Chapter 6

Disturbance and Climate Change in the Interior West

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Executive Summary

Within the continental United States, average annual temperature increased during the Twentieth Century by approximately 0.65 ºC. The most extreme warming occurred throughout the northern and western United States (IPCC 2007a; Williams and others 2010). Disturbances such as fire, drought, grazing, urbanization, and energy development are predicted to have a heightened impact on the western United States under a changing climate. For example, extreme drought conditions accompanied by rising temperatures characterized the American Southwest during the past decade (Floyd and others 2009). Key future issues to consider are:

- Longer and more severe droughts.
- Longer periods of dry conditions leading to increased potential for "mega fires."
- Increased ecosystem susceptibility to insect pests and disease.
- Increased susceptibility of ecosystems to invasion of non-native species.
- Changes in the relationships among plants, water, nutrients, and soils on grazed lands.
- Increased effects of grazing on greenhouse gas (GHG) levels.
- Increased conflicts over use of freshwater for native ecosystems and for growing human populations.
- Changes in precipitation runoff and potential for changes in flooding patterns.
- Increased concern over the potential for fire as human development extends the wildland-urban interface.
- Increased disturbance associated with domestic fuel exploration and production.

Some examples of research the RMRS GSD Program is conducting to address many of these key issues are:

- Studies of the response of Great Basin upland and riparian plant communities to climate change and anthropogenic disturbance and the implications for future responses to climate and management activities.
- Methods for maintaining and restoring riparian communities and their ecosystem services based on an understanding of the effects of climate change.
- Understanding the interacting effects of climate and fire on successional processes at landscape scales.

- Plant-climate relationships in the western United States and the effects of climate change on those relationships and on the landscape distribution of key species and communities.
- The interacting effects of climate change and livestock grazing on rangeland resources of the United States.
- The role of climate variation on historic fire regimes at local to sub-continental scales.
- The effects of climate and land use factors on successional dynamics and ecological threshold crossings in grassland ecosystems and the use of this information for state-and-transition models.
- The effects of climate on pinyon-juniper woodlands in western landscapes over the last 150 years.

However, there are gaps in our knowledge base. Some major research needs are:

- Improved methods for post-fire restoration of arid ecosystems and of ecosystems dominated by fire-adapted exotic grasses.
- Ecosystem recovery after fire, including effects of livestock grazing and re-seeding and re-planting of plant species.
- Relationships of weather and climate patterns to past and present fire regimes at local scales.
- Regional climate change predictions and improved capacity to predict ecological responses.
- Interactions among the primary climate change variables: precipitation regimes, elevated CO_2 and increased temperature.
- The most appropriate and least impactful sites for energy development.
- Appropriate plant materials for use in reclamation and restoration of disturbed sites under expected climate change scenarios.
- Effects of large solar generating facilities and wind-power developments on migration corridors, seed movement, and potential off-site effects of chemical dust control agents.

Our research sponsors, collaborators, and partners include: universities, The National Forest Service, Bureau of Land Management, Agricultural Research Service, Natural Resources Conservation Service, U.S. Geological Survey, Bureau of Indian Affairs, U.S. Fish and Wildlife Service, National Park Service, National Science Foundation, Long Term Ecological Research Network, state and municipal governments, tribal governments, Joint Fire Science Program, Department of Defense, Department of Energy, Bureau of Reclamation, non-Governmental organizations and other RMRS programs.

Introduction

We examine the interactions between climate change and natural and anthropogenic disturbances in grassland, shrubland, and desert ecosystems of the Interior West. Disturbances such as fire, drought, grazing, urbanization, and energy development are predicted to have a heightened impact on the western United States under a changing climate. We identify key issues related to these predictions, and provide examples of research that the RMRS GSD Ecosystems Program is conducting to address many of these predictions, as well as identify future research needs.

Interaction of Climate Change and Fire

Climate change is predicted to have multiple effects on fire regimes in grassland, shrubland and desert ecosystems. Current climate change models predict increased temperatures that will result in higher evaporative potential and heat stress across the western United States (Bates and others 2008). Predicted changes in precipitation are less certain, but it is likely that the southwestern United States and central Rockies will exhibit decreased annual precipitation.

Key Issues

Increases in spring and summer temperatures of ~0.9 °C and a one to four week earlier melting of snowpacks have been related to increased fire activity across the West (Westerling and others 2006). Since 1986, the length of the active wildfire season has increased by 78 days and the average burn duration of large fires has increased from 7.5 to 37.1 days (Westerling and others 2006). Earlier snowmelt at high elevations and lack of snow retention at mid elevations in GSD ecosystems (Mote and others 2005) is resulting in longer periods of dry conditions and, when coupled with hot, dry, and windy weather, provides the conditions for wildfire.

The number of days of high fire danger (based on the energy release component index) is increasing and the Great Basin and the Southwest are among the regions most affected (Brown and others 2004). Extremely dry conditions result in more erratic fire behavior, with large flame lengths, torching, crowning, and blowups (Brown and others 2004). Mega fires, or large-scale fires that significantly exceed those of recent decades, are now occurring in GSD ecosystems as evidenced by the 264,260-ha burn in the Murphy Complex wildfire in Idaho and Nevada and 146,901-ha burn in the Milford Flat wildfire in Utah in 2007 (Chambers and Pellant 2008).

Relationships among climate and fire regimes differ among the Bailey's ecoregions (Bailey 1995) due to a diversity of vegetation types and historic fire regimes.

- In most mountainous ecoregions, low precipitation, high temperatures, and a high Palmer's Drought Severity Index in seasons prior to and including the fire season are associated with higher burn areas due to low fuel moisture, increased probability of ignition, and higher potential for fire spread (Westerling and others 2006; Littel and others 2009).
- In southwestern and arid ecoregions, precipitation in seasons prior to the fire season is more highly associated with burn area than warmer temperatures or drought the year of fire due to the importance of fine fuel production (Littel and others 2009).
- In the Great Basin, prior year relationships are even more important and burn area is associated solely with warm, wet conditions in winter or spring one or more years prior to the fire season. A warming climate with less snowpack and a higher proportion of rain at low to mid elevations in mountainous ecoregions may result in increases in area burned at these elevations due to decreased water availability and longer growing seasons (Littel and others 2009).
- In southwestern and arid ecoregions, increasing aridity may result in a decrease in area burned due to a reduction in fine fuels.

Current ecological conditions within different ecoregions influence the responses to climate-induced changes in fire regimes. In arid and semi-arid shrublands and deserts, invasion of exotic grasses with higher flammability and fire spread than native species is increasing both fire frequency and extent.

- In the Mojave and western Sonoran Deserts, invasion of the winter annual grasses *Bromus madritensis* subsp. *rubens* and *Schismus barbatus* is resulting in frequent and large fires in ecosystems that seldom burned in the past (Brooks and McPherson 2006).
- In the eastern Sonoran Desert, invasion of exotic perennial grasses such as *Eragrostis lehmanniana* and *Pennisetum ciliare* are resulting in increased fire frequency and size (Brooks and McPherson 2008).
- In cold desert shrublands, invasion of exotic annual grasses, especially cheatgrass (*Bromus tectorum)*, is increasing fine fuels and fire spread and resulting in conversion of diverse shrublands to near monocultures with greatly increased fire frequency and size (Knapp 1996).
- In many arid and semi-arid grassland ecosystems, expansion and dominance of woody species is resulting in significant decreases in fire frequency and lower resilience to fire (Van Auken 2000).

In these topographically diverse ecosystems, a warmer and drier climate will likely increase the susceptibility of higher-elevation and more mesic ecosystems to invasion by exotic grasses that are currently constrained to lower elevation systems, thus, increasing the risk of wildfire (Chambers and others 2007). Lower-elevation ecosystems may become less susceptible to invasion due to hotter and drier conditions that exceed the ecological amplitude of the invader. As a consequence, active restoration may be necessary (Bradley and others 2009).

Research Needs

- Relationships of weather and climate patterns to past and present fire regimes at local scales.
- Ecological factors and management strategies that increase ecological resistance to exotic species invasions.
- Ecological factors and fire and fuels management strategies that increase ecological resilience to fire at landscape scales and prevent threshold crossings.
- Effects of changes in fire regimes and fuels management on watershed function (erosion, water quality and quantity, and biotic organisms).
- Effects of fire and fuels management on riparian ecosystems, stream channels, and aquatic habitat.
- Improved methods for post-fire restoration of arid ecosystems and ecosystems dominated by fire-adapted exotic grasses.
- Effects of livestock grazing on ecosystem recovery after fire.

Effects of Drought

Recent climate change predictions indicate increasing periods of drought for the western United States (Bates and others 2008). Decreased annual precipitation in the southwestern United States and central Rockies coupled with increased evapotranspiration due to higher temperatures will increase the potential for longer and more severe droughts across most of the western United States. In addition, the Interior West is one of three areas where heat waves are predicted to become more frequent, more intense, and longer lasting (IPCC 2007b). Since 1950, the western United States has already experienced up to four more days per decade with extreme high temperatures.

Key Issues

Differential effects of climate change on GSD ecosystems may increase susceptibility of some ecosystems to the effects of drought and heat waves. For example, earlier snowmelt and a lower proportion of precipitation falling as snow will decrease the extent of snow cover and result in lower snow water equivalent at mid elevations in mountainous regions (Mote and others 2005). A decrease in snow water equivalent and increase in the amount of solar radiation absorbed on snow-free surfaces (Mote and others 2005) may exacerbate the effects of drought and heat waves on ecosystems at these elevations.

Increases in the severity and frequency of drought have the potential to significantly increase the level of stress experienced by native ecosystems. Drought typically results in reductions in plant primary production and water use, mortality of immature plants (seedlings) and animals, and increased susceptibility to insects or disease (Hanson and Weltzin 2000).

Severe or prolonged drought can eventually result in mortality of adult plants despite adaptations to arid conditions (Breshears and others 2005). Changes in biogeochemical cycling can occur, and reductions in plant cover can significantly increase soil erosion (Rapport and Whitford 1999).

Drought can increase the susceptibility of ecosystems to invasion of non-native species, especially under elevated CO_2 conditions (Smith and others 2009). However, prolonged drought or drought that occurs at the margin of a species range can result in mortality of non-native invaders such as *Bromus tectorum* (Jeanne Chambers, personal observation). Drought also can alter fire regimes but effects differ among ecoregions (Westerling and others 2006; Littel and others 2009).

- In most mountainous ecoregions, drought conditions in seasons prior to and including the fire season are associated with larger burn areas.
- In southwestern and arid ecoregions, precipitation in seasons prior to the fire season is more highly associated with burn area than warmer temperatures or drought the year of fire due to the importance of fine fuel production (Littel and others 2009). However, prolonged drought can decrease production of fine fuels and may decrease the probability of fire.

The ecological conditions and anthropogenic stressors of GSD ecosystems can influence their responses to drought and heat waves. Many GSD ecosystems, including hot desert grasslands (Rapport and Whitford 1999), cold desert shrublands (Chambers and Wisdom 2009) and hot desert shrublands (Smith and others 2009), have undergone significant transformations as a result of overgrazing by livestock, agriculture, mining, energy production, urban, suburban and exurban development, recreation, and road development. A high proportion of these ecosystems have crossed ecological thresholds or are at risk of crossing thresholds to less desirable alternative states than existed prior to Anglo-American settlement. Severe or prolonged drought has the potential to result in additional threshold crossings and novel alternative states.

The potential for large-scale die-offs of key species and the consequences for ecosystems can be illustrated by recent, widespread mortality of *Pinus edulis* in the Southwest. In 2002 to 2003, 40 to 80% of *P. edulis*, a dominant, overstory tree species, suffered mortality in a four-state region of the Southwest after 15 months of soil water depletion (Breshears and others 2005). Mortality of the trees resulted from subcontinental drought and anomalously high temperatures. The proximal cause of mortality was apparent infestation by bark beetles, which is often related to drought-induced water stress (Allen and Breshears 1998). The die-off was not constrained to *P. edulis*;

a dominant herbaceous species *Boutelua gracilis* exhibited a 50% reduction in live basal cover at one of the study sites. Interrelated effects included large changes in near-ground solar radiation (Martens and others 2000), runoff and erosion (Allen and Breshears 1998), and genetic structure of *Pinus edulis* on the landscape (Mitten and Duran 2004).

The potential for regional vegetation die-off under global-change-type drought remains a pivotal uncertainty in projections of climate change impacts (IPCC 2001). Regional mortality of key species has the potential to rapidly alter vegetation composition, associated ecosystem properties, and land surface conditions for decades.

Research Needs

- Regional climate change predictions and improved capacity to predict ecological responses.
- Experiments that examine the interactions of the primary climate change variables: precipitation regimes, elevated CO_2, and increased temperature.
- Patterns of response of key species over environmental gradients.
- Interactive effects of soil moisture and temperature on competitive interactions.
- Effect of precipitation and drought on secondary succession and carbon sequestration.
- Role of drought in increasing/decreasing susceptibility to invasion by exotic plant species.
- Role/importance of precipitation seasonality, serial correlation, and extremes on ecosystem structure and function.
- Role of precipitation on nutrient cycling and feedbacks to plant production.
- The level of drought that kills key native perennial species.

Grazing and Climate Change

Rangelands are defined as lands where native vegetation is predominantly grasses, shrubs, or open woodlands, and includes grasslands, shrublands, savannas, and most desert, tundra, meadow, wetland, and riparian ecosystems (Kauffman and Pyke 2001). Rangelands provide important ecosystem services such as biological diversity, wildlife habitat, soil conservation, and GHG sequestration (Ritten and others 2010). Globally, livestock grazing is an important factor affecting ecosystem integrity as it occurs on more area than any other land use. It has been considered the most widespread influence on native ecosystems in western North America (Fleischner 1994). Grazing can reduce biological diversity and ecosystem integrity through removal of vegetation; trampling of soils, vegetation, and biological soil crusts; redistribution of nutrients; and dispersal of exotic plant species and pathogens (Kauffman and Pyke 2001). Many arid grasslands evolved in the presence of large mammalian herbivores (Brown and MacDonald 1995), and thus the intensity of grazing is an important consideration when evaluating past, current, and future effects of grazing on plant species in grasslands (Loeser and others 2007). Also, these effects can be influenced by drought (Loeser and others 2007); therefore, drought should be considered when evaluating the results of grazing studies. In addition, carefully managed grazing may provide opportunities for reducing the density of non-native plant species if such species are consumed by livestock (Kleppel and LaBarge 2011). In another example, targeted cattle grazing on rangeland dominated by cheatgrass reduced cheatgrass cover and, in turn, reduced rate of spread of prescribed fire in the northern Great Basin (Diamond and others 2009).

Key Issues

A variety of studies have addressed issues related to grazing under a changing climate, with topics ranging broadly from quantifying the impact of grazing on GHG levels (Wolf and others 2010) to evaluating potential direct impacts on animals from nutritional stress (Craine and others 2010). Relatively few studies have addressed the impacts of both grazing and climate change on native species of animals and plants. Research results are more readily available that address how grazed lands may change in their ability to support grazing as a livelihood in the future. Furthermore, there is a shortage of work aimed specifically at arid and semi-arid lands in the western United States. Some of the issues that are expected to face managers of public lands where grazing occurs are:

- Changes in the relationships among plants, water, nutrients, and soils on grazed lands are expected to occur under climate change.
- Determining appropriate stocking rates for maintenance of ecosystem function and long-term conservation of rangelands will become more difficult.
- Determining how grazing may affect GHG levels.

Hatfield and others (2008) identified several ecological processes that have the potential to be affected by climate change that relate to grazing: growing season length and plant phenology, net primary production, species composition, and nitrogen cycle feedbacks.

Effects are expected to vary by region. The spatial and temporal distribution of precipitation is a primary driver in the ecology of rangelands (Hatfield and others 2008). The water content of soil and the relationship of water to plants are influenced by levels of CO_2 and ambient temperature. Warming is expected to lead to an earlier onset of green-up in spring and a longer growing season (Badeck and others 2004), but species are expected to vary in their responses to these phenomena. In some areas, modeling efforts have suggested that the spring growing season may shorten (Cullen and others 2009). Furthermore, precipitation variability and increased CO_2 may cause deviations from the overall patterns set by temperature.

Climate change and increased atmospheric CO_2 concentrations are considered to have had an influence on the expansion of shrublands over the past couple hundred years (Hatfield and others 2008). Shrub encroachment into grasslands reduces forage for livestock and wildlife (Burkinshaw and Bork 2009). On the other hand, estimates of future suitable climate in western states covered in this review suggest that changes will favor an increase in area possessing conditions that would support semi-desert grasslands (Friggens and others, Chapter 1 this volume). The threat of soil erosion on grazed lands increases in periods of years with reduced precipitation (Washington-Allen and others 2010). Herbivory by native herbivores can alter plant community responses to warming (Post and Pedersen 2008), yet experimental manipulations aimed at the potential consequences of climate change on rangelands often have not incorporated native herbivory.

Overall, nutrient and water cycles on grazed lands are complex. Del Grosso (2010) pointed out that the results from various studies demonstrate that “generalizations about how changes in climate and land management affect element cycling are often confounded.”

Concerns exist over how to make appropriate stocking decisions in the face of climate change (Ritten and others 2010; Tietjen and Jeltsh 2007). The long-term sustainability of rangelands depends on appropriate range management. Variable range production, caused in large part by stochastic precipitation, is already complex, with stocking decisions often made before growing season precipitation is known (Ritten and others 2010). Semi-arid and arid regions show high variability in mean annual rainfall (references in Tietjen and Jeltsh 2007). Rainfall directly influences primary productivity, which, in turn, significantly influences the carrying capacity of a given system for livestock. If net primary productivity is reduced, the carrying capacity is reduced and overgrazing is exacerbated (Tietjen and Jeltsh 2007). An increase in grazing pressure can lead to the reduction of palatable grasses and herbs and an increase in unpalatable grasses and herbs and woody plants (references in Tietjen and Jeltsh 2007).

Craine and others (2010) indicated that "predictions of how forage quality will be affected by changes in temperature and precipitation are varied and conflicting." The increased threat of drought severity, frequency, and duration under climate change increases the complexity of making sound stocking rate decisions (Ritten and others 2010; Popp and others 2009). Sustainable management of arid and semi-arid rangelands is expected to depend heavily on how well rangeland managers understand important ecological processes (Popp and others 2009).

Livestock production contributes to GHG emissions. On a global level, livestock are considered to produce 37% of the global anthropogenic methane (CH_4) through digestive processes (Neely and others 2009), though others have put that value closer to 50% (Morrison 2009). Nitrous oxide, also a GHG, is released mostly as a side-effect of using nitrogen fertilizer or animal manure (Morrison 2009), although high levels of grazing are thought to increase nitrous oxide emissions because grazing increases the rate of nitrogen cycling (Del Grosso 2010).

Recent evidence suggests that grazing can reduce such emissions in semi-arid grasslands that experience soil freeze-thaw cycles in spring (Wolf and others 2010). Options exist in terms of more efficient use of grazing lands and manure to reduce GHG emissions (Gill and others 2010).

The value of rangeland soils in carbon sequestration has been identified as important on a national and an international level (Brown and others 2010; Follett and Reed 2010; Neely and others 2009), particularly as degradation of rangeland reduces the ability of the soils to sequester carbon. Worldwide, grazing lands have been estimated as reducing approximately 20% of the CO_2 released annually into the atmosphere from global deforestation and land use changes (Follett and Reed 2010).

Research Needs

- Continue efforts to improve predictions about future trends of vegetation dynamics under climate change and various management alternatives on grazed lands.
- Increase the scale at which field experiments are conducted (i.e., more large-scale studies) and ensure that rigorous experimental design is employed. Craine and others (2010) noted that climate change experiments are generally too small to allow grazing to be adequately characterized.
- More research on understanding the mechanisms driving observed changes in rangelands with respect to temperature, precipitation, soil cycles, etc. Nutrient cycles on rangelands (carbon, nitrogen, temperature, water, and soil) are critically important as they affect plant growth and quality of forage, which, in turn, influence stocking rates.
- Increase research focus beyond grasslands to grazing in deserts and shrublands.
- Incorporate interactions of invasive plant species and fire behavior in models and field studies.

- Develop decision-support tools to help managers evaluate how stocking rates may need to be adjusted under the threat of climate change.

Population Growth, Development, and Climate Change

The population of the United States continues to increase. In 2000, the population of the United States was 281 million people (U.S. Census Bureau 2000a), and between 1990 and 2000, the U.S. population increased by 33 million people, the largest census-to-census increase recorded in the census history. Growth rates in the West (Montana, Wyoming, Colorado, New Mexico, and the seven states to the west) were higher than the national rate during this period at 20%.

Increasingly, human populations are concentrated in cities. Globally, almost all of the expected population growth is projected to occur in urban areas (Alig and others 2004). In the United States, according to the 2000 census, 79% of the population lived in urban areas (defined as all "urbanized areas" of 50,000 or more people, and "urban clusters" of 2500 to 49,999 people; U.S. Census Bureau 2000b). In each of the 12 states considered by this assessment, there was an increase in the percentage of the population that lived in urban areas between 1960 and 1990.

Population growth creates increased demands on natural resources, such as water and wood products, as well as energy products (coal, oil, natural gas, etc.). Clumping development into urban areas can reduce certain kinds of energy demands (e.g., housing and work locations may be closer) but can negatively impact agricultural output from the loss of farmlands and can lead to fragmentation of forests and other adjacent landscapes (Alig and others 2004).

Key Issues

There are a variety of ways in which climate change will interact with factors that arise from a growing population that increasingly will be concentrated in cities, including: changes in the availability of freshwater, changes in precipitation runoff and potential for changes in flooding, increased energy demands, and ex-urban development.

Increases in population place increasing demands on freshwater resources. While predictions vary as to future changes in the timing and total amount of precipitation according to model and region, the IPCC predicts an increase in precipitation in northern areas and a decrease in southern areas of the western half of North America (Christensen and others 2007). Thus, in southern areas, inputs of freshwater from precipitation are likely to decrease, and increasing demands for freshwater for human consumption (from increased population) will worsen existing impacts on native flora and fauna.

- Summer and autumn flows in river basins supplied by snowmelt water are predicted to be reduced (Kundzewicz and others 2008).
- Alterations to streamflow will differ by region due to variation in the degree to which precipitation and temperature change as well as variation in the characteristics of individual hydrologic basins (DeWalle and others 2000).

Changes to the timing of peak flows in spring are likely to alter freshwater availability for municipalities and exacerbate issues of water storage in reservoirs (Bartolino and Cunningham 2003). The High Plains Aquifer lies under portions of eight states and has supported irrigation of agricultural lands; in some areas, water levels have dropped greater than 30 m since pre-pumping periods (Bartolino and Cunningham 2003). In

Tucson and Phoenix, groundwater levels have dropped 91 to 152 m in some places and riparian vegetation has been lost; similar problems exist in Las Vegas, Nevada.

An increase in population leads to an increase in the demand for energy. In 2006, the three top sources of energy in the United States were petroleum, natural gas, and coal (McDonald and others 2009). McDonald and others (2009) evaluated the land-use intensity of different types of energy production that are expected to increase in the United States based on the Energy Information Administration forecast for energy production by 2030, particularly if legislation passes to implement a system of cap-and-trade to regulate emissions:

- The type of energy development expected to impact the most total area (km^2) is biofuel development. Biofuels and biomass burning of energy crops take up the most space per unit power (320 to 375 km^2/TW hr/yr, and 433 to 654 km^2/TW hr/yr, respectively).
- Wind and solar power have intermediate values of space required per unit of power. Wind power was estimated to account for a relatively small percentage of the new land area impacted between 2006 and 2030.
- Nationally, future energy development is likely to impact temperate deciduous forests and temperate grasslands the most.
- Regardless of whether cap-and-trade policy is implemented, MacDonald and others (2009) estimated that by 2030, the total new area affected by energy production in the United States will be greater than 206,000 km^2 (more than the area of Nebraska).

This loss of land to energy development will directly impact native species of flora and fauna. Furthermore, some forms of energy production require substantial amounts of water, which leads to additional indirect impacts.

Urban residents worldwide tend to produce less GHG than residents elsewhere in the same countries (Dodman 2009). In the United States in 2001, urban households drove less on average; for households with vehicles, urban households traveled on average ~21,000 miles, whereas rural households traveled on average ~28,000 miles (U.S. EIA 2005). However, in cities that experience a substantial heat island effect, residents may use more energy in summer to maintain cool temperatures indoors. Increasing development reduces natural areas that are likely to be critical as plant and animal communities change due to temperature and precipitation changes. The impacts of fire as human development extends into suburbs and the wildland urban interface need to be considered along with impacts from population growth on natural areas adjacent to large population centers.

Research Needs

- Continue research on regional-scale predictions of changes in precipitation under climate change.
- Identify streams, rivers, and associated riparian areas at greatest risk from altered streamflow and changes in water quality due to human-induced freshwater consumption and reduced precipitation.
- Identify policies that could be implemented to conserve water, either through reduced consumption and/or re-use by industrial and residential consumers.
- Identify regionally specific recommendations on locating new development to reduce energy consumptions and minimize impacts to natural areas.

Energy Development and Climate Change

There is an almost universal consensus among the international scientific community that GHG must be reduced in order to slow the rate of global warming (Abbasi and Abbasi 2000; Dincer 2000). As fossil fuel costs and the impact of their use have become more readily apparent, there has been increased industry investment and Government support for the development of renewable energy sources (Kunz and others 2007). Renewable alternative energy sources include nuclear power, biomass energy (Abbasi and Abbasi 2010), solar power, and wind power. Traditional oil, coal, and natural gas exploration and production occur within the boundaries of GSD and will continue for the foreseeable future.

In the western United States, the sprawl of energy development will have a potentially greater impact than in other areas of the country due to several factors, including the availability of large tracts of Government-owned land, high solar radiation, a fast-growing population, space available for new transmission corridors, and public acceptance of alternative energy production. Climate change velocities are also expected to be highest in low-elevation communities such as deserts, temperate grasslands, and shrublands (Loarie and others 2009). Development of alternative energy sources has far surpassed our understanding of their environmental impacts. It is important that we understand the potential environmental impacts of alternative energy development in order to mitigate undesirable effects.

Key Issues

Traditional energy production using fossil fuels can be expected to continue well into the Twenty-First Century. The geographic area covered by RMRS includes significant sources of these fuels as well as uranium deposits. Disturbances associated with fuel exploration and production include: drill pads, roads, pipeline corridors, open pits, mine tailings, and wind turbine sites.

While considerable research has already been focused on techniques for reclaiming these sites, the current goal of restoring historic communities may no longer be viable. Given the predicted ecotone and community shifts under climate change projections, large areas within the western states may no longer support present ecosystems (Saxon and others 2005), significantly complicating the selection of plant materials for restoration (Hufford and others 2010). Researchers must identify and develop new plant materials that better tolerate increasing drought and high temperatures and are competitive with invasive species (Hufford and others 2010).

Energy production from biomass, termed "biofuels," has been touted as a way to reduce reliance on fossil fuels and reduce GHG emissions. Biofuels are considered carbon neutral because they use recently fixed carbon as opposed to the ancient carbon of fossil fuels (Abbasi and Abbasi 2010). Key considerations in the conversion of large acreages to biofuel production are:

- Biomass production is not "nutrient neutral," and large production may not be sustainable due to soil degradation and depletion of nutrients (Abbasi and Abbasi 2010).
- Use of crop plants and agricultural lands traditionally used for food production for biofuels competes with feed and food demands, increasing world prices and decreasing supplies of foodstuffs.
- Alternatives include the use of non-food energy crops, such as crop residues, hydrocarbon-rich plants, organic waste products, weeds, and fast-growing grasses and woody species (Schmer and others 2008; Abbasi and Abbasi 2010).

- Additional mitigation may come from use of degraded rangeland and abandoned cropland for biofuel production rather than diverting existing agricultural lands needed for food production (Fargione and others 2010).

Construction of alternative energy-generating facilities is a high priority for utility companies, state and Federal governments, and the public. The arid Southwest contains a large amount of Federal lands that also receive significant amounts of solar radiation, and the majority of large-scale solar facilities are slated for development on these lands. Six new solar facilities were approved on Federal land in Nevada and California in October 2010 (USA Today 2010). The largest is 2830 ha (greater than 10 square miles) and larger facilities are being considered (USGS 2010). The solar facilities are approved for construction on the fast track, though extensive environmental assessment will not be completed prior to breaking ground (USGS 2010). While new solar facilities are significantly more efficient than traditional power plants and produce far fewer CO_2 emissions, they are not without environmental impacts in their construction and operation. Limited experience with large-scale solar facilities means that there is little on-the-ground experience regarding these potential impacts (Tsoutsos and others 2005; McDonald and others 2009). The U.S. Department of the Interior has identified 24 solar energy zones in six western states that have high potential for solar energy development and have limited environmental impacts. The zones will facilitate more rapid solar energy development. The final number and size of the solar energy zones will be determined in 2012 (BLM 2011). Some issues to consider are:

- Facilities must be kept free of vegetation in order to prevent the possibility of heat-induced wildfires, resulting in large areas devoid of vegetation.
- Dust emissions from construction, and resulting un-vegetated areas and roads will likely increase. Little is known regarding potential off-site movement of chemical dust-control agents or their effect on surrounding vegetation.
- The impact of solar energy development on wildlife has not been well researched. Effects on migration corridors as well as effects on resident species are largely unknown (USGS 2010).
- Service roads may serve as transmission corridors for exotic plant species.
- Attention during the planning, construction, and operation phases could minimize potential environmental impacts (Tsoutsos and others 2005).

Wind energy is increasingly important as a means of alternative energy production. As with solar installations, new and much larger wind farms are planned or under development. Wind-generating turbines are installed in linear arrays on ridge tops, in canyons, along coastlines, and offshore. Smaller-scale development occurs in more urban settings. The technology to develop energy from wind on a large scale is more mature than that of large-scale solar development. Several studies have been conducted on wildlife impacts, but questions still remain.

- Habitat types most likely affected by wind energy production are temperate conifer forests and temperate grasslands (McDonald and others 2009).
- As with fossil fuel production, impacts on wildlife from wind turbines will largely come from habitat fragmentation, species avoidance behavior, and bird and bat mortality rather than from direct effects from installation (McDonald and others 2009).
- Our understanding of potential impacts of proposed large-scale wind farms, especially offshore, is severely lacking (Drewitt and Langston 2006).
- Recent monitoring studies indicate large numbers of bat fatalities associated with wind energy facilities (Kunz and others 2007).

- Potential effects on birds include collision mortality, displacement due to disturbance, altered migration flyways or local flight paths, and habitat change or loss (Drewitt and Langston 2006).

Research Needs

- Background research to help managers and companies select the most appropriate and least impactful sites for energy development.
- Rigorous, long-term studies of the environmental impacts of large-scale power development, including pre-construction assessments where possible.
- Development of appropriate plant materials for use in reclamation and restoration of disturbed sites under expected climate change scenarios.
- Identification of biomass materials suitable for use in small-scale rural applications as well as development of high-yield, non-food energy crops.
- Research to examine the impact of large, solar generating facilities and wind farms on migration corridors and seed movement and potential off-site effects of chemical dust control agents.
- Multi-year monitoring and hypothesis-based research on causes of bat and bird mortality (Kunz and others 2007), particularly in the Southwest where data are lacking.
- Development of education programs to teach citizens the economic and ecological value of energy efficiency and conservation as a step in reducing energy development sprawl in the western United States.

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