TACCIMO
Template for Assessing Climate Change Impacts and Management Options

TACCIMO Literature Report
Management Options Literature Report – Annotated Bibliography Format
Report Date: May 29, 2013

Content Selections:
FACTORS – Plant Communities
CATEGORIES – ALL
REGIONS – All Western Regions

How to cite the information contained within this report

Each source found within the TACICMO literature report should be cited individually. APA 6th edition formatted citations are given for each source. The use of TACCIMO may be recognized using the following acknowledgement:

"*We acknowledge the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) for its role in making available their database of climate change science. Support of this database is provided by the Eastern Forest & Western Wildland Environmental Threat Assessment Centers, USDA Forest Service.*"

Best available scientific information justification

Content in this Literature report is based on peer reviewed literature available and reviewed as of the date of this report. The inclusion of information in TACCIMO is performed following documented methods and criteria designed to ensure scientific credibility. This information reflects a comprehensive literature review process concentrating on focal resources within the geographic areas of interest.

Suggested next steps

TACCIMO provides information to support the initial phase of a more comprehensive and rigorous evaluation of climate change within a broader science assessment and decision support framework. Possible next steps include:

1. Highlighting key sources and excerpts
2. Reviewing primary sources where needed
3. Consulting with local experts
4. Summarizing excerpts within a broader context

More information can be found in the user guide. The section entitled Content Guidance provides a detailed explanation of the purpose, strengths, limitations, and intended applications of the provided information.

Where this document goes

The TACCIMO literature report may be appropriate as an appendix to the main document or may simply be included in the administrative record.

Brief content methods

Content in the Literature Reports is the product of a rigorous literature review process focused on cataloguing sources describing the effects of climate change on natural resources and adaptive management options to use in the face of climate change. Excerpts are selected from the body of the source papers to capture key points, focusing on the results and discussions sections and those results that are most pertinent to land managers and natural resource planners. Both primary effects (e.g., increasing temperatures and changing precipitation patterns) and secondary effects (e.g., impacts of high temperatures on biological communities) are considered. Guidelines and other background information are documented in the user guide. The section entitled Content Production System fully explains methods and criteria for the inclusion of content in TACCIMO.

TABLE OF CONTENTS

Management Options by Source

Wednesday, May 29, 2013

RESOURCE AREA (FACTOR): PLANT COMMUNITIES

GENERAL IMPACTS

NATIONAL

Bernazzani, P., Bradley, B., and Opperman, J. (2012). Integrating climate change into habitat conservation plans under the U.S. Endangered Species Act. Environmental Management, 49(6), 1103-1114. doi:10.1007/s00267-012-9853-2

"Managing for a range of ages in forested ecosystems would reduce the likelihood of substantial loss due to either drought or infestation."

Cleland, E. E., Allen, J. M., Crimmins, T. M., Dunne, J. A., Pau, S., Travers, S. E., … & Wolkovich, E. M. (2012). Phenological tracking enables positive species responses to climate change.   Ecology, 93 (8), 1765 – 1771.

"In conclusion, we found that phenological sensitivity was a significant predictor of species performance under experimental warming. These results provide important justification for current and proposed phonological monitoring efforts, and suggest that phenological sensitivity may be useful as an indicator for identifying species at particular risk for declines with future climate change. "

Joyce, L. A., Blate, G. M., Littell, J. S., McNulty, S. G., Millar, C. I., Moser, S. C., . . . Peterson, D. L. (2008). National forests. in: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. a report by the U.S. climate change science program and the subcommittee on global change research. U.S.Environmental Protection Agency, 1-127.

"A benefit of redundant plantings across a range of environments is that they can provide monitoring information if survival and performance are measured and analyzed. Further, plantations originating as genetic provenance tests and established over the past several decades could be re-examined for current adaptations."

"Other examples [of risk diversification] include planting with mixed species and age classes, as in agroforestry (Lindner, Lasch, and Erhard, 2000); increasing locations, sizes, and range of habitats for landscape-scale vegetation treatments; assuring that fuels are appropriately abated where vegetation is treated; and increasing the number of rare plant populations targeted for restoration, as well as increasing population levels within them (Millar and Woolfenden, 1999)."

"...opportunistic monitoring, such as horticultural plantings of native species in landscaping, gardens, or parks, may provide insight into how species respond in different sites as climate changes, as well as engaging the public in such information gathering."

Kueppers, L. M., Snyder, M. A., Sloan, L. C., Zavaleta, E. S., & Fulfrost,B. (2005). Modeled regional climate change and California oak ranges. Proceedings of the National Academy of Sciences, 102(45), 16281-16286.

"As conservation planners confront climate change, it will be critical that they employ a selection of RCM [regional climate models]-based scenarios that resolve variation in climate response on scales relevant to restricted species and regional reserves [as opposed to global climate models]."

West, J. M., Julius, S. H., Kareiva, P., Enquist, C. Lawler, J. J., … & Shaw, M. R. (2009). U.S. natural resources and climate change: Concepts and approaches for management adaptation. Environmental Management, 44, 1001 – 1021. DOI 10.1007/s00267-009-

"An understanding of a system's long history can be essential because the historical record may include information about past responses to extreme stresses and perturbations. When dealing with sensitive, endangered, or stressed systems, experimental perturbation is not feasible. When available, paleoecological records can be used to examine past ranges of natural environmental variability and past organismal responses to climate change (Willis and Birks 2006). Although in an experimental sense ''uncontrolled,'' there is no lack of both historic and recent examples of perturbations and recoveries through which to examine resilience."

"However, baselines also have the potential to be misleading. For example, Joyce and others (2008) noted that historic baselines are useful only if climate is incorporated into those past baselines and the relationship of vegetation to climate is explored. An ecological baseline based on an historic climate that will never again be seen in a region should not be used as a goal. At the same time, adjusting baselines to accommodate changing conditions requires caution to avoid unnecessarily compromising ecosystem integrity for the future and losing valuable historical knowledge."

"Monitoring targets will have to be carefully selected to represent the system in a tractable way and to give clear information about possible management options (Gregory and Failing 2002). Some systems will require site-specific monitoring, whereas others will be able to take advantage of more general monitoring programs (see Kareiva and others 2008 for examples of potential monitoring targets). For instance, Joyce and others (2008) highlight the need to monitor both native plant species and non-native species while suggesting a more general monitoring program would be adequate to detect changes in tree establishment, growth and mortality. One example of such a general program is the National Phenology Network's monitoring of the timing of ecological events across the country (Joyce and others 2008)."

"Along with developing multiple scenarios using the methods described above to discover potential ecosystem changes, it may also be useful to conduct sensitivity analyses that further explore ecosystem behaviors and identify ranges of potential changes in ecosystem endpoints. In such analyses, key attributes of an ecosystem are examined to see how they respond to systematic changes in selected climate drivers (IPCC-TGICA 2007; Johnson and Weaver 2009). For example, precipitation and temperature would be perturbed at specific increments over a plausible range of changes—e.g., 1% changes in precipitation over a range of -5% to +10% from the historic baseline, and 1°C changes in temperature over a range of +1° to +4°C from the historic baseline—as inputs to an ecosystem model to determine how ecosystem processes and endpoints would respond. This approach may help managers to identify thresholds beyond which key management goals become unattainable."

"Within ecosystems, there may be particular structural characteristics (e.g., three-dimensional complexity, growth patterns), organisms (e.g., functional groups, native species), or areas (e.g., buffer zones, migration corridors) that are particularly important for promoting the resilience of the overall system. Such key ecosystem features could be important focal points for special management protections or actions. For example, managers of national forests may proactively promote stand resilience to diseases and fires by using silviculture techniques such as widely spaced thinnings or shelterwood cuttings (Joyce and others 2008). Another example would be to aggressively prevent or reverse the establishment of invasive non-native species that threaten native species or impede current ecosystem function (Baron and others 2008). "

"Managing for change means actively managing an ecosystem through a transformation to a new state (see Walker and others 2004). This could involve, for example, using species properly suited to the expected future climate when revegetation and silviculture are used for post-disturbance Rehabilit ation; genotypes and species (including‘‘new’’ species) that are better adjusted to projected changes in mean temperature, rainfall, variability and extremes could be used. In Tahoe National Forest, managing for change may mean that white fir would be favored over red fir, pines would be preferentially harvested at high elevations over fir, and species would be shifted upslope within expanded seed transfer guides (Joyce and others 2008). As another example, given climate change, some restoration may cease to be an appropriate undertaking. In a situation where warming waters render selected river reaches no longer suitable for salmon, restoration of those reaches may not be a realistic management activity (Joyce and others 2008). The same applies to meadows, where restoration efforts may need to be abandoned due to probable succession to non-meadow conditions."

WEST

Jones, B. E., Rickman, T. H., Vazquez, A. Sado, Y. & Tate, K. W. (2005). Removal of encroaching conifers to regenerate degraded aspen stands in the Sierra Nevada. Restoration Ecology, 13(2), 373 – 379.

"In Wyoming, Kilpatrick et al. (2003) found that successful aspen [Populus tremuloides] regeneration was induced by either conifer removal or fire, and that all treated sites had adequate sucker densities for clone establishment 3–9 years post-treatment. Shepperd (2001) removed competing conifers around two decadent aspen trees that were not sprouting, which stimulated root suckering and expanded the clone to 0.1 ha in size. Benedict (2001) had 346–1,031 stems/ha of aspen 4 years following conifer removal. "

Littell, J. S., Peterson, D. L., Millar, C. I. & O’Halloran, K. A. (2011). U.S. National Forests adapt to climate change through Science – Management partnerships. Climatic Change, DOI 10.1007/s10584-011-0066-0

"Appropriate species and genotypes can be planted in anticipation of a warmer climate, assuming that credible scientific justification is available on which to base planting decisions. This allows resource managers to hedge their bets by diversifying the phenotypic and genotypic template on which climate and competition interact, and to avoid widespread mortality at the regeneration stage.• Plant multiple tree species rather than monocultures. This would include common local species and perhaps species that are common in adjacent warmer landscapes.• Plant nursery stock from warmer, drier locations than what is prescribed in genetic guidelines based on current seed zones.• Plant nursery stock from a variety of geographic locations."

R5: PACIFIC SOUTHWEST

Jones, B. E., Rickman, T. H., Vazquez, A. Sado, Y. & Tate, K. W. (2005). Removal of encroaching conifers to regenerate degraded aspen stands in the Sierra Nevada. Restoration Ecology, 13(2), 373 – 379.

"These results [from the Sierra Nevada] illustrate the effectiveness of using conventional timber harvest and hand thinning of conifers in aspen [Populus tremuloides] stands as part of a restoration effort to stimulate regeneration of degraded aspen communities. We found that mechanical harvesting of conifers acted as a slight disturbance mechanism (hormonal stimulation) but predominantly created the proper growth environment (sunlight) required for aspen regeneration. We found that post-treatment aspen density is positively associated with pre-treatment aspen density, indicating that pre-treatment aspen density may be a useful selection tool for treatment application."

Loarie, S. R., Carter, B. E., Hayhoe, K., McMahon, S., Moe, R., Knight, C. A., & Ackerly, D. D. (2008). Climate Change and the Future of California's Endemic Flora. PLoS ONE 3(6), e2502. doi:10.1371/journal.pone.0002502

"The projected impacts are also very sensitive to the potential rate of plant movement, and rapid dispersal could mitigate much of the impact on individual species and overall diversity. However, rapid movement by natural dispersal is unlikely on a century time-scale, except for weedy species with short generation time and highly dispersable propagules. Human assisted dispersal must be considered as a critical component of conservation and biodiversity management in the next century."

"Areas that are projected to harbor species with shrinking ranges, on average (Fig. 4, A–D), include many mountainous areas scattered across the study area. We identify these areas as refugia that may disproportionately contain the most ''threatened'' species. These ''future refugia'' present valuable opportunities as conservation targets. They may protect significant components of biodiversity into the next century. The number of species projected to survive in these refugia (Fig. 4, E through H) depends critically on the ability to disperse, highlighting the importance of landscape connectivity and potential restoration in the face of increasing urbanization, land use change, and disturbance."

McLaughlin, B. C. & Zavaleta, E. S. (2012). Predicting species responses to climate change: demography and climate microrefugia in California valley oak (Quercus lobata). Global Change Biology, 18, 2301 – 2312. doi: 10.1111/j.1365-2486.2011.02630.x

"Specifically, our results suggest that in Mediterranean systems, where important terrestrial species often depend on access to groundwater (Howard et al., 2010), maintaining groundwater levels and wisely managing riparian areas should be a priority to buffer the system against climate change. More generally, our findings underscore the importance of a focus on life stage-specific climate vulnerability in understanding and predicting climate-related species movement."

ALPINE & BOREAL FORESTS

WEST

Cortini, F., Comeau, P. G., Boateng, J. O., Bedford, L., McClarnon, J. & Powelson, A. (2011). Effects of climate on growth of lodgepole pine and white spruce following site preparation and its implications in a changing climate. Canadian Journal of Forest Research, 41, 180 – 194. doi:10.1139/X10-194

"Plant community analyses at Inga Lake [British Columbia] highlight that, even 20 years after planting, deciduous tall shrubs were still a major component of the untreated plots whereas grasses and forbs were more common in the mechanical site preparation and vegetation control treatments (Haeussler et al. 1999; Forest Practices Branch 2008). In boreal region stands, Matsushima and Chang (2006) also found that white spruce [Picea glauca] would not benefit from nitrogen fertilization unless the grass layer was removed. The effect of the competing vegetation suggests that drought stress levels could increase in the future for young untreated white spruce plantations up to age 20. Thus the application of proper site preparation could potentially offset the negative impact of climate change on early white spruce growth (i.e., drought stress) by decreasing competition from tall shrubs (e.g., willow and alder) and grass, improving soil temperature, reducing limitations from excess spring moisture, increasing nutrient availability, and accelerating early root growth of white spruce to make it better able to overcome competition. "

"Mechanical preparation and competing vegetation control can potentially ease the competitive effect of unwanted vegetation in a changing climate, although every treatment needs to be planned carefully at the stand level and more studies are required to explore the impact of these treatments in relation to climate change. Nitrogen-fixing species (e.g., Alnus viridis subsp. sinuata (Regel) A . Love & D. Love) have the capability to enhance site fertility with potential benefit to the crop trees; thus, their complete removal from the stand would not be indicated on poor sites or given the uncertainty related to the current climatic changes (Brockley and Sanborn 2003; Laubhann et al. 2009). Maintenance of some woody vegetation cover may also afford protection of trees from cold injury during winters with low snow cover (Krasowski et al. 1993)."

Smith, C. M., Shepherd, B., Gillies, C. & Stuart-Smith, J. (2013). Changes in blister rust infection and mortality in whitebark pine. Canadian Journal of Forest Research, 43, 90 – 96. dx.doi.org/10.1139/cjfr-2012-0127

"The slowing rates of infection and mortality [in whitebark pine, Pinus albicaulis] that we found in our study suggest that some level of natural selection may already be occurring in areas with high levels of both, increasing the importance of protecting these areas from industrial activity, MPB [mountain pine beetle, Dendroctonus ponderosae] attack, or wildfire. In addition, areas with high canopy kill (thus low cone production) and low natural regeneration will require active management such as collecting and testing seed from potentially blister rust resistant trees, protecting these trees from MPB attack (Smith 2009), and burning areas to improve microsite conditions for planting seedlings (Schwanke and Smith 2010) to maintain whitebark pine populations on the landscape. In areas with lower levels of infection and mortality, less-intensive proactive strategies could be implemented (Schoettle and Sniezko 2007)."

"The relatively high WPBR [white pine blister rust, Cronartium ribicola] infection levels (~49%) near the northern limit of whitebark pine [Pinus albicaulis] may have implications for natural migration latitudinally as a response to climate warming (Hamann and Wang 2006) or for assisted migration (McLane and Aitken 2012)."

ARID LANDS

WEST

Meyer, S. E. (2012). Restoring and managing cold desert shrublands for climate change mitigation. In, Finch, Deborah M., ed. 2012. Climate change in grasslands, shrublands, and deserts of the interior American West: a review and needs assessment. General Technical Report RMRS-GTR-285. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

"The most important consideration for high-condition shrublands is prevention of degradation. This means keeping the cryptobiotic crust and the herbaceous understory in the best possible condition, which minimizes the probability of massive annual grass expansion after fire and maintains surface stability to minimize dust generation. Direct protection from invasion, for example, by controlling nearby weed infestations that could be propagule sources, is another way to maintain ecosystem integrity, as is providing priority protection in the event of wildfire. Even though occasional wildfire was a natural occurrence before settlement, especially in sagebrush steppe, protection from burning under current conditions is a top priority because of the threat of annual grass invasion."

Wisdom, M. J. & Chambers, J. C. (2009). A landscape approach for ecologically based management of Great Basin shrublands. Restoration Ecology, 17 (5), 740 – 749. doi: 10.1111/j.1526-100X.2009.00591.x

"One demonstration of such an approach [a strategy to reduce risk of sagebrush (Artemesia spp.) loss] is described here. The approach first characterizes each block as one of four types, based on percent area of sagebrush and its resistance to invasion by cheatgrass [Bromus tectorum] and woodlands. A spatial priority of high, moderate, or low is assigned to each type of block, based on the assumed efficiency by which sagebrush can be maintained above the 27% threshold associated with Sagegrouse [Centrocercus urophasianus] presence (Table 1). Blocks of high spatial priority contain both adequate sagebrush area (above the threshold) and are dominated by sagebrush of higher resistance. These blocks are referred to as “strongholds” because they contain adequate, secure areas of sagebrush that can be maintained efficiently for Sage-grouse. Blocks of moderate or low priority have substantially less sagebrush area, either currently or projected, with lower resistance. These blocks are referred to as “support” because they may not provide adequate area in sagebrush by themselves, but would benefit Sage-grouse when stronghold blocks also are present."

"A variety of passive and active management prescriptions can be implemented to address spatial priorities and objectives. Passive management includes the removal or attenuation of existing disturbances or management practices that contribute to an undesired effect (McIver & Starr 2001). Active management, by contrast, uses new inputs to the system to stop, mitigate, or reverse undesired effects (McIver & Starr 2001). Passive management is effective where the structure and ecological processes of the shrubland are intact and can recover without new resource inputs. This may be the situation for many sagebrush [Artemesia spp.] types at low or moderate risk of conversion to cheatgrass [Bromus tectorum] (Suring et al. 2005b; Wisdom et al. 2005c). In this case, passive management prescriptions that mitigate effects of existing land uses, such a grazing, motorized activities, and energy development, are required to maintain current conditions or reduce risk (Suring et al. 2005b; Wisdom et al. 2005c)."

"Most sagebrush [Artemesia spp.] types at high risk of conversion to cheatgrass [Bromus tectorum], or at moderate or high risk of conversion to woodlands, require a combination of passive and active management to effectively reduce these risks (Suring et al. 2005b; Wisdom et al. 2005c). Without active management, the potential is high for crossing thresholds to alternative, undesired states (Suring et al. 2005b; Wisdom et al. 2005c). On sites with high risk of conversion to cheatgrass, active prescriptions include reductions in sagebrush biomass to decrease competition with perennial herbaceous species, herbicide treatments to control cheatgrass, and seeding of desired grasses and forbs that can decrease the future invasibility of the site (Suring et al. 2005b; Wisdom et al. 2005c; D’Antonio et al. in press). The passive management prescriptions described above also are required to ensure recovery of these areas."

"For sagebrush [Artemesia spp.] sites at moderate or high risk of conversion to woodlands, active prescriptions are required (Suring et al. 2005b; Wisdom et al. 2005a, 2005c). These can include prescribed fire or mechanical treatments to reduce the cover of juniper [Juniperus spp] or pinyon pine [Pinus monophylla], followed by seeding of desired plant species and grazing rest. Repeated use of fire or mechanical treatments over time may be required to prevent further invasion of juniper or pinyon pine and to maintain sagebrush communities. If these sites also are at high risk of conversion to cheatgrass [Bromus tectorum], the use of fire or mechanical treatments to control woodland expansion may enhance cheatgrass invasion at lower elevations. Consequently, use of both active and passive management prescriptions described for cheatgrass control may be required."

R3: SOUTHWESTERN

Gitlin, A. R., Sthultz, C. M., Bowker, M. A., Stumpf, S. Paxton, K. L., … & Whitham, T. G. (2006). Mortality gradients within and among dominant plant populations as barometers of ecosystem change during extreme drought. Conservation Biology, 20 (5), 1477 –

"We believe that conservation of imperiled habitat types with high endemism (a hotspot-like approach) is essential for conserving regional biodiversity. If rare hotspot habitat types are lost, entire communities and their associated species could disappear. Fremont cottonwood [Populus fremontii], Manzanita

[Arctostaphylos pungens], and quaking aspen [Populus tremuloides] are found in <2% of our study area, and each experienced >14% mortality. It is important to understand and potentially alleviate the factors that could further these species' decline because their dependent communities are already confined to limited areas."

"Our results demonstrate that extreme drought can cause sudden and dramatic changes in the abundance and spatial arrangement of dominant plants, and that site characteristics will differentially affect the dominant species that characterize many vegetation types. The key to maintaining resilient populations of dominant plants will be to conserve areas that are subject to a wide variety of environmental extremes, including sites that are under stress, while restoring habitat structure to increase rare habitat abundance and reduce water stress on dominant plant populations."

Karl, T. R., Melillo, J. M., & Peterson, T. C. (2009). Global climate change impacts in the United States. New York, NY, USA: Cambridge University Press.

"Given the mountainous nature of the Southwest, and the associated impediments to species shifting their ranges, climate change likely places other species at risk. Some areas have already been identified as possible refuges where species at risk could continue to live if these areas were preserved for this purpose (Loarie et al. 2008). Other rapidly changing landscapes will require major adjustments, not only from plant and animal species, but also by the region's ranchers, foresters, and other inhabitants."

GRASSLANDS

NATIONAL

Bachelet, D., Johnson, B. R., Bridgham, S. D., Dunn, P. V., Anderson, H. E. & Rogers, B. M. (2011). Climate change impacts on western Pacific Northwest prairies and savannas. Northwest Science, 85(2), 411-429.

"Managers of protected sites should harness the existing heterogeneity of their sites to sustain species and processes in the face of climate change. This may mean facilitating species shifts into new microhabitat types or even new community types."

Carter, D. L. & Blair, J. M. (2012). High richness and dense seeding enhance grassland restoration establishment but have little effect on drought response. Ecological Applications, 22 (4), 1308 – 1319.

"We recommend the use of HR [high richness] and HD [high density] methods and suggest that these may be substitutable if either diversity or density alone are limiting, particularly where the establishment of small-scale species richness, native species cover, and low exotic species cover are restoration targets. Positive effects of high seeding density on native vs. exotic cover and richness were still evident four to five years after the initial seeding."

"Neither HR [high richness] nor HD [high density] treatments produced plant communities with superior drought resistance, recovery, or resilience, which may be important properties for restored grasslands given projected increases in drought frequency and severity. The insurance hypothesis predicts that diverse communities should be more likely to contain species that will compensate for others in response to perturbation (Yachi and Loreau 1999). In our case, greater representation of native annual/biennial species or species known to have drought tolerance traits in seed mixtures may confer greater stability to a one-year drought, and this should be evaluated in future studies."

R2 & R4: MOUNTAIN WEST

Bachelet, D., Lenihan, J. M., Daly, C. & Neilson, R. P. (2000). Interactions between fire, grazing and climate change at Wind Cave National Park, SD. Ecological Modelling, 134, 229 – 244.

"The [Wind Cave National] Park's current prescribed fire program is thus a valuable tool to sustain grasslands in the future as long as native herbivore herds (bison, antelopes) are not allowed to expand beyond the Park's carrying capacity and to significantly reduce fuel loads. A more frequent prescribed fire schedule may be required to maintain grazing areas in the next century. The timing of these prescribed fires would need to be adjusted to prevent fuel build-up and resulting intense fires. Large fires that kill older trees would have to be suppressed while promoting small frequent fires to reduce tree seedling density, sapling competition for available resources, and thus prevent the establishment of even-aged crowded woodlands. In healthy forests stands, C sequestration would be favored over habitat for herbivores since total biomass and soil organic matter content are higher when trees dominate than when grasslands are present (Tables 1, 3 and 4)."

R6: PACIFIC NORTHWEST

Halpern, C. B., Haugo, R. D., Antos, J. A., Kaas, S. S. & Kilanowski, A. L. (2012). Grassland restoration with and without fire: evidence from a tree-removal experiment. Ecological Applications, 22 (2), 425 – 441.

"It is commonly assumed that fire is fundamental to maintaining the open nature of grasslands and thus is critical to restoring systems invaded by woody plants. Our study challenges the generality of this assumption. For this common western North American grassland, our experiment indicates that fire (broadcast burning) is not necessary to reverse the effects of decades to multiple centuries of forest influence. Tree removal alone is sufficient to cause a significant shift in dominance from forest understory to meadow species. If the principal contribution of fire is to prevent tree establishment in grasslands or meadows, mechanical removal of trees (preferably at an early stage in the invasion process) may be a simple alternative. "

"Nevertheless, we found that broadcast burning did not adversely affect soils or recovery of meadow species, suggesting that once trees are removed, low-intensity fire could be used to maintain these open habitats. Burning is necessary, however, from a management perspective, to dispose of logging residues, thus reducing future fire hazard. It also removes woody debris that would otherwise shade the ground surface, creating conditions that benefit forest herbs and inhibit meadow species."

TEMPERATE FORESTS

NATIONAL

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., … & Cobb, N. (2010). A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management, 259(4), 660-684. doi:10.1016/j.foreco.2009.09.001

"In summary, given the potential risks of climate-induced forest die-off, forest managers need to develop adaptation strategies to improve the resistance and resilience of forests to projected increases in climate stress (Seppala et al., 2009). Options might include thinning stands to reduce competition, selection of appropriate genotypes (e.g., improved drought resistance), and even translocation of species to match expected climate changes (e.g. Millar et al., 2007b; Joyce et al., 2008; Richardson et al., 2009)."

Joyce, L. A., Blate, G. M., Littell, J. S., McNulty, S. G., Millar, C. I., Moser, S. C., . . . Peterson, D. L. (2008). National forests. in: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. a report by the U.S. climate change science program and the subcommittee on global change research. U.S.Environmental Protection Agency, 1-127.

"Monterey pine (Pinus radiata), endangered throughout its small native range, has naturalized along the north coast of California far disjunct from its present native distribution. Much of this area was paleohistoric range for the pine, extant during climate conditions that have been interpreted to be similar to expected futures in California (Millar, 1999). Using these locations specifically for "neo-native" conservation stands, rather than planning for the elimination of the trees as undesired exotics (which is the current management goal), is an example of how management thinking could accommodate a climate-change context (Millar, 1998)."

Lindroth, R. L. & St. Clair, S. B. (2013). Adaptations of quaking aspen (Populus tremuloides Michx.) for defense against herbivores. Forest Ecology and Management, htttp://dx.doi.org/10.1016/j.foreco.2012.11.018

"As our understanding of the fundamental genetic, physiological and ecological components of aspen's [Populus tremuloides] success improves, better management approaches can be implemented to increase its resilience under conditions that threaten its future sustainability. Management strategies that emphasize the significance of maintaining genetic variation in aspen populations are of paramount importance in maintaining resilient aspen forests. Even the most effective aspen defense strategies, however, fail to mitigate excessive browsing pressure in areas with high livestock and wildlife densities. Parallel work is needed to identify aspen regeneration densities that are required for stand re-establishment, so when herbivory reduces regeneration below critical thresholds, appropriate management actions to control browsing can be initiated."

Mote, P. W., Parson, E. A., Hamlet, A. F., Keeton, W. S., Lettenmaier, D., … & Snover, A. K. (2003). Preparing for climatic change: The water, salmon, and forests of the Pacific Northwest. Climatic Change, 61, 45 – 88.

"Another approach, particularly for unmanaged forests, would expand or adjust the region's protected areas to incorporate greater geomorphic or landscape diversity, thereby facilitating distributional or range-shifts in terrestrial communities and enhancing ecosystem resilience to change. Other adaptive strategies (Mote et al., 1999b) include managing forest density for reduced susceptibility to drought stress, using prescribed fire to reduce vulnerability to large fires, and monitoring trends in forest conditions and climate."

WEST

Crookston, N. L., Rehfeldt, G. E., Dixon, G. E., & Weiskittel, A. R. (2010). Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics. Forest Ecology and Management, 260, 1198-1211.

"Climate–FVS [Forest Vegetation Simulator] provides forest managers a tool useful for considering the effects of climate change on forested ecosystems. The model relies on the original FVS growth equations to predict performance in the absence of climate change. To accommodate the effects of change, FVS components are modified rather than replaced with new estimators. In this respect, the primary intrinsic components of FVS and its empirical heritage remain intact. "

Long, J. N. & Mock, K. (2012). Changing perspectives on regeneration ecology and genetic diversity in western quaking aspen: implications for silviculture. Canadian

Journal of Forest Research, 42, 2011 – 2021. doi:10.1139/x2012-143

"Variations on uneven-aged methods could be used across the range of aspen [Populus tremuloides] stand composition, from pure aspen to mixed species, and across a wide range of site quality. For example, group selection might be useful in maintaining an aspen component in late-successional conifer-dominated stands (David et al. 2001; Long 2003; Kurzel et al. 2007). Group selection refers to a method of regeneration where mature "trees are removed and new age classes are established in small groups" (e.g., the width of the opening might be twice the height of the mature trees) (Helms 1998). The previously underestimated occurrence of aspen in mixed-species and uneven-aged stands has important implications for management of some western landscapes. For example, even small amounts of aspen in conifer-dominated stands and landscapes have been shown to contribute to avian species richness (Li and Martin 1991; Griffis-Kyle and Beier 2003; Hollenbeck and Ripple 2007)."

Rehfeldt, G. E. & Jaquish, B. C. (2010). Ecological impacts and management strategies for western larch in the face of climate change. Mitigation and Adaptation Strategies for Global Change, 15, 283 – 306. DOI 10.1007/s11027-010-9217-2

"An additional practical lesson learned from this work [with western larch, Larix occidentalis] is that comprehensive programs of conservation or management will either require or benefit from cooperation across national boundaries. Our figures demonstrate unequivocally that climatic ecotypes transcend political boundaries. Consequently, programs involving seed procurement and deployment, tree breeding and maintenance of breeding populations, and accrual of genetic gains in commercially important traits will be most efficient through transboundary cooperation. Threatened populations in particular may require conservation plantings in ex situ reserves outside political jurisdictions where future climates are amenable to the species."

Shepperd, W. D., Rogers, P. C., Burton, D. & Bartos, D. L. (2006). Ecology, biodiversity, management, and restoration of aspen in the Sierra Nevada. General Technical Report RMRS-GTR-178. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station 122 p.

"If this predicted climate trend materializes, a practical approach toward natural range of variability management in aspen [Populus tremuloides] may be to emulate patterns and processes favored during the Medieval Warm Period, rather than those found during the Little Ice Age just prior to Euro-American settlement. After all, a warm/dry summer weather pattern facilitating increased frequency of fires may be one more favorable to aspen expansion, or at least more favorable to greater renewal of aspen and regular culling of competing conifers."

Shinneman, D. J., Baker, W. L., Rogers, P.C. & Kulakowski, D. (2013). Fire regimes of quaking aspen in the Mountain West. Forest Ecology and Management. http://dx.doi.org/10.1016/j.foreco.2012.11.032

"If treatments are planned to intentionally maintain or increase aspen [Populus tremuloides] in stands in which it is seral and naturally being replaced by conifers [in the mountain west], it is practical to consider several key factors that are likely to influence aspen regeneration success. For instance, prefire stand conditions and potential interaction among disturbance agents (e.g., fire severity and post-fire herbivory) may decrease the probability of successful post-disturbance regeneration of aspen (e.g., Bailey and Whitham, 2002). Moreover, it is not clear that fire alone will increase dominance of aspen in all seral stands if, for example the vigor of aspen clones has been reduced (Calder and St. Clair, 2012; Smith et al., 2011). "

"Under projected climate change effects, environmental settings prone to aspen [Populus tremuloides] mortality and reduced growth rates due to increased temperature or drought (e.g., Hanna and Kulakowski, 2012) may not be optimal for future disturbance based manipulations, and it is uncertain how well aspen will track shifting patterns of cooler and more mesic growing conditions in the MW [Mountain West] (e.g., by moving to higher elevations or north-facing slopes). Thus, understanding the historical range of variability, the influence of current site-specific and landscape-level environmental settings, and likely future perturbations and climate change effects are all important considerations for how to maintain or restore aspen ecosystems."

R3: SOUTHWESTERN

Ganey, J. L. & Vojta, S. C. (2011). Tree mortality in drought-stressed mixed-conifer and ponderosa pine forests, Arizona, USA. Forest Ecology and Management, 261, 162 – 168. doi:10.1016/j.foreco.2010.09.048

"Our results suggest that these forests [mixed conifer and ponderosa pine (Pinus ponderosa) in the Southwest] currently are not resilient to such changes [increasing temperature and aridity]. Consequently, management aimed at increasing resilience in these forests in the face of changing climate may be desirable (e.g., Millar et al., 2007). Possible approaches include treatments aimed at restoring more open stand conditions and appropriate species mixes in these forest types, which historically burned relatively frequently (Kaufmann et al., 2007; Fulé, 2008). Our data suggests that efforts to restore appropriate species mixes may be effective, as this will increase proportions of species with higher drought tolerance. Our data, as well as several other studies (e.g. van Mantgem and Stephenson, 2007; Floyd et al., 2009; van Mantgem et al., 2009), do not strongly support the hypothesis that stands with lower density experience lower mortality during severe drought, however. Thus, although reducing stand density should reduce competition for moisture and may increase resilience in most years, it is not clear that it will effectively reduce mortality during periods of severe drought."

R6: PACIFIC NORTHWEST

Coulston, J. W. & Riiters, K. H. (2005). Preserving biodiversity under current and future climates: a case study. Global Ecology and Biogeography, 14, 31-38.

"Many of the areas where reserves were lacking occurred in the edge and relatively wet and warm portions of the ecological envelope (Fig 4a). These areas were concentrated in western Washington, western Oregon, and north-western California (Fig 4b). Some of the areas where conservation efforts would be beneficial are in publicly owned land such as national forests. For example, the Willamette National Forest in western Oregon has approximately 1062 km2 of the Douglas-fir [Pseudotsuga menziesii] forest type that were classified as warm and wet interior habitat that were not under protection based on the DellaSala et al. (2001) classification. Transferring some of this area to a protected area status would fill in some of the gaps in protection. There was also approximately 1800 km2 of the Douglas-fir forest type warm and wet habitat on private land in the Puget Sound area. Some of this area would also be a candidate for protection."

R5: PACIFIC SOUTHWEST

Holmes, K. A., Veblen, K. E., Young, T. P. & Berry, A. M. (2008). California oaks and fire: A review and case study. In A. Merenlender, D. McCreary & K. L. Purcell, Kathryn L., tech. eds. Proceedings of the sixth California oak symposium: today's challenges, tomorrow's opportunities. General Technical Report PSW-GTR-217. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

"Land managers interested in using prescribed fire in young oak [Quercus spp.] tree stands may want to minimize potential fire damage by addressing factors that have been shown to be predictive of severe fire response. Fire temperatures can be lowered by conducting burns when ambient temperatures are low and when relative humidity and fuel moisture is high; for example, either in early morning or early season. Understory biomass around sapling oaks can be reduced through the use of weed control fabric or via aggressive weed-whacking within the canopy line of individual sapling oaks immediately before

Hurteau, M., & North, M. (2009). Response of Arnica dealbata to climate change, nitrogen deposition, and fire. Plant Ecology, 202, 191-194.

"In the long-term, specific management actions should depend upon the climate change scenario that unfolds. Under a range of modeled greenhouse gas concentrations, Lenihan et al. (2008) found that the area burned in California is likely to increase. If a general increasing trend in precipitation occurs, fire could be a useful tool for maintaining A. dealbata [Arnica dealbata] [Mimosa]. However, if a general decreasing trend in precipitation occurs, A. dealbata abundance may diminish further. Regardless of the trend in precipitation, a prudent hedge against uncertainty for A. dealbata would be managing for increased soil moisture availability by restoring a more open historic forest condition."

Loarie, S. R., Carter, B. E., Hayhoe, K., McMahon, S., Moe, R., Knight, C. A., & Ackerly, D. D. (2008). Climate Change and the Future of California's Endemic Flora. PLoS ONE 3(6), e2502. doi:10.1371/journal.pone.0002502

"However, rapid movement by natural dispersal is unlikely on a century time-scale, except for weedy species with short generation time and highly dispersable propagules. Human assisted dispersal must be considered as a critical component of conservation."

North, M., Stine, P., O'Hara, K., Zielinski, W. & Stephens, S. (2009). An ecosystem management strategy for Sierran mixed-conifer forests. (General Technical Report PSW-GTR-220). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 1 – 49.

"In contrast, upslope areas [in Sierra Nevada mixed conifer forests], where soils may be shallower and drier and where fire can burn with greater intensity, historically had lower stem densities and canopy cover (Agee and Skinner 2005) (fig. 8). On these sites, thinning might reduce the density of small or, where appropriate, intermediate trees and ladder and surface fuels toward a more open condition. In some circumstances this thinning may reduce water stress, accelerating the development of large residual trees (Kolb et al. 2007, Latham and Tappenier 2002, McDowell et al. 2003, Ritchie et al. 2008). Within a stand, varying stem density according to potential fire intensity effects on stand structure would create horizontal heterogeneity."

"We suggest creating landscape heterogeneity in the Sierra Nevada by mimicking the forest conditions that would be created by the fire behavior and return interval associated with differences in slope position, aspect, and slope steepness (Sherlock 2007). In general, stem density and canopy cover would be highest in drainages and riparian areas, and then decrease over the midslope and become lowest near and on ridgetops (fig. 10). Stem density and canopy cover in all three areas would be higher on northeast aspects compared to southwest. Stand density would also vary with slope becoming more open as slopes steepen."

Rogers, P. C., Shepperd, W. D. & Bartos, D. L. (2007). Aspen in the Sierra Nevada: Regional conservation of a continental species. Natural Areas Journal, 27 (2), 183 –

"Maintenance of stand variability, and a complimentary strategy of biotic diversity, is dependent on restoration of trophic interactions. Specifically, a conservation approach, which favors reduction and movement of wild herbivores by reintroduction of carnivores, and domestic livestock through reduction and strategic rotation, will promote aspen [Populus tremuloides] regeneration after disturbance. Large reserves and a series of linked smaller reserves will be essential to retaining home ranges for carnivores that prey on wild ungulates."

Stephenson, N. L. (1999). Reference conditions for giant sequoia forest restoration: Structure, process, and precision. Ecological Applications, 9(4), 1253 – 1265.

"Over the last few decades, climate in [giant] sequoia [Sequoiadendron giganteum] groves has fallen within the range of the millennium preceding Euro-American settlement, though toward the warm, wet extreme (Fig. 2). This fact, coupled with the longterm compositional shifts and lagged vegetation response to climatic change, lead me to suggest that the millennium preceding Euro-American settlement is a reasonable reference period for giant sequoia ecosystems (Stephenson 1996; but see Millar and Woolfenden [1999] for a contrasting viewpoint)."

INTERACTIONS WITH OTHER FACTORS

NATIONAL

Dale, V. H., Lannom, K. O., Tharp, M. L., Hodges, D. G., & Fogel, J. (2009). Effects of climate change, land-use change, and invasive species on the ecology of the Cumberland forests. Canadian Journal of Forest Research, 39, 467-480.

"Because trees are so long-lived and climate changes are occurring so rapidly, the research must combine modeling, experimental, and management approaches to be able to address complexities and scales of the challenge. We recognize that adapting to this need often requires a change in planning perspectives. A management approach engaged with research provides an appropriate way for decision makers to deal with the uncertainties inherent in climate change. Management actions can be treated as experiments that test hypotheses, answer questions, and thus, provide future management guidance. This approach requires that both conceptual models be developed and used and relevant data be collected and analyzed to improve understanding as the system changes."