GRAND CANYON TRUST

ANNOTATED BIBLIOGRAPHY

Current and Projected Climate Change Impacts for the Colorado Plateau Assessment Implications for the Manti-La Sal NF Plan Revision

Cerissa Hoglander, Mary O'Brien[1]
Grand Canyon Trust
October 2016

CONTENTS

[1] Primary Contact: Mary O'Brien, maryobrien10@gmail.com

Introduction

This annotated bibliography summarizes 68 research studies and literature surveys relevant to climate change impacts on the Manti-La Sal National Forest in the northern Colorado Plateau. The resources are organized based on impact categories: multiple projected impacts, impacts to water resources, impacts to forests (including fire regime shifts), ecological community shifts, and climate adaptation opportunities.

Multiple Projected Impacts

Archer, S. R., and K. I. Predick. 2008. Climate change and ecosystems of the southwestern United States. Rangelands 30:23–28.

Topic: Climate change projections and related impacts for the Southwest.

Climate change impacts include shifting ecosystem boundaries; altered vegetation composition, diversity, and growth; reduced water availability, particularly in already arid ecosystems; loss of net primary productivity (i.e., vegetation productivity); shifts in the hydrologic cycle due to changes in precipitation intensity, timing, and frequency; increased losses from soil erosion; reductions of native fish diversity; and an expansion of non-native species invasions.

Management discussed: More agile and climate change-focused fire and livestock management as well as ongoing monitoring of ecosystems to track changes and inform adaptive management actions.

Implications for forest plan assessment: The Environmental Impact Statement (EIS) for the Manti-La Sal National Forest (MLSNF) forest plan revision needs to be explicit about best available science on climate change impacts in combination with user and management activities on the forest as a basis for determining Need for Change.

Chambers JC, Pellant M. 2008. Climate change impacts on northwestern and intermountain United States rangelands. Rangelands 30:29–33.

Topic: Climate change impacts on grazed lands in the western United States.

Climate change impacts outlined include reductions in water quantity and quality; shifts in species and community distributions (e.g., migrations northward); biodiversity loss (e.g., 20% of sagebrush flora/fauna are imperiled); increases in non-native species invasions (especially annual grasses where perennial cover is light); and changes in fire regimes.

Management discussed: Conservation easements, migration corridors, watershed scale management, restoration of degraded ecosystems, coordinated resource management, engaging stakeholders, and, "*most importantly, explaining the changes that are likely to occur and the reality of responding to a changing climate."*

Implications for forest plan assessment: The EIS needs to assess potential impacts of rising temperatures and drought on biodiversity, invasive species, and water in addition to other elements of forest health.

Donahue DL. 2000. Elephant in the room: Livestock's role in climate and environmental change. Michigan State Journal of International Law 22:1–28.

Topic: Cumulative impacts of livestock grazing and climate change.

This paper reviews scientific literature associated with the links between extensive livestock grazing; greenhouse gas emissions (e.g., methane, ammonia, carbon dioxide); and other environmental impacts (e.g., dryland degradation and habitat fragmentation) at a global scale. For example, the paper cites global studies which conclude that extensive grazing is both less efficient in producing livestock and has a proportionally greater impact on climate and the environment than intensive production systems when operated on marginal lands.

Management discussed: The paper suggests approaches such as payment for environmental services which could encourage farmers/ranchers to employ natural resource management practices that have additional environmental benefits (e.g., water resource and fragile soil area protection, biodiversity conservation). Donahue notes, "Paying western ranchers to produce native seed and plants for desperately needed range rehabilitation projects, for example, would be far more sensible than subsidizing public land grazing, given its minor contribution to meat production and substantial environmental externalities."

Implications for forest plan assessment: Livestock grazing impacts on marginal areas within MLSNF should be assessed in light of global scientific studies in other arid and semi-arid regions.

Hughes MK, Diaz HF. 2008. Climate variability and change in the drylands of western North America. Global and Planetary Change 64:111–118.

Topic: Projected climate change for North America.

Recent multi-decadal drought in western North America provides some insight for the multi-decadal drought projected to continue for the remainder of the century. Climate changes outlined in this paper included earlier snowmelt, less precipitation as snow, warmer temperatures, and changes in streamflow. Ongoing climate change will bring a drier climate to North America, with more extreme and extensive drought to the continent for the next 50 years.

Implications for forest plan assessment: The EIS needs to describe projected cumulative effects of earlier snowmelt, less precipitation as snow, warmer temperatures, and changes in streamflow for recreation, elk browse of aspen, exotic mountain goat use of Mount Peale Research Natural Area and other alpine areas, carrying capacity of grass production for livestock, etc.

Knowles N. 2015. Trends in snow cover and related quantities at weather stations in the conterminous United States. Journal of Climate 28:7518–7528.

Topic: Climate change impacts to precipitation (snow cover).

Using national weather data from 1950-2010, this study found a national decline in the annual number of days with snow cover. Regionally, the study identified trends in later snow-cover onset in the western United States but earlier snow-cover onset in the eastern United States. When combined with an overall earlier final meltoff of snow cover, these trends contributed to shorter snow seasons across the nation except for the Great Plains and southern Rockies regions where snow seasons were lengthened. Ongoing warming with climate change will force a continued decline in the annual number of days with snow cover and overall less snow cover in low to middle elevations. In addition, winter precipitation shifts and temperature increases will amplify flooding risk across the interior and northeastern regions of the United States.

Implications for forest plan assessment: The EIS needs to describe trends in both onset and melt-off of snow pack on the forest.

Maestre FT et al. 2012. Plant species richness and ecosystems multifunctionality in global drylands. Science 335:2014–2017.

Topic: Climate change impacts to biodiversity and ecological functionality.

Using global data on plant species richness and abiotic factors (climate, slope, elevation, and soil texture), this study evaluated the influences of these elements on nutrient cycling and carbon storage functions across dryland ecosystems using regression models. While species richness alone was found to have only small influence on ecosystem functionality, it was found to be a critical influence. Ecosystem functionality is likely also affected by other factors such as intensity of herbivory, presence of keystone and invasive species, and soil faunal diversity. Drylands will continue to become more arid with climate change, changes which will impact nutrient cycling and carbon storage in complex ways (increased temperature will reduce ecosystem functionality while increased carbon dioxide may mitigate some of these plant impacts). However, species richness is critical for maintaining ecosystem functionality and protection should be a priority.

Implications for forest plan assessment: The EIS needs to assess what is known and not known about observed versus potential plant species richness on the forest, including the degree to which diversity is reduced by seeded and invasive species.

Mazdiyasni O, AghaKouchak A. 2015. Substantial increase in concurrent droughts and heatwaves in the United States. Proceedings of the National Academy of Sciences 112:11484–11489.

Topic: Climate change extremes.

This study found increases in the concurrence of heatwaves and droughts from the 1960-1980 period to the 1990-2010 period. Longer heatwaves have become more frequent in the more recent 1990-2010 period (as compared to shorter heatwaves). In addition, the instances in which there have been more than 30 extreme warm days per year has increased. Heatwaves typically increase energy consumption, lower yields of agricultural production, and intensify wildfires while droughts reduce gross primary productivity and reduce food production, among other impacts. When extreme climate events like heatwaves and droughts co-occur, environmental and societal impacts are amplified.

Implications for forest plan assessment: The EIS needs to assess the trends of increased heat and drought periods within the MLSNF and the implications of this for cumulative stress on vegetation, production on the forest.

McCabe GJ, Wolock DM. 2015. Increasing Northern Hemisphere water deficit. Climatic Change 132:237–249.

Topic: Climate change impacts on precipitation.

The Northern Hemisphere water deficit recently (at around the year 2000) increased dramatically coinciding with a recent increase in temperature and potential evapotranspiration in the same region. Using global climate data, this study modeled this shift in global water balance and found that this substantial change occurred as a result of global warming.

Implications for forest plan assessment: The EIS needs to assess trends in temperature on the MLSNF for the totality of temperature records; and, to discuss these trends in light of global warming science.

Schwinning S, Belnap J, Bowling D, Ehleringer JR. 2008. Sensitivity of the Colorado Plateau to change: climate, ecosystems, and society. Ecology and Society 13:28.

Topic: The sensitivity of Colorado Plateau ecosystems to historical and future climate change and surface-disturbing land uses.

Colorado Plateau ecosystems developed over thousands of years under low and highly variable precipitation conditions and under low disturbance (e.g., "low disturbance frequencies either from grazing or fire in the lower elevation scrublands"). The review article focuses on amplified surface disturbances in this region over the past 150-200 years that alter species composition, "*destroy biological crusts, reduce soil carbon and nitrogen stocks, and increase rates of soil erosion …* ", and reduce resilience to drought conditions.

Management discussed: Examples of how economic investments (private and public) can support overexploitation of the Colorado Plateau. Extractive effort reduces ecological reserves.

Implications for forest plan assessment: The EIS needs to assess the extent of soil disturbance associated with grazing, recreational use, and mining. Any economics discussion needs to be explicit about public and private inputs in relation to resource extraction.

Swetnam TW, Betancourt JL. 1997. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. Journal of Climate 11:3128-3147.

Topic: The effects of climatic variability and related disturbance on terrestrial ecosystems in the Southwest.

Using models of historical climate and future climate projections, the study characterizes climatic variability on seasonal, interannual, and interdecadal scales and links this variability with regional decadal patterns in insect outbreaks, wildfires, and dry and wet period-driven population dynamics (e.g., tree mortality). Climate variability can mask or amplify and compound anthropogenic stresses on terrestrial ecosystems.

Implications for forest plan assessment: The EIS needs to describe future climate projections and their potential interactions with multiple uses on the Manti-La Sal National Forest.

Weltzin JF et al. 2003. Assessing the response of terrestrial ecosystems to potential changes in precipitation. BioScience 53:941-952.

Topic: Climate change impacts on precipitation.

This article evaluates seasonal precipitation projections for the United States through 2090 and reviews literature on the effects of shifting precipitation regimes on terrestrial ecosystems. For example, extreme wet periods will amplify biomass but accumulate fire fuels, increasing the risk of severe wildfires particularly if wet periods are followed by dry periods (e.g., wet winters followed by dry summers). Similarly, increasing variability in precipitation can harm grassland productivity with implications for grassland ecosystems and land uses such as livestock grazing. This article concludes by summarizing research needs and reviewing the existing tools available for monitoring precipitation and understanding terrestrial impacts.

Implications for forest plan assessment: The EIS needs to assemble the best available science regarding climate change projections and their implications for cumulative impacts with grazing and fire.

Climate Change Impacts to Water Resources and Riparian Areas

Barnett TP et al. 2008. Human-induced changes in the hydrology of the western United States. Science 319:1080–3.

Topic: Observed climate change impacts to water in the western United States.

Using global climate and regional hydrologic models, this study reviewed observed changes in the hydrologic cycle of the western United States, including timing of river flow and snowpack, as a means of understanding the most relevant climate change impacts to this water-limited region. Using 1,600 years of data from global climate models, the study evaluated whether observed changes in snowpack, river flow, and regional temperature could be due to natural variability or to anthropogenically-driven changes between 1950 and 1999. Natural variability alone could not explain the decreases in river flow and snowpack. Rather, the majority of the detrimental changes observed in the western United States was found to be a result of human-induced effects (i.e., anthropogenic climate change). Given these findings, ongoing climate change will continue to change hydrologic cycles in the western United States and will include shortages in water availability, increases in spring stream flow, and decreases in summer stream flow.

Implications for forest plan assessment: The EIS needs to assess records of snowpack amount and timing of snowmelt as well as spring and summer flows of streams. The EIS needs to assess the degree to which MLSNF snowpack and seasonal water flow changes appear to be consonant with the patterns noted in Barnett, et al. (2008) and other research.

Capon, S. J., L. E. Chambers, R. MacNally, R. J. Naiman, P. Davies, N. Marshall, J. Pittock, M. Reid, T. Capon, M. Douglas, J. Catford, D. S. Baldwin, M. Stewardson, J. Roberts, M. Parsons, and S. E. Williams. 2013. Riparian ecosystems in the 21st century: hotspots for climate change adaptation? Ecosystems 16:359–381.

Topic: Climate change impacts to riparian ecosystems.

This article is a synthesis of the literature relevant to climate vulnerability of riparian ecosystems across the globe. Riparian ecosystems are considered to be particularly vulnerable due to high levels of exposure and sensitivity to climate change (e.g., rapid and direct responses to increasing water temperatures and changing precipitation patterns) and low levels of capacity to adapt because of other stressors (e.g., degradation due to intense human activity). Riparian ecosystems are important ecologically and for humans, particularly in the context of climate change, and provide a substantial amount of ecosystem services (e.g., biodiversity hotspots, climate refugia) that is disproportionate to their relatively small surface area.

Management discussed: Management can be adapted to address non-climate threats (e.g., pollution control, flow restoration, riparian fencing) to decrease the sensitivity of riparian areas to disturbance.

Implications for forest plan assessment: The EIS needs to describe the condition of riparian ecosystems, including springs, on the MLSNF in light of expected climate change impacts (e.g., higher temperatures, reduced snowpack, increased drought) such as: what proportion of springs are free of livestock impacts; what proportion of riparian exclosure fences are maintained; what proportion of springs have experienced dewatering, etc.

Cates RG, Zou J, Wooley SG, Singer FJ, Mack LC, Zeigenfuss L. 1999. Predisposition of willows to elk browsing due to willow interactions with abiotic factors. Pages 191–195. USDA Forest Service Proceedings RMRS-P-11.

Topic: Cumulative impacts of ungulate grazing and climate change on willow.

Substantial willow declines over a recent 60-year period in Yellowstone National Park (Wyoming) have been hypothesized to be due to a variety of factors, including increased elk populations and subsequently increased browsing pressure, changes in climate and hydrology (e.g., reduced precipitation), and/or declines in native beaver resulting in changed water dynamics (e.g., shifting stream flows). Using chemical analyses of willow shoots (i.e., detecting chemical changes in response to browsing) and a literature review of climate, hydrological, and beaver influences on willow, this paper summarizes the possible causes of recent willow declines. It concludes that browse is not the only factor in willow declines, and that literature documenting the impact of unfavorable growing conditions indicate that the trend toward aridity, lowered water tables, reduced stream flow, lack of flooding, and absence of beaver also contribute to willow declines.

> **Implications for forest plan assessment:** The EIS needs to use both on-the-ground data on browsing of willow and scientific research to estimate the cumulative impacts of climate change, ungulate grazing, and current status of beaver on MLSNF willow.

Cayan, D. R., T. Das, D. W. Pierce, T. P. Barnett, M. Tyree, and A. Gershunov. 2010. Future dryness in the southwest US and the hydrology of the early 21st century drought. Proceedings of the National Academy of Sciences of the United States of America 107:21271–6.

Topic: Climate projections and related impacts for the Southwest.

This study evaluated temperature and precipitation projections for the Southwest, including the Colorado River Basin, to model the probability of drought behavior for the remainder of the 21st century. Drought activity is projected to increase over the remainder of the century, including drier soils and warmer summer temperature. However, this drier trend is not uniform across the Southwest and areas like the Colorado River Basin may experience harsher droughts compared to other areas of the Southwest. As recent drought has already affected water availability in the region, ongoing drought further challenges the sustainability of water uses into the future.

Implications for forest plan assessment: The EIS needs to assess the consequences of drought combined with higher temperatures, and reduced snowpack for water use within the MLSNF.

Hood GA, Bayley SE. 2008. Beaver (*Castor canadensis*) mitigate the effects of climate on the area of open water in boreal wetlands in western Canada. Biological Conservation 141:556–567.

Topic: Beaver presence protects water resources during drought.

This study evaluated the effects of temperature, precipitation, and beaver on open water areas of wetlands in a forested region of Alberta, Canada (aspen, poplar, birch, black and white spruce canopies). The study evaluated aerial photos, climate data, and beaver population data for twelve separate blocks of time between 1948-2002. The study found beaver presence explained 80% of open water during the study period. During both wet and dry years, beaver presence was also found to be associated with a 9-fold increase in open water as compared to when beaver were absent from the same sites. This study suggests that removal of beaver from aquatic systems is a significant wetland disturbance equivalent to others such as groundwater withdrawal or in-filling.

Management discussed: Beaver presence should be protected as this species represents natural approaches to wetland restoration, drought impact mitigation, and climate change adaptation.

Implications for forest plan assessment: The EIS needs to assess currently occupied and potential future beaver habitat sites on MLSNF as well as the potential for wetland conservation.

Meixner T et al. 2016. Implications of projected climate change for groundwater recharge in the western United States. Journal of Hydrology 534:124–138.

Topic: Climate change impacts on groundwater recharge.

This study evaluated changes in recharge mechanisms and total recharge for eight representative aquifers across the western United States. The study described its climate change impact findings as "wet gets wetter and dry gets drier" scenarios. The study estimated either no change or average declines of 10-20% for total recharge across southern aquifers due to increasing temperatures and decreasing precipitation. For northern aquifers, the study estimated little charge to slight increases in total recharge for northern aquifers as climate change will bring increases in the intensity of precipitation events. Although the study identified knowledge gaps that limit the certainty of some of these estimates, they also concluded that climate change will also decrease snowpack across much of the western United States and cause an overall decline in mountain system recharge.

Implications for forest plan assessment: The EIS needs to assess all MLSNF data and trends regarding snowpack, springs, and wetlands and relate these data to regional and national projections for climate change impacts on snowpack, springs, and wetlands.

National Wildlife Federation. 2015. Wildlife in Hot Water: America's Waterways and Climate Change.

Topic: Climate change impacts to water resources and wildlife.

This report, based on a science literature review, outlines the climate change impacts to water resources and wildlife, including aquatic and riparian habitats in headwater streams, rivers, lakes, prairie potholes, coastal wetlands and estuaries, and oceans. Headwater streams, which comprise about 60% of the nation's stream miles, will experience shifts in flow and temperature due to loss of snowpack and earlier snow melt associated with climate change. Warming temperatures impact the amount of dissolved oxygen in water which, in turn, impacts native fish and other riparian fauna, including trout which thrive in cold, oxygen-rich water. By the end of the century, up to 50% of the habitat for cold water native fish species is expected to be lost. Freshwater resources provided by rivers are also anticipated to decline, threatening already water-limited communities across the West. More frequent and more extreme weather events such as floods, droughts, and wildfires are also projected to increase and dramatically alter existing wildlife habitat. During drought, some water resources may dry up, while intense flood and wildfire events can encourage erosion in riparian areas. Specifically for lakes, there is an increased threat for carbon pollution and algal blooms. As temperatures warm lake ice cover is lessening, and there is greater evaporation and lower water levels as climate change continues.

Management discussed: This report encourages that the public and land managers mitigate climate change by reducing fossil fuel use, leverage the Clean Air and Water Acts to reduce source pollution, improve energy efficiency and widespread use of wildlife-friendly energy resources, and continue to protect wildlife and wildlife habitat from climate change.

Implications for forest plan assessment: The EIS needs to link fossil fuel production from the MLSNF with contributions to state, national, and global greenhouse gas emissions and to assess those wildlife (e.g., cold water fish) most vulnerable to habitat loss by drought, flooding, and temperature increases.

Nusslé S, Matthews KR, Carlson SM. 2015. Mediating water temperature increases due to livestock and global change in high elevation meadow streams of the Golden Trout Wilderness. PLOS ONE 10:1–22.

Topic: Livestock grazing is cumulative with climate change impacts on riparian ecosystems in montane meadows.

This study evaluated the impact of livestock grazing on neighboring stream ecosystems in montane meadows of California's Inyo National Forest. The study found that livestock exclosures promoted riverbank vegetation compared to grazed areas that had less dense and less vegetation cover. Water temperatures were found to be cooler in ungrazed areas than grazed areas, and projected temperatures under different climate change scenarios were likely to be higher in the presence of livestock. The study concluded that livestock grazing can exacerbate the impacts of warming temperatures, including degradation of riparian vegetation (including willows), reducing stream shade cover, and influencing stream temperatures in favor of warmer stream habitats which adversely impact cold water-adapted fish species.

Implications for forest plan assessment: The EIS needs to assess climate change impacts to riparian areas and compare cumulative impacts with and without livestock grazing.

Steward AL, Von Schiller D, Tockner K, Marshall JC, Bunn SE. 2012. When the river runs dry: human and ecological values of dry riverbeds. Frontiers in Ecology and the Environment 10:202–209.

Topic: Dry river and streambed ecosystems provide unique human and ecological values.

Temporarily dry river and streambeds are elements of river systems that are common to every continent. Most river and stream systems have beds that can remain dry for days to years at a time and have important human and ecological values, including unique biodiversity, specialized refugia for some species, landscape connectivity for terrestrial species, and regions of organic matter and nutrient processing. Dry river and stream beds may increase with ongoing climate change, but may also be impacted by land uses such as livestock grazing and water diversion. Protection of these landscapes from disturbances like overgrazing, weed infestation, and human impacts is important for preserving the unique human and ecological values of these systems into the future.

Implications for forest plan assessment: The EIS needs to assess the proportion of ephemeral streambeds in the MLSNF and the capability of these to support biodiversity, refugia, and wildlife connectivity (e.g., riparian willows [*Salix* spp.]).

Climate Change Impacts to Forests

Allen CD et al. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management 259:660–684.

Topic: Climate-induced tree mortality.

This paper provides a broad array of case studies of recent climate-induced tree mortality (i.e., due to drought and heat stress) across the globe. Specific to the western North American region, drought and warmth in the last decade have contributed to extensive insect outbreaks and mortality. For example, higher temperatures have been linked with a 3.9-fold increase in annual mortality rate (1955-2007) across all western forest types in the western North American region. With higher temperatures and more intense droughts anticipated as part of climate change, the chronic forest stress and mortality risk indicated here is anticipated to increase globally.

Implications for forest plan assessment: The EIS needs to assess which MLSNF tree species are most vulnerable to mortality due to drought and temperature increases.

Breshears DD et al. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences of the United States of America 102:15144–15148.

Topic: Climate-induced pinyon pine mortality.

This study evaluated the impacts of drought on the extensive and rapid pinyon pine (*Pinus edulis*) mortality across the Southwest from 2000-2003. The study used monthly precipitation and temperature data from southwestern meteorological stations and correlated it with a vegetation greenness index. It found that anomalously high temperatures coupled with regional drought was a driver of mortality and compounded the impacts of bark beetle outbreaks. Ongoing drought will likely further increase pinyon pine mortality across the region. (Emphasis added.)

Management discussed: Pinyon pine die-off will need to be considered in management decisions over the next several decades, i.e., the shortest interval required for a *P. edulis*-dominated overstory structure to reestablish. This is relevant to current vegetation treatments that remove pinyon along with juniper.

Implications for forest plan assessment: The EIS needs to assess past climate-driven losses of pinyon pine on the MLSNF as well as future losses of this species due to increasing drought.

Brown RT, Agee JK, Franklin JF. 2004. Forest restoration and fire: principles in the context of place. Conservation Biology 18:903–912.

Topic: Place-based forest restoration.

Management discussed: Forest restoration actions are needed to remedy historical fire exclusion, intense livestock grazing, extensive road networks, and selective logging practices of the late nineteenth century which have degraded forest ecosystems. This article reviews the approaches of thinning and prescribed burning in the restoration of low-, mid-, and high-severity fire forest types. It prioritizes the lowest fire severity forest types (e.g., dry pine and mixed conifer forest types) above others on the restoration list as they can easily transition to high severity fire locations, can be impacted substantially by high severity fire, and offer readily accessible opportunities for forest restoration (e.g., strategic thinning combined with prescribed burning) to support wildlife habitat and high severity fire resilience. It emphasizes the need for site-specific applications of minimal-impact thinning and prescribed burning, a diverse toolset rather than a single-treatment approach, and a commitment to long-term monitoring and adaptive management.

Implications for forest plan assessment: The EIS needs to map fire severity risk and fire history across the MLSNF, including an identification of lowest fire severity forest types.

Dale VH et al. 2001. Climate change and forest disturbances. BioScience 51:723.

Topic: Climate change impacts to forest structure, composition, and function in the United States.

This study is a meta-analysis of case studies of climate change impacts documented in various forests across the nation. The article hones in on eight types of disturbance regimes that are present for United States forests: fire, drought, insect and pathogen outbreaks, introduced species, hurricanes, windstorms, ice storms, and landslides.

Implications for forest plan assessment: The EIS needs to assess which types of disturbance regimes are most prevalent across the MLSNF. For instance, non-native species (e.g., dandelion

[*Taraxacum officinale*], Kentucky bluegrass [*Poa pratensis*], orchard grass [*Dactylis glomerata*]) are the most common understory species in aspen stands.

Hoglander C. 2014. Changes in Vegetation Productivity for Three National Forests in Utah, 1986-2011: Dixie, Fishlake, and Manti-La Sal National Forests. Grand Canyon Trust. Unpublished Document. Available from www.grandcanyontrust.org/sites/default/files/ANALYSIS_PAPER_UT3FNDVI_15FEB2016_Final.pdf.

Topic: Changes 1986-2011 in vegetation productivity on Manti-La Sal NF, Dixie, and Fishlake National Forests.

Using remotely-sensed vegetation greenness data (LANDSAT Normalized Difference Vegetation Index) for three Utah National Forests – Dixie, Fishlake, and Manti-La Sal – this study found an overall decline in vegetation productivity from 1986-2011. In addition, all vegetation types across the three national forests showed an average negative value for change in vegetation productivity.

Management discussed: Reduced average vegetation productivity is a red flag for ecosystem health and affects forage resources for wildlife and livestock. This study suggests that the landscape may not be able to sustain disturbances such as intense livestock grazing.

Implications for forest plan assessment: The EIS needs to discuss all data available on MLSNF regarding trends in vegetation production.

McDowell NG et al. 2015. Multi-scale predictions of massive conifer mortality due to chronic temperature rise. Nature Climate Change 6:295–300.

Topic: Climate change impacts to Southwest evergreen trees.

Mortality of evergreen trees in the Southwest is projected to be widespread through 2100 as the climate continues to change (i.e., warming temperatures, increased aridity). This study corroborated its climate change impact model projections using experimental field studies on pinyon pine (*Pinus edulis*) and juniper (*Juniperus monosperma*) trees in New Mexico (2007-2012). These studies concluded that changes in pre-dawn water potential affected canopy-scale stomatal conductance and therefore regulation of carbon and water balance.

Implications for forest plan assessment: The EIS needs to assess what is known and projected about the relationship between warming temperatures, increasing aridity, and tree mortality within the MLSNF.

Mork LA. 2010. Livestock Grazing After Wildfire: Understory Response, Current Management, and Implications for Conservation of Southwestern Forests. Thesis. School of Earth Sciences and Environmental Sustainability, Northern Arizona University.

Topic: Interactions between livestock grazing and post-fire vegetation conditions.

This Master's thesis evaluated the practice of re-introducing livestock grazing to a burned area two years post-fire. Using paired treatment and control sites within a before-after-control-impact experimental design, enclosures with grazing treatments averaging 40% utilization, and modified Whittaker plot sampling, the science chapter of the thesis looked at vegetation cover and biomass and soil bulk density as indicators of vegetation condition. Community composition and (species) relative abundance was not found to be significantly different one growing season after grazing but grass cover was found to be significantly reduced, suggesting the potential for long-term effects, even after one season of low-moderate grazing.

Implications for forest plan assessment: In light of projected increases in severe fires with climate change, the EIS needs to assess the implications of studies that indicate reduced grass cover with post-fire grazing compared to no grazing (this thesis references several such studies).

van Mantgen PJ et al. 2009. Widespread Increase of Tree Mortality Rates in the Western United States. Science 323:521–524.

Topic: Warming temperatures drive increases in conifer tree mortality rates.

This study found that regional warming (and related drought stress) was the dominant contributor to the increases in conifer tree mortality rates across the western United States. The study analyzed data on environmental conditions and old (>200 year old) forest demography and found that mortality rates increased while recruitment rates remained relatively unchanged. For the majority of the study (1970s to 2006), the mean annual temperature increased by 0.3-0.4°C per decade. Ongoing warming in the western United States with climate change therefore brings substantial changes in forest structure, composition, and function, and, in some case, abrupt dieback in some forest types.

Implications for forest plan assessment: The EIS needs to assess tree mortality rates in the MLSNF over time and indicate those forest types most vulnerable to drought-related mortality.

Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313:940–3.

Topic: Drivers of the recent increases in wildfire in the western United States.

The study evaluated data on large (>400 ha) wildfires in the western United States from 1970-2003 in combination with data on hydroclimatic and land surface variables. The study found that fire frequency and the length of the fire season increased substantially in the mid-1980s, especially in mid-elevation forests. This notable increase was found to be primarily driven by warmer springs, longer summer dry periods, drier vegetation, reduced winter precipitation, and earlier spring snowmelt during the study period. While land use history did indeed impact forest fire disturbance regimes, climatic drivers played a larger role in the recent increase of wildfire activity.

Implications for forest plan assessment: The EIS needs to present observed trends over time for length of fire season, acres burned for all forest types, length of summer dry periods, winter snowpack and precipitation, and timing of spring snowmelt for all of southern Utah's national forests, including the MLSNF.

Williams AP, Allen CD, Millar CI, Swetnam TW, Michaelsen J, Still CJ, Leavitt SW. 2010. Forest responses to increasing aridity and warmth in the southwestern United States. Proceedings of the National Academy of Sciences of the United States of America 107:21289–94.

Topic: Southwestern forests are projected to have reduced growth and increased mortality.

This study presents a model linking forest and climatic conditions that was applied to 21st century projections associated with climate change in southwestern (Arizonan, New Mexican) forests. Driven by increases in temperature and aridity anticipated for the remainder of the century, southwestern forests are projected to have reduced growth and increased mortality. Specifically, ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menzeisii*) trees were found to be more sensitive to drought and warming temperatures in already arid areas while pinyon pine (*Pinus edulis*) trees were found to be sensitive across the full study extent. Researchers emphasize that as warming continues with climate change, forest productivity, disturbance regimes (e.g., wildfire), and species ranges will be altered.

Management discussed: Opportunities for building forest resilience to climate change impacts include promotion of stand diversity, genetic adaptation through selective survival, and retention of forests rather than conversion to scrublands or grasslands.

Implications for forest plan assessment: The EIS needs to assess the extent of ponderosa pine, Douglas fir, and pinyon pine trees on the MLSNF and discuss potential reductions in growth and increases in mortality as projected by climate models for southern Utah.

Aspen

Brodie J, Post E, Watson F, Berger J. 2012. Climate change intensification of herbivore impacts on tree recruitment. Proceedings of the Royal Society B: Biological Sciences 279:1366–1370.

Topic: Cumulative effects of ungulate grazing on climate change impacts to aspen.

This study evaluated the interactions of elk (*Cervus elaphus*) habitat selection and foraging with winter snowpack and how these interacting factors affect the recruitment of aspen (*Populus tremuloides*) in Yellowstone National Park, Wyoming. The study used indicators of snowpack depth and density along with elk detections by camera traps. As thick snowpack physically limits elk browse on aspen, the long-term decline of snowpack in the study area was found to contribute to increased elk-to-aspen access and subsequently the reduction of aspen recruitment.

Implications for forest plan assessment: In consultation with the Utah Division of Wildlife Resources, the MLSNF needs to map and track elk winter use areas within aspen communities, which may be subject to extended winter accessibility and therefore increased aspen browse and limited aspen recruitment.

Martin TE, Maron JL. 2012. Climate impacts on bird and plant communities from altered animal–plant interactions. Nature Climate Change 2:195–200.

Topic: Climate change impacts on bird and plant communities.

Using 22 years (1985-2010) of field data and paired control and exclosure plots in Arizona, this study found that aspen (*Populus tremuloides*) abundance and associated songbird abundance have declined as a result of decreasing snowfall. Declines in snowfall allow for greater winter herbivory by elk (*Cervus elaphus*), which are otherwise limited from browse by snowpack during portions of the winter period. Through this indirect effect, habitat quality for songbirds was substantially diminished and therefore affected songbird recruitment. Loss of snowpack with ongoing climate change threatens to continue this trend of reduced songbird habitat quality and subsequent population impacts.

Implications for forest plan assessment: The EIS needs to project snowpack and songbird trends within the MLSNF.

Rehfeldt, GE, DE Ferguson, and NL Crookston. 2009. Aspen, climate, and sudden decline in Western USA. Forest Ecology and Management 258 (11): 2353–64.

Topic: Sudden aspen decline in the western United States.

Models of aspen (*Populus tremuloides*) distribution identified that the primary predictor of aspen presence in the western United States is the annual dryness index (a ratio of growing degree days to annual precipitation). The area occupied by the current aspen climate profile is projected to move upwards in elevation and decline substantially by the end of the century.

Implications for forest plan assessment: The EIS needs to discuss recent (as many years back as possible) dryness-driven sudden aspen decline in the MLSNF and consider how projected aridity will further impact aspen on the MLSNF.

Seager ST, Eisenberg C, St. Clair SB. 2013. Patterns and consequences of ungulate herbivory on aspen in western North America. Forest Ecology and Management 299:81–90.

Topic: Ungulate herbivory compounds other environmental impacts to aspen.

This literature review assesses the impacts of ungulate browsing on aspen (*Populus tremuloides*) recruitment and understory. Heavy browsing can remove shrubs, understory structure, and ground litter, all of which greatly decreases wildlife presence and diversity. Chronic herbivory can decrease native plant species and increase the potential for plant invasion. Increased snow-free forest seasons leads to increased ungulate herbivory of aspen stands.

Management discussed: "Ungulate herbivory is more heterogeneous with human hunters, wolves, or fire on the landscape." The authors recommend management approaches that include disturbance (e.g., fire) and predation on ungulates to increase aspen resilience. In addition, exclosures and seeding genetically diverse aspen stands can also improve aspen resilience to current and future environmental changes.

Implications for forest plan assessment: Aspen utilization by ungulates and aspen demographics (regeneration and recruitment) vary across the MLSNF, but herbivory and a lack of recruitment are highest where wild ungulate herds concentrate. The EIS needs to map the aspen areas of the MLSNF that are most vulnerable to ungulate herbivory due to wild ungulate patterns of use, e.g. on low gradient slopes.

Worrall, JJ, GE Rehfeldt, A Hamann, EH Hogg, SB Marchetti, M Michaelian, and LK Gray. 2013. Recent declines of *Populus tremuloides* in North America linked to climate. Forest Ecology and Management 299:35–51.

Topic: Influences on the distribution of aspen.

While climate, moisture stress, and insect defoliation contribute to aspen (*Populus tremuloides*) decline, exceptional droughts are a primary factor in aspen decline, particularly in already arid regions, highlighting a sensitivity to drought for aspen across much of its range.

Implications for forest plan assessment: The EIS needs to map areas of observed and projected exceptional drought in MLSNF over the last decades; and instances of aspen dieback.

Pinyon Pine

Barger NN, Adams HD, Woodhouse C, Neff JC, Asner GP. 2009. Influence of livestock Grazing and climate on pinyon pine (*Pinus edulis*) dynamics. Rangeland Ecology & Management 62:531–539.

Topic: Influence of livestock grazing and climate on pinyon pine recruitment and growth.

In well-established (> 200-year) pinyon-juniper woodlands in the Southwest the study found that pinyon pine (*Pinus edulis*) growth was positively correlated with winter/spring precipitation and negatively correlated with June temperatures, and that pinyon pine density and basal area were relatively similar across grazed and ungrazed sites over the last century. The study concluded that past climate may be a more important influence on pinyon pine population dynamics than historic land uses, and that prolonged drought coupled with slow regeneration times can result in substantial pinyon pine declines across the region.

Management discussed: The authors suggests that as "… anthropogenic changes in grazing and fire regimes have not played a significant role in structuring pinyon-juniper populations over the last century … the call to restore mature, persistent pinyon-juniper woodland to a more historic condition using mechanical methods and prescribed fire must be closely scrutinized."

Implications for forest plan assessment: The EIS needs to map aspen woodlands as distinct from areas in which pinyon pine establishment is recent, and indicate those areas/elevations projected to be most vulnerable to drought.

Barger NN, Woodhouse C. 2015. Piñon pine (*Pinus edulis* Engelm.) growth responses to climate and substrate in southern Utah, U.S.A. Plant Ecology 216:913–923.

Topic: Influence of geologic substrate and water availability on pinyon pine growth.

This study evaluated the growth response of pinyon pines in the western United States to climate over the last century to identify whether these growth responses could be explained by site specific characteristics such as geologic substrate (e.g., shale, sandstone). Using cluster analysis of tree ring widths of pinyon pines in Grand Staircase-Escalante National Monument (Utah), the study observed pinyon pine growth declines in trees highly sensitive to summer temperature – i.e., with soils that had low available water capacity – compared to trees that were less sensitive and showed no change in growth. The study identified areas where the soil available water capacity will likely correspond to declines in pinyon pine growth with increasing summer temperatures.

Implications for forest plan assessment: The EIS needs to map those MLSNF soil areas where available water capacity may limit pinyon pine growth, especially in the context of increasing summer temperatures.

Redmond MD, Forcella F, Barger NN. 2012. Declines in pinyon pine cone production associated with regional warming. Ecosphere 3:1–14.

Topic: Climate change impacts to pinyon pine cone production and reproduction.

This study evaluated pinyon pine (*Pinus edulis*) cone production at long-term monitoring sites in New Mexico and Oklahoma to understand the impacts of regional climate change on pinyon pine reproduction. The study found substantial declines in cone production from the 1969-1978 analysis period to the 2003-2012 analysis period. These declines were the largest in the areas with the greatest increases in growing season temperatures, indicating that regional warming contributed to declines in cone production. This study concluded that longer-term temperature shifts associated with advancing climate change represents a notable stress for pinyon pine cone production, regeneration, and overall population dynamics.

Implications for forest plan assessment: The EIS needs to assess observed and projected growing season temperature trends on the MLSNF and/or in the southern Utah region, and map the distribution of pinyon pine including recently and currently occupied areas.

Ecological Community Shifts

Plant Species

Krause CM, Cobb NS, Pennington DD. 2015. Range shifts under future scenarios of climate change: dispersal ability matters for Colorado Plateau endemic plants. Natural Areas Journal 35:428–438.

Topic: Projected shifts in species distribution in response to climate change.

This study evaluated the change in distribution of 239 plant species endemic to the Colorado Plateau as a result of two climate change scenarios (driest A1B scenario and wettest B1 scenario, representing the two extremes of climate change projections) for 30-year increments across the remainder of this century (i.e., until 2099). Specifically, the study sought to evaluate

(1) the impact of climate change on the location of suitable habitat for plants endemic to the Colorado Plateau, (2) the extent to which dispersal ability (or lack thereof) affects adaptive capacity, and (3) the potential for management actions to mitigate negative outcomes. The study projected that plants endemic to the Colorado Plateau will lose current suitable habitat and have the potential to experience range collapse and dislocation from climate change impacts. With limited dispersal capability these impacts could be more severe, but could be mitigated with management actions such as relocation.

Implications for forest plan assessment: The EIS needs to list all MLSNF native species that are endemic to (a) MLSNF and (b) the Colorado Plateau. Habitat for these species need to be described, because they should all be considered species of conservation concern – whether "Species of Conservation Concern" or not.

Munson SM, Belnap J, Schelz CD, Moran M, Carolin TW. 2011. On the brink of change: plant responses to climate on the Colorado Plateau. Ecosphere 2:1-15.

Topic: Warming temperatures reduce grass cover and increase shrub cover.

Plant species and functional types across a wide range of environmental conditions have shifted in response to climate variability (i.e., temperature and precipitation variability) over a twenty-year period (1989-2008) in Arches, Canyonlands, and Natural Bridges National Parks in Utah. Analysis of these long-term monitoring data from these permanent plots demonstrated an overall loss of grass cover and a general increase in shrub cover. For perennial grasslands, there was an overall decline in C3 perennial grass cover but no change in C4 perennial grass cover. Woodland shrub canopy cover increased in areas with already high initial cover, although *Atriplex* shrub species (e.g., four-wing saltbush [*Atriplex canescens*]) declined. The study found that species were most sensitive to higher temperatures in the late spring and summer when water stress was driven by evapotranspiration. These results imply that ongoing warming temperatures bring loss of forage and habitat for livestock and wildlife.

Implications for forest plan assessment: The EIS needs to assess all data for C3 grass demographics and conditions inside and outside of exclosures/reference areas, including long-term trend transects. Perennial C3 grasses are less tolerant to drought and the EIS needs to discuss the potential for loss of grass cover and the transition of native grasslands to shrub-dominated ecosystems.

Munson SM, Duniway MC, Johanson JK. 2015. Rangeland monitoring reveals long-term plant responses to precipitation and grazing at the landscape scale 69:76–83.

Topic: Species responses to climate and land-use shifts.

This study leverages forty-six years of monitoring data to understand the responses of various plant species to cool-season precipitation, land type categorizations (based on soil and ecological community types), and livestock grazing intensity on the Colorado Plateau. The study found that cool-season precipitation was more important than warm-season precipitation for C4 perennial grass (e.g., needle-and-thread [*Hesperostipa comata*] and ricegrass [*Achnatherum hymenoides*]) growth. Heavy grazing (i.e., >60% utilization) reduced the C3 perennial grass response to cool-season precipitation in most ecological communities. The study demonstrates the importance of long-term monitoring, and the value of accounting for land types in understanding plant responses to climate and land uses.

Management discussed: Livestock grazing intensity should be reduced during prolonged drought periods which stress C3 perennial grasses. Long-term monitoring should be employed to understand the trends of C3 grasses.

Implications for forest plan assessment: The EIS needs to map all long-term trend monitoring sites to help understand ecological responses to land uses and shifting precipitation regimes.

Reeves MC, Moreno AL, Bagne KE, Running SW. 2014. Estimating climate change effects on net primary production of rangelands in the United States. Climatic Change 126:429–442.

Topic: Projected changes in vegetation productivity for the western United States.
The study leveraged vegetation data (including species composition) and climate projection data to understand the spatial and temporal patterns of changes in net primary productivity (NPP). The study found that projected changes in NPP were not uniform across the western United States through 2100. NPP was found to increase for northern and central regions of the western United States, particularly at higher elevations, but to decrease across the southwestern United States. Temperature was found to drive changes more in the northern regions while precipitation was found to drive changes more in the southern regions.

Implications for forest plan assessment: The EIS needs to describe projected reductions in NPP on MLSNF, as well as observed downward trends in production on the MLSNF (see Hoglander [2016] reference above).

Rehfeldt GE, Crookston NL, Warwell M V., Evans JS. 2006. Empirical analyses of plant-climate relationships for the western United States. International Journal of Plant Sciences 167:1123–1150.

Topic: Projected climate-driven shifts in species distribution across the western United States.

This study modeled climate profiles for 25 biotic communities in the western United States as a foundation for understanding distribution shifts anticipated with ongoing climate change. The study also produced species-specific models and found that Gambel oak (*Quercus gambelii*) will likely increase the area it occupies by the end of the century, Douglas fir (*Pseudostuga menziesii*) should hold constant, and western larch (*Larix occidentalis*), pinyon pine (*Pinus edulis*), Engelmann spruce (*Picea engelmannii*), and juniper (*Juniperus osteosperma*) will likely decrease by the end of the century.

Implications for forest plan assessment: The projected reduction in pinyon pine, Engelmann spruce, and juniper by the end of the century needs to be discussed in the EIS.

Schwinning S, Starr BI, Ehleringer JR. 2005. Summer and winter drought in a cold desert ecosystem (Colorado Plateau) part I: effects on soil water and plant water uptake. Journal of Arid Environments 60:547–566.

Topic: Effects of drought on native plant species on the Colorado Plateau.

This study looked at the effects of winter and summer drought on the Colorado Plateau for three species, each with distinct root distributions: Indian ricegrass (*Oryzopsis* [*Achnatherum*] *hymenoides*), snakeweed (*Gutierrezia sarothrae*), and winterfat (*Ceratoides lanata*). The study found that summer drought conditions affected all three species similarly as it depleted soil moisture in both shallow and deeper soil layers. For winter drought, the study found that Indian ricegrass was more sensitive while winterfat was least sensitive. The study hypothesized that differences in seasonal drought responses were likely due to springtime shifts in root development and structure. This study complements the other Schwinning et al. (2005) study in this section.

Implications for forest plan assessment: The EIS needs to provide an assessment of status of Indian ricegrass throughout MLSNF, as it is an important C3 native, perennial grass vulnerable to drought.

Schwinning S, Starr BI, Ehleringer JR. 2005. Summer and winter drought in a cold desert ecosystem (Colorado Plateau) part II: effects on plant carbon assimilation and growth. Journal of Arid Environments 61:61–78.

Topic: Effects of drought on native plant species on the Colorado Plateau.

This study complements the above Schwinning et al. (2005) study in this section and looked at the effects of winter and summer drought on the Colorado Plateau for three species, each with distinct root distributions: Indian ricegrass (*Oryzopsis* [*Achnatherum*] *hymenoides*)], snakeweed (*Gutierrezia sarothrae*), and winterfat (*Ceratoides lanata*). The study focused on leaf photosynthesis effects and analysis of leaf carbon and nitrogen, and concluded that winter drought rather than summer drought was a primary driver of reduced plant growth during the study period.

Implications for forest plan assessment: The EIS should examine MLSNF trends over the last decades of both winter and summer drought.

Whitcomb HL. 2011. Temperature Increase Effects on Sagebrush Ecosystem Forbs: Experimental Evidence and Range Manager Perspectives. Thesis. Utah State University.

Topic: Climate change impacts to sagebrush ecosystems.

This Master's thesis evaluates the effect of increased temperature on native and non-native forb species that are common to sagebrush ecosystems in the western United States. It also evaluated land manager perspectives on ecosystem change in the western United States. The study found that increased temperature has the potential to increase the competition between native and non-native forbs in sagebrush ecosystems. In addition, it found some forb species (e.g., *Sphaeralcea munroana*, *Linum lewisii*, and *Penstemon palmeri*) may be more resistant to a warming climate than others (e.g., *Crepis acuminata* and *Oenothera pallida*). The study found that land managers basing management decisions on recent weather patterns were more likely to not detect a climate-driven change whereas land managers that based management decisions on longer-term patterns were more likely to detect a climate-driven change.

Management discussed: The thesis concluded with recommendations for outreach and communications to land managers with respect to local climate and change, as well as forb vulnerabilities and related conservation approaches.

Implications for forest plan assessment: The MLSNF needs to discuss the relationship between local climate change and best available science on climate change impacts to native forb species and species diversity (e.g., species- or ecosystem-specific climate vulnerability assessments).

Grasslands and Invasive Annual Grasses

Abatzoglou JT, Kolden CA. 2011. Climate change in western US deserts: potential for increased wildfire and invasive annual grasses. Rangeland Ecology and Management 64:471–478.

Topic: Projected climate change amplifies the invasive annual grass-wildfire positive feedback cycle.

Models of projected climate change were used to assess the frequency of extreme fire danger and the onset of fire season (associated with moisture availability) through the mid-21st century for the deserts of the Western United States. Models demonstrated that projected increases in the freeze-free season have the potential to favor invasive annual grasses (e.g., cheatgrass [*Bromus tectorum*]) and changes in the frequency of wet winters (whether increasing across cold deserts or decreasing across warm deserts) will similarly alter the potential for invasive annual grasses to establish. These projected changes result in an earlier onset of the fire season and a longer window in which conditions are conducive to fire ignition, and, subsequently, will amplify the fire-invasive grasses feedback cycle.

Implications for forest plan assessment: The EIS needs to discuss the length of freeze-free seasons over past decades in southern Utah/MLSNF and its relationship to spread of invasive grasses (e.g., cheatgrass).

Bradley BA, Oppenheimer M, Wilcove DS. 2009. Climate change and plant invasions: restoration opportunities ahead? Global Change Biology 15:1511–1521.

Topic: Climate change impacts on non-native, invasive species are not uniform.

With ongoing climate change, some non-native invasive species distributions may expand while others may contract. This study evaluated bioclimatic envelopes for yellow starthistle (*Centaurea solstitialis*), tamarisk (*Tamarix* spp.), cheatgrass (*Bromus tectorum*), spotted knapweed (*Centaurea biebersteinii*), and leafy spurge (*Euphorbia esula*). The study found that yellow starthistle and tamarisk will likely expand their ranges with ongoing climate change while the distribution of leafy spurge is likely to contract. It also found that cheatgrass and spotted knapweed will likely shift in range, both expanding and contracting in various areas. The study emphasized that such distribution shifts should be monitored by land managers and that native plant re-seeding opportunities could become available in invasive distribution contractions.

Management discussed: Invasive plant distributions should be monitored by managers over the long term to identify distribution shifts to inform management actions, including native plant re-seeding opportunities where invasive plant distributions contract.

Implications for forest plan assessment: The EIS needs to map changes in cheatgrass extent over the past decades on MLSNF.

Bradley BA, Curtis CA, Chambers JC. 2016. Bromus Response to Climate and Projected Changes with Climate Change. Pages 257-274 in United States Forest Service, editor. Exotic Brome-Grasses in Arid and Semiarid Ecosystems of the Western US. Springer Switzerland.

Topic: Projected climate-driven distribution shifts for invasive cheatgrass.

This study reviewed experimental and modeling studies and updated empirical range models of non-native *Bromus* grass species to understand range shifts anticipated with ongoing climate change. The study found that the overall distribution and relative abundance of invasive red brome (*Bromus rubens*) and cheatgrass (*Bromus tectorum*) within their existing ranges are anticipated to shift. Red brome specifically is likely to expand its distribution into areas of the southern Great Basin and Colorado Plateau due to the warmer winters that reduce range constraints associated with cold intolerance.

Implications for forest plan assessment: The EIS needs to map recent (past decades) and projected changes in red brome and cheatgrass distributions on the MLSNF.

Briggs JM, Knapp AK, Blair JM, Heisler JL, Hoch GA, Lett MS, McCarron JK, Carron JKMC. 2005. An ecosystem in transition: causes and consequences of the conversion of mesic grassland to shrubland. BioScience 55:243-254.

Topic: Transition from grasslands to ecosystems co-dominated by grasses and woody plants.

This literature review concludes that multiple pathways for transition between C4-dominated grasslands to savanna-like ecosystems co-dominated by grasses and woody plants are possible in the United States and are driven by changes in climate, heavy livestock grazing, and fire regimes. In contrast, only one pathway, one of frequent fire and the absence of or low intensity grazing, is possible to maintain a mesic grassland system.

Implications for forest plan assessment: The EIS needs to discuss the relationship of grazing to increases in shrubs in mesic grasslands. The EIS needs to map mesic grasslands on MLSNF.

Brookshire ENJ, Weaver T. 2015. Long-term decline in grassland productivity driven by increasing dryness. Nature Communications 6:7148.

Topic: Climate-induced changes in grassland shifts.

This study assessed four decades (1969-2012) of data on grassland production to understand the influences of climate variation and atmospheric changes. Over the study period, increasing aridity was found to be the primary driver in the sustained decline in aboveground net primary productivity for the native C3 grassland within the Greater Yellowstone Ecosystem (Wyoming). In addition, changes in nitrogen deposition and atmospheric carbon dioxide were found to have little influence on the long-term pattern of this productivity. This negative impact of recent climate change on grassland net primary productivity projects further impacts to this ecosystem with ongoing climate change.

Implications for forest plan assessment: The MLSNF needs to review and consider documentation and data regarding recent primary productivity of grasses on the forest (e.g., Hoglander [2016] referenced above).

Gremer JR, Bradford JB, Munson SM, Duniway MC. 2015. Desert grassland responses to climate and soil moisture suggest divergent vulnerabilities across the southwestern United States. Global Change Biology 21:4049–4062.

Topic: Climate variability drives changes in grass cover.

This study models temporal fluctuations in perennial grass cover based on climate and soil properties in the Colorado Plateau, Sonoran Desert, and Chihuahuan Desert regions of the United States over 20-56-year periods. The model demonstrated that climate variables were primary drivers of grass cover and that climate variability negatively impacted grass cover. Soil water metrics were secondarily important in explaining grass cover dynamics, particularly C3 and C4 grass species responses. The study concluded that the current climate and soil conditions that support perennial grasses will likely be altered in the future, particularly on the Colorado Plateau and Chihuahuan Desert regions, suggesting impacts to perennial grass cover in these regions with ongoing climate change.

Implications for forest plan assessment: The EIS needs to discuss the projections of loss of grass cover due to climate change. This is cumulative with ungulate grazing.

Shinneman DJ, Baker WL. 2009. Environmental and climatic variables as potential drivers of post-fire cover of cheatgrass (Bromus tectorum) in seeded and unseeded semiarid ecosystems. International Journal of Wildland Fire 18:191-202.

Topic: Factors influencing post-fire cheatgrass invasion.

This western Colorado study evaluated the factors influencing post-fire invasions by non-native cheatgrass, including ecosystem type (sagebrush [*Artemesia* spp.]-dominated and pinyon-juniper [*Pinus edulis-Juniperus osteosperma*] woodlands), pre-fire cover of annual forbs, time since fire, pre-fire cover of biological soil crust, precipitation the year before fire, and seeding of perennial competitor species by managers post-fire. The study found that lower pre-fire biological soil crust cover, lower native species richness, and high soil carbon facilitated cheatgrass invasion.

Management discussed: The authors recommend "… long-term restoration of biological soil crust and native species diversity cover. Reducing livestock grazing intensity before fire occurs, along with using native-seed mixes in burned areas (e.g., where pre-fire biological soil crust cover was reduced) may provide a more effective strategy for controlling cheatgrass invasion after fire."

Implications for forest plan assessment: The EIS needs to include a review of cheatgrass distribution and projected expansion information, including information on factors that influence the likelihood of invasion: native species diversity, biological soil crust cover, and soil carbon content.

Dust, Erosion, Soils, and Biological Soil Crusts

Alvarez LJ, Epstein HE, Li J, Okin GS. 2012. Aeolian process effects on vegetation communities in an arid grassland ecosystem. Ecology and Evolution 2:809–821.

Topic: Arid grassland changes in response to wind-transported sediment**.**

Using grass removal treatment plots (simulating overgrazing or drought conditions), control plots, and downwind-of-treatment control plots, this southern New Mexico study tested the relationship between arid grassland vegetation changes and aeolian sediment transport. The study found lower seed bank production from soil samples taken in grass removal areas versus control areas; and shrub cover increased significantly in grass removal areas compared to control areas. Downwind of grass removal areas, there was decreased grass cover and increased shrub cover whereas downwind of control areas there was increased grass cover and decreased shrub cover. The study concluded that grass removal from disturbance (e.g., overgrazing or drought) can result in increased shrub cover, increased aeolian flux rates, depletion and redistribution of soil nutrients, and seed bank depletion. (Emphasis added.)

Implications for forest plan assessment: The EIS needs to map areas of excessive bare soil.

Belnap, J., S. L. Phillips, and T. Troxler. 2006. Soil lichen and moss cover and species richness can be highly dynamic: The effects of invasion by the annual exotic grass *Bromus tectorum,* precipitation, and temperature on biological soil crusts in SE Utah. Applied Soil Ecology 63–76.

Topic: Moss and lichen responses to livestock grazing and climatic factors, and subsequent expansions in invasive cheatgrass.

This eight-year study evaluated grass-dominated sites across a range of land use histories to determine the effects of non-native grass dominance, temperature changes, and soil surface disturbance (e.g., from trampling by livestock) on moss and lichen communities in Canyonlands National Park, Utah. The study found that livestock grazing likely contributed to declines in species richness for both mosses and lichens and declines in lichen cover. It also found that invasive cheatgrass (*Bromus tectorum*) cover contributed to reductions in total moss and lichen cover across sites and, in historically grazed areas, also reduced species richness. An increase in monthly maximum temperatures also contributed to a loss of cover for some lichen types that are primary nitrogen-fixers for native grasslands. These results suggested that invasive species, livestock grazing, and climate change were compounding factors that contributed to negative impacts on some lichen and moss species and related native grassland health.

Implications for forest plan assessment: Trampling from livestock grazing, cheatgrass invasion, and warmer temperatures act both individually and cumulatively to reduce lichens (i.e., late-seral biological soil crust). The EIS needs to map cheatgrass presence and assess level of ecosystem invasion (e.g., absent, <25% cover, 26-50% cover, >50% cover) and document trends in temperature. The EIS needs to map suitable habitat for biological soil crusts and describe the degree to which biological soil crusts have or have not been assessed (including for light cyanobacteria) to inform management proposals. The USGS in Moab can guide the MLSNF to the most recent soils mapping for biological soil crust potential.

Belnap J, Reynolds RL, Reheis MC, Phillips SL, Urban FE, Goldstein HL. 2009. Sediment losses and gains across a gradient of livestock grazing and plant invasion in a cool, semi-arid grassland, Colorado Plateau, USA. Aeolian Research 1:27–43.

Topic: Soil disturbance and annual plant invasion influences on sediment flux.

This study evaluated sediment flux across gradients of soil disturbance and annual plant invasion for nine years in two sites in the eastern Utah region of the Colorado Plateau. During drought periods sediment flux increased substantially in areas that were most disturbed (dominated by annual grasses, historically plowed, currently grazed by livestock) compared to areas that were not disturbed (dominated by perennial grasses and biological soil crusts). The study found that biological soil crusts and perennial plant cover were most important in predicting site stability.

Implications for forest plan assessment: Because of its implications for sediment flux (i.e., soil erosion and dust generation), the EIS needs to map suitable habitat for biological soil crusts and indicate any existing biological soil crust data already in hand at the MLSNF. The USGS in Moab can guide the MLSNF to the most recent soils mapping for biological soil crust potential.

Ferrenberg S, Reed SC, Belnap J. 2015. Climate change and physical disturbance cause similar community shifts in biological soil crusts. Proceedings of the National Academy of Sciences 112:12116–12121.

Topic: Cumulative warming, precipitation shift, and trampling impacts on biological soil crusts.

Researchers evaluated the effects of experimentally replicated impacts of warming temperatures, precipitation regime shifts, and disturbance from trampling on biological soil crust communities over a 10-year period (2005-2014) in the Castle Valley, Utah, region of the Colorado Plateau. All three treatments had impacts across the biological soil crust communities, and the climate-driven treatments had similar impacts to the human disturbance-driven treatments. Warming and increased number of precipitation events (frequency shift, but constant total precipitation amount) caused a decrease in lichen cover over time while trampling led to a complete loss of lichen. Lichen mortality was most closely linked with warming while moss mortality was most closely linked with shifting precipitation treatments (simulated more frequent, small volume monsoonal precipitation) and associated carbon starvation.

Implications for forest plan assessment: The MLSNF EIS needs to assess observed and projected warming trends, observed and potential precipitation regime shifts as cumulative impacts of ungulate grazing, ORV use, and other soil disturbances.

Maestre FT et al. 2015. Increasing aridity reduces soil microbial diversity and abundance in global drylands. Proceedings of the National Academy of Sciences of the United States of America 112:15684–15689. Available from http://www.pnas.org/lookup/doi/10.1073/pnas.1516684112.

Topic: Impacts of aridity trends on soil bacteria and fungi.

Soil microbial abundance and diversity are reduced by aridity and a trend toward aridity is anticipated to continue with the amplified aridity related to ongoing climate change. This study utilized 80 field studies from a wide range of climatic, edaphic, and vegetation conditions across the globe. It also evaluated the effect of other variables, including soil pH and plant cover, on soil bacteria and fungi characteristics. While these other variables did have various effects on soil bacteria and fungi, increased aridity reduced the abundance and diversity of both soil bacteria and fungi in drylands on a global scale.

Implications for forest plan assessment: The EIS needs to map the soils on the MLSNF in light of the vulnerability of soil microbial abundance and diversity to soil aridity.

Munson SM, Belnap J, Okin GS. 2011. Responses of wind erosion to climate-induced vegetation changes on the Colorado Plateau. Proceedings of the National Academy of Sciences of the United States of America 108:3854–9.

Topic: Climate-driven changes in plant cover affect dust emission and wind erosion.

This twenty-year study is based on vegetation monitoring data within a wind erosion model from four national parks on the Colorado Plateau that demonstrated how climate changes can indirectly affect dust emission by modifying plant cover. Researchers concluded that perennial grass cover was particularly susceptible to increasing temperature which was found to decline by 8% per 1°C increase in mean annual temperature over the study period. Researchers also found that well-developed biological soil crusts were associated with the prevention of aeolian sediment flux (i.e., windblown dust) as simulated biological soil crust disturbance (e.g., driving over with a vehicle) corresponded with increases in aeolian sediment flux during simulated high-speed wind events and subsequent declines in perennial grass cover.

Implications for forest plan assessment: Because of the implications of loss of biological soil crusts for increases in sediment flux (i.e., soil erosion and dust generation), the EIS needs to map MLSNF soils that are expected to support biological soil crust (USGS in Moab can assist the forest do this).

Climate Adaptation Management and Policy Opportunities

Beschta RL, Donahue DL, Dellasala DA, Rhodes JJ, Karr JR, O'Brien MH, Fleischner TL, Williams CD. 2013. Adapting to climate change on western public lands: Addressing the ecological effects of domestic, wild, and feral ungulates. Environmental Management 51:474–491.

Topic: Ungulate impacts can be cumulative with climate change impacts.

This literature review notes the points of intersection and cumulative effects of climate change impacts with ungulate grazing impacts. For instance, livestock grazing and trampling can impact biological soil crusts which, in turn, protect against wind-driven erosion and dust emission which are exacerbated by drought. Or, ungulate herbivory can impact riparian vegetation which can compound the stresses of increased aridity on riparian ecosystems.

Management discussed: The authors suggest that reduction of livestock grazing and feral ungulates across public lands is a primary means of mitigating the compounding of climate change impacts. See also Svejcar et al. 2014 (a critique of this article) and Beschta et al. 2014 (a response to the Svejcar critique) this section.

- **(Critique of Beschta et al. 2013)**
  Svejcar T et al. 2014. Western land managers will need all available tools for adapting to climate change, including grazing: a critique of Beschta et al. Environmental Management 53:1035–1038.

  Topic: Critique of Beschta, et al. 2013.

  This literature review is a critique of Beschta, et al. 2013 and states that the article lacks consideration of the complexities associated with the range of ungulate impacts, i.e., the influence of management on mitigating livestock grazing impacts. It contends that some studies have demonstrated that, under certain conditions, livestock grazing can minimize fire fuel accumulation and aid in the mitigation of climate change impacts associated with increased wildfire risk.

  Management discussed: The authors suggest that broad scale reduction of domestic and feral ungulates is not needed. See also Beschta et al. 2014 (a response to the Svejcar et al. [2014] critique) this section.

- **(Response to Svejcar et al. 2014)**
  Beschta RL, Donahue DL, DellaSala DA, Rhodes JJ, Karr JR, O'Brien MH, Fleischner TL, Williams CD. 2014. Reducing livestock effects on public lands in the Western United States as the climate changes: a reply to Svejcar et al. Environmental Management 53:1039–1042.

  Topic: A response to the Svejcar et al. 2014 critique of Beschta, et al. 2013.

  This article contends, contrary to Svejcar, et al. (2014), that both historical and current livestock grazing work in concert to alter ecosystems and apply stresses; livestock grazing is not an effective tool for reducing wildfire risk (e.g., it favors cheatgrass and woody invasion); and reduction of livestock grazing is recognized as a primary tool for reducing cumulative impacts. See also Beschta et al. (2013) and Svejcar et al. (2014) this section.

Implications for forest plan assessment: The MLSNF is not exempt from climate change and existing land uses, including livestock grazing, will compound climate change impacts. The EIS needs to review the full suite of scientific literature that can inform livestock management on the forest in the context of climate change. The EIS must consider how livestock numbers, grazing intensities, and timing and duration of livestock grazing can interact cumulatively with climate change impacts.

Briske DD, Joyce LA, Polley HW, Brown JR, Wolter K, Morgan JA, McCarl BA, Bailey DW. 2015. Climate-change adaptation on rangelands: linking regional exposure with diverse adaptive capacity. Frontiers *in Ecology and the Environment 13:249–256.*

Topic: Climate change adaptation opportunities on grazed lands.

Management discussed: Drought management planning, enterprise reorganization, conservative stocking rates, lower grazing intensities, changes in livestock breeds, and management of invasive species.

Implications for forest plan assessment: The EIS needs to assess the potential impacts of climate change on grazed lands and grazing operations.

Joyce LA, Blate GM, McNulty SG, Millar CI, Moser S, Neilson RP, Peterson DL. 2009. Managing for multiple resources under climate change: National forests. Environmental Management 44:1022–1032.

Topic: Climate adaptation in national forests.

Management discussed: This paper advocates for the consideration of climate change impacts and adaptation actions across all levels of policy making and planning within the Forest Service (i.e., at national, regional, and forest levels). In addition to the standard forest or project planning process, the steps to consider climate change are: (1) evaluate vulnerabilities under changing conditions, (2) identify suitable adaptive actions that can be taken within the immediate to short term, and (3) identify suitable climate adaptation actions that can be taken in the longer term. This planning should be implemented within an adaptive management framework that can allow for objectives and approaches to be adjusted as the local effects of climate change become apparent. These approaches should focus on: reducing existing stresses (e.g., invasive species mitigation, drought preparedness), promoting resilience to global warming (e.g., monitoring species migration to inform current and future habitat conservation, monitoring and promoting ecosystem biodiversity), and enabling ecosystems to adapt to climate change (e.g., forward-thinking restoration, replanting with climate-adapted species). The paper indicates "There is an urgent need for policy makers, managers, scientists, stakeholders, and the general public to share the specific evidence of global climate change and its projected consequences on ecosystems, as well as their understanding of the choices, future opportunities, risks, and difficult trade-offs."

Implications for forest plan assessment: The EIS should assess all evidence provided by the Forest Service, independent scientists, and the public regarding climate change impacts.

Meyer SE. 2011. Is climate change mitigation the best use of desert shrublands? Natural Resources and Environmental Issues 17:1–10.

Topic: Carbon sequestration by desert shrublands.

This literature review addresses the factors that affect the ability of cold desert shrublands to sequester carbon as both biomass and soil organic carbon. The semi-desert shrublands of the interior West typically have more standing biomass than true deserts, but the amount of carbon storage varies across desert shrubland habitats depending on dominant vegetation and other factors. Carbon storage can be affected by gradual grassland-shrubland transitions as well as the displacement of native desert shrubs by non-native invasive annual grasses, whether through increased wildfire frequency or overgrazing. For example, the recent expansion of an invasive cheatgrass (*Bromus tectorum*) monoculture in the Great Basin has caused the landscape to transition from carbon sink to carbon source. Invasive annual grasses and land uses like livestock grazing can also disturb biological soil crusts, encouraging lesser soil stability and greater windblown dust generation, complicating vegetation impacts.

Management discussed: Non-native invasive grass management, proper livestock grazing management, windblown dust abatement, and mitigation of the invasive grass-wildfire feedback cycle that intensifies with climate change.

Implications for forest plan assessment: The EIS needs to assess MLSNF carbon storage across major habitat types and threats to the intactness of these ecosystems (e.g., mapping cheatgrass and other annual grass cover).

Shinneman DJ, Baker WL, Lyon P. 2008. Ecological restoration needs derived from reference conditions for a semi-arid landscape in Western Colorado, USA. Journal of Arid Environments 72:207–227.

Topic: Ecological restoration needs in semi-arid landscapes of the western United States.

Using plant community data over a large semi-arid landscape in western Colorado, this study analyzed ecological conditions across different community and vegetation types to identify reference areas that could inform restoration needs, to understand species composition and diversity changes along a gradient of environmental degradation, and identify common restoration needs across spatially disparate semi-arid communities. The study found few remaining reference areas, often in lower productive conditions (e.g., rocky and rugged with shallow soil depth), as compared to more naturally productive sites which had long histories of land use influences, including livestock grazing, fire exclusion, and clearing or thinning of overstory trees and shrubs. Areas with closer-to-reference conditions (as opposed to highly degraded conditions) had higher native grass (graminoid), forb, and biological soil crust cover but across the study sites, these indicators had declined substantially over the study period. Reference areas were found to generally support greater species richness and diversity, but trends for non-native species invasions were inconsistent across the reference to degraded area spectrum.

Management discussed: Restoration of native plant composition and abundance in semi-arid ecosystems requires both active (e.g., re-seeding) and passive (e.g., reducing livestock grazing ecological stresses) approaches at both local and landscape levels. Reference plant community information, including ungulate exclosures which provide reference areas regarding potential conditions in the absence of livestock and/or elk and/or deer populations, is needed to guide restoration.

Implications for forest plan assessment: The EIS needs to map major reference areas (including but not limited to exclosures) existing on MLSNF and provide data that have been gathered to compare these reference areas with comparable MLSNF lands, and for which features.

Stavins RN, Richards KR. 2005. The Cost of U.S. Forest-based Carbon Sequestration. Pew Center on Global Climate Change. Arlington, VA, USA.

Topic: The cost of carbon sequestration in United States forests.

Carbon sequestration is a possible tool in mitigating global climate change. Forests and other highly productive ecosystems can aid in removing carbon dioxide from the atmosphere and storing it as plant material, decomposing material, and organic soil. To evaluate monetary costs of forest-based carbon sequestration, this report considered seven main factors: (1) tree species, forestry practices, and rates of carbon uptake that affect sequestration capability; (2) land value for alternative uses; (3) characteristics of biomass in burning, harvesting, and forest product sinks; (4) anticipated changes in forest and agricultural product prices; (5) analytical methods for modeling carbon flow; (6) discount rates used in analytical methods; and (7) policy methods used to achieve a carbon sequestration target. Considering these factors, the report concluded that there is a broad range of forest-based carbon sequestration opportunities with varied outcomes and costs, including opportunities for significant climate change mitigation that are cost-effective and have high return values.

Implications for forest plan assessment: The EIS needs to indicate the potential for carbon sequestration that exist under current and projected conditions within MLSNF.

Wentz J, Glovin G, Ang A. 2016. Survey of Climate Change Considerations in Federal Environmental Impact Statements, 2012-2014.

Topic: Climate change considerations in federal Environmental Impact Statements.

A survey of 238 federal Environmental Impact Statements (EISs) from 2012-2014 was conducted to evaluate the extent to which climate change was addressed, e.g., with respect to climate mitigation, climate adaptation, or energy or water efficiency. While climate change has increased in prominence in EISs since the 2009 study and most agencies were found to be applying the 2010 Council on Environmental Quality guidance, the scoping of indirect contributions to greenhouse gas emissions and adaptation to climate change impacts was found largely absent across agencies.

Implications for forest plan assessment: The EIS needs to identify all contributions to greenhouse gas emissions on the MLSNF (e.g., methane production by livestock, prescribed burning and wildfire, loss of carbon storage within the soil, coal mining) and document changes on the forest that are contributing to mitigation of or adaptation to climate change.

Additional Reports

Intermountain and Southwest-specific

- Finch DM. 2012. Climate Change in Grasslands, Shrublands, and Deserts of the Interior American West: A Review and Needs Assessment. RMRS-GTR-2. U.S. Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA.
- Garfin, G. M., A. Jardine, R. Merideth, M. Black, J. T. T. Overpeck, and S. LeRoy. 2013. Assessment of Climate Change in the Southwest United States. G. M. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, editors. Island Press, Washington, DC, USA.

Colorado Plateau-specific

- U.S. Bureau of Land Management. 2012. Potential Future Conditions of the Colorado Plateau. Pages 109–158 in Dynamac Corporation and I. MDA Information Systems, editors. Colorado Plateau Rapid Ecoregional Assessment. U.S. Bureau of Land Management, Denver, Colorado, USA.

National Public Land-specific

- Vose JM, Peterson DL, Patel-Weynand T. 2012. Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the US Forest Sector: 265 pages. Available from http://www.usda.gov/oce/climate_change/effects_2012/FS_Climate1114 opt.pdf.
- Peterson DL, Vose JM, Patel-Weynand T. 2014. Climate Change and United States Forests. U.S. Forest Service, Seattle, Washington, USA.
- Vose JM, Clark JS, Luce CH, Patel-Weynand T. 2015. Effects of Drought on Forests and Rangelands in the United States: A Comprehensive Science Synthesis. U.S. Forest Service, Washington, DC, USA.
- U.S. Government Accountability Office. 2007. Report to Congressional Requesters: Climate Change: Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources. Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources. U.S. Government Accountability Office.

General/Global

- Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G. 2013. Tackling Climate through Livestock - A Global Assessment of Emissions and Mitigation Opportunities. Food and Agriculture Organization of the United Nations. Rome, Italy.
- Hansen LJ, Biringer JL, Hoffman JR. 2003. Buying Time: A User’s Manual for Building Resistance and Resilience to Climate Change in Natural Systems. World Wildlife Fund. Washington, D.C., USA.