L. Baker, P. C. Rogers and D. Kulakowski (2013). "Fire regimes of quaking aspen in the Mountain West." Forest Ecology and Management **299**: 22-34.

Taylor, A. H. and R. M. Beaty (2005). "Climatic influences on fire regimes in the northern Sierra Nevada mountains, Lake Tahoe Basin, Nevada, USA." Journal of Biogeography **32**(3): 425-438.

Thorne, J. H., R. Boynton, L. Flint, A. Flint and T.-N. G. Le (2012). Development and Application of Downscaled Hydroclimatic Predictor Variables for Use in Climate Vulnerability and Assessment Studies, Prepared for California Energy Commission, Prepared by University of California, Davis. **CEC-500-2012-010**.

Westerling, A. L. and B. P. Bryant (2006). Climate Change and Wildfire in and around California: Fire Modeling and Loss Modeling. Prepared for California Climate Change Center. **CEC-500-2005-190-SF:** 33.

Westerling, A. L., B. P. Bryant, H. K. Preisler, T. P. Holmes, H. G. Hidalgo, T. Das and S. R. Shrestha (2011). "Climate change and growth scenarios for California wildfire." Climatic Change **109**(S1): 445-463.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan and T. W. Swetnam (2006). "Warming and earlier spring increase western U.S. forest wildfire activity." Science **313**: 940-943.

Worrall, J. J., L. Egeland, T. Eager, R. A. Mask, E. W. Johnson, P. A. Kemp and W. D. Shepperd (2008). "Rapid mortality of Populus tremuloides in southwestern Colorado, USA." Forest Ecology and Management **255**(3-4): 686-696.

Worrall, J. J., G. E. Rehfeldt, A. Hamann, E. H. Hogg, S. B. Marchetti, M. Michaelian and L. K. Gray (2013). "Recent declines of *Populus tremuloides* in North America linked to climate." Forest Ecology and Management **299**: 35-51.

Young, C. A., M. I. Escobar-Arias, M. Fernandes, B. Joyce, M. Kiparsky, J. F. Mount, V. K. Mehta, D. Purkey, J. H. Viers and D. Yates (2009). "Modeling The Hydrology Of Climate Change In California's Sierra Nevada For Subwatershed Scale Adaptation." Journal of American Water Resources Association **45**(6): 1409-1423.

EcoAdapt™

Meeting the challenges of climate change

EcoAdapt, founded by a team of some of the earliest adaptation thinkers and practitioners in the field, has one goal - creating a robust future in the face of climate change. We bring together diverse players to reshape planning and management in response to rapid climate change.

P.O. Box 11195
Bainbridge Island, WA 98110

EcoAdapt.org
+1 (206) 201 3834