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Climate Change and the Shoshone National Forest

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First in the Nation

Shoshone
NATIONAL FOREST

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Introduction

In light of evolving research and the extent of unknowns regarding climate change impacts, this report focuses on our current understanding of the potential climate change related stresses that may impact the Shoshone National Forest, what factors may influence desired conditions identified in the forest plan, and what appropriate management strategies and future research studies are being developed to address climate change. These strategies focus on ways to incorporate climate and resulting resource changes, enhance ecosystem resilience when and where practicable, and adapt to inevitable changes.

While the pith of this report is how climate change will affect management of the Shoshone, it's important to mention how management of the Shoshone will affect climate change. Nationally, the Forest Service recognizes the value of incorporating environmental stewardship into its daily business operations (USDA Forest Service 2007). Locally, the Shoshone participates in the Greater Yellowstone Sustainable Operations Subcommittee, which is part of the Greater Yellowstone Coordinating Committee. The Subcommittee, chartered in 2005, facilitates the overall coordination and collaboration of sustainable operations practices throughout the public lands of the Greater Yellowstone Area. Through the Subcommittee, the 10 federal units of the Greater Yellowstone Coordinating Committee exchange information and ideas about sustainable operations.[1]

Shoshone National Forest employees are committed to thinking and acting sustainably as a matter of standard operating procedure—the resources we use and the waste we generate. We are identifying ways to reduce the impacts we make on the environment, including wise energy consumption, purchasing environmentally preferable products, water conservation at our facilities, more efficient fleet and transportation management, and hosting sustainable meetings and activities.

Climate change and national forests

In developing strategies for addressing climate change, some of the challenges facing national forests are the uncertainties about the direction of change, especially at local levels, and how natural ecosystems will respond to future natural and human-induced pressures. Forest Service scientists have been studying various aspects of climate change on forests for many years, and the Forest Service Chief has identified climate change as one of three overarching challenges facing the agency.[2] Yet, our knowledge of how ecosystems respond to changing climate and how to respond appropriately at local levels where management actions are most effective is still very limited (Solomon 2008).

In developing management strategies to deal with a changing climate, it has been recognized that forests can play an important role in both mitigating and adapting to climate change. Mitigation measures focus on strategies such as carbon sequestration by natural systems, ways to increase carbon stored in wood products, ways to provide renewable energy from woody biomass to reduce fossil fuel consumption, and ways to reduce environmental footprints. Adaptation measures address ways to maintain forest health, diversity, productivity, and resilience under uncertain future conditions (USDA Forest Service 2008).

[1] More information about the Subcommittee is available from the Greater Yellowstone Coordinating Committee Web site at http://fedgycc.org/index.html.
[2] The Forest Service climate change Web site is at http://www.fs.fed.us/kidsclimatechange/climate.shtml#usmap

At this time, the science of climate change modeling is at the stage of stepping down global models to regional scales (Davis 2007), so regional-level climate trends for the western United States will be used as the most reliable context for describing expected climate changes and impacts. Specifics regarding many mitigation measures, such as the appropriate calculations for carbon offsets and how to consider carbon sequestration rates, are still being developed, so most of the focus at the forest level will be on management options to improve resilience and adaptability of native ecosystems under changing conditions. Then, over the 10- to 15-year life of the forest plan, as issues are better understood and appropriate measures are identified, climate change strategies can be adjusted through the adaptive management process.

Adaptation approaches to climate change

The goal of adaptation is to reduce the risk of adverse environmental outcomes through activities that increase the resilience of ecological systems to climate change. Here, resilience refers to the amount of change or disturbance that a system can absorb without undergoing a fundamental shift to a different set of processes and structures. The adaptation approaches described here are derived from discussions of management practices to maintain or increase ecosystem resilience (Julius 2008).

- **Protecting key ecosystem features** involves focusing management protections on structural characteristics, organisms, or areas that represent important "underpinnings" or "keystones" of the overall system.
- **Reducing anthropogenic stresses** is the approach of minimizing localized human stressors (e.g., pollution, fragmentation) that hinder the ability of species or ecosystems to withstand climatic events.
- **Representation** refers to protecting a portfolio of variant forms of a species or ecosystem so that, regardless of the climatic changes that occur, there will be areas that survive and provide a source for recovery.
- **Replication** centers on maintaining more than one example of each ecosystem or population such that if one area is affected by a disturbance, replicates in another area provide insurance against extinction and a source for recolonization of affected areas.
- **Restoration** is the practice of rehabilitating ecosystems that have been lost or compromised.
- **Refugia** are areas that are less affected by climate change than other areas and can be used as sources of "seed" for recovery or as destinations for climate-sensitive migrants.
- **Relocation** refers to human-facilitated transplantation of organisms from one location to another in order to bypass a barrier (e.g., urban area) (Julius 2008).

Each of these adaptation approaches ultimately contributes to resilience, whether at the scale of individual protected area units, or at the scale of regional/national systems.

Over time, our ability to "manage for resilience" of current systems in the face of climate change will be limited as temperature thresholds are exceeded, climate impacts become severe and irreversible, and socioeconomic costs of maintaining existing ecosystem structures, functions, and services become excessive. At this point, it will be necessary to "manage for change," with a reexamination of priorities and a shift to adaptation options that incorporate information on projected ecosystem changes (Julius 2008).

While multiple benefits may result from continuing with today's best practices, key adjustments in their application across space and time may be needed to ensure their continued effectiveness in light of climate change (Julius 2008).

Reducing anthropogenic stresses is one approach for which there is considerable scientific confidence in its ability to promote resilience for virtually any situation (Julius 2008).

Adaptation approaches for the Shoshone National Forest

The potential management approaches in this report relate to those anticipated changes in climate that are most likely to affect Forest resources and the desired conditions of those resources central to the forest plan.

In developing strategies for managing change, the range of possible approaches could be quite broad, but the strategies that follow are based on recommendations from recent research. These strategies appear to be reasonable for the Shoshone, and balance effectiveness, feasibility, and available resources. Although some strategies are new concepts, most encompass existing practices and can serve multiple needs to respond to climate changes occurring over the next 10 to 15 years.

As climate continues to change, these ecosystems will likely cross a threshold above which maintaining resilience will be either very expensive or not feasible. The strategy of focusing on resilience will serve the Shoshone well in the near term and possibly longer, but may need to be adjusted as resource managers and scientists learn more about the on-the-ground effects of climate change on the Shoshone.

Though a number of adaptation approaches are reflected in this report, the approach most used is to reduce the impact of current stressors. This approach is broadly supported and has the additional benefit of promoting other ecosystem goals. Other approaches reflected in the strategies include protecting key features, representation, replication, and refugia. All these approaches are most applicable in the time scale covered by the revised forest plan (10 to15 years), and are the easiest to incorporate with current knowledge.

The approaches of restoration and relocation as they relate to climate change are longer-term approaches that require increased knowledge of anticipated changes. The approach of dealing with change that will come if temperatures reach thresholds from which ecosystem change is irreversible will also require more knowledge than we currently have. These approaches will be further considered in the future as our knowledge and understanding of climate change and its impacts increase.

Two other key concepts were considered in the developing the management responses to climate change.

1. Efforts to achieve a particular desired forest structure, composition, and function have been based on an understanding of ecosystem dynamics as captured in historical references or baselines (i.e., observed range of variation), and the now outdated theory that communities and ecosystems are at equilibrium with their environment. Under a changing climate (increased temperatures; changes in rainfall intensity; and greater occurrence of extreme events, such as drought, flooding, etc.), such an approach may no longer be sensible. Ecosystem composition, structure, and function will change as species respond to these changes in climate. Thus, as climate change interacts with other stressors to alter ecosystems, it will be important to focus as much on maintaining and enhancing ecosystem processes as on achieving a particular composition. For these reasons, it will be increasingly important for the Forest Service to consider evaluating current management practices, their underlying climatic and ecological

assumptions, and to consider managing ecosystems for change (Joyce et al. 2008).

2. It is important not to generalize assumptions about habitat and climate change in specific areas. Local climate trajectories may be far different from state or regional trends, and local topography and microclimatology interact in ways that may yield very different climate conditions than those given by broad-scale models. In mountainous terrain especially, the climate landscape is patchy and highly variable, with local inversions, wind patterns, aspect differences, soil relations, storm tracks, and hydrology influencing the weather that a site experiences (Joyce et al. 2008)

Future research on climate change

Forest Service research activities in the coming years are expected to help both public and private land managers better understand changing conditions and determine appropriate management approaches for both adaptation and mitigation. The global change research approach that will guide Forest Service Research and Development for the next 10 years will not only address enhanced ecosystem sustainability (adaptation) and increased carbon sequestration (mitigation) but will also provide decision support models for land managers and facilitate scientific collaboration and technology transfer (USDA Forest Service 2008).

Forest Service researchers and managers are working together to develop and test decision support tools and reference material that incorporate climate change considerations into decision making. The target audience of this program—called A Toolkit for Adapting Climate Change on Western National Forests: Incorporating Climate into Resource Management and Planning—is Forest Service managers and decision makers, ranging from ranger districts to regional offices. Other federal agencies (U.S. Geological Survey, National Park Service), universities, and other partners are participating in the program.

The Shoshone has been selected to participate in this program as a case study. The Forest will be part of the larger effort to evaluate existing ecological and management paradigms and tools. Three western national forests and national parks are paired as case studies: Olympic National Forest/Olympic National Park, Shoshone National Forest/Glacier National Park, and Sierra Nevada-Tahoe National Forest/Devils Postpile National Park.

Dr. Ron Nielsen will provide a post doctorate student to work with us this fall (2008), starting with the development of nine climate change scenarios, modeled specifically for the Shoshone. Using the climate change scenarios, forest management and planning strategies for numerous resources (invasive species, cold water fisheries, watersheds, forest health, and monitoring variables) can be evaluated. The scenarios will allow us to test hypotheses and assumptions and develop long-term plans to better respond to the uncertainty of climate change.

Information developed from this effort will be used to update this report and modify forest plan components to better address climate change. Some changes will be incorporated between the draft and final revised forest plans; others may occur after additional information is available and be incorporated into future amendments to the revised plan.

Climate change trends and expectations

Although climate change is a global occurrence, the changes in climate and their associated impacts will vary from region to region. Over the past decade, a number

of models have been developed to simulate the anticipated future climate. These scenarios are based on historical data, trends, and analysis of different plausible assumptions. While climate model simulations are continuing to be developed and refined, climate projections typically do not yet accurately address expected conditions below the regional scale in the United States.

Western forests and grasslands provide a wealth of services and products including clean water, clean air, biological habitats, recreation opportunities, carbon storage, timber, specialty commodities, fuel, and aesthetic and cultural values. Scientists have indicated that a changing climate can affect the future biodiversity and function of the ecosystems that support these services and products. Species distributions may shift, some species are likely to decline while others expand, and whole new communities may form. Forest productivity may be reduced in some instances due to a decline in photosynthesis caused by increased ozone, and productivity may be enhanced in other settings where elevated levels of carbon dioxide (CO_2) have a fertilizing effect on overall plant growth. Anticipated increases in extreme weather events outside the historic range of natural variability may alter the frequency, intensity, duration, and timing of disturbances such as fire, drought, invasive species, and insect and pathogen outbreaks. Changes in forest composition and growth may also have associated impacts on wildlife habitats, the supply of wood products, specialty markets, and recreational opportunities (Marques 2008).

Climate change will exacerbate the impact of other major stressors on national forests and national grassland ecosystems. Wildfires, non-native and native invasive species, extreme weather events, and air pollution are the most critical stressors that climate change will amplify within ecosystems. Reduced snowpack, earlier snowmelt, and altered hydrology associated with warmer temperatures and altered precipitation patterns are expected to complicate western water management and affect other ecosystem services that national forests provide (e.g., winter recreational opportunities). Drought will likely be a major management challenge across the United States. Ozone exposure and deposition of mercury, sulfur, and nitrogen already affect watershed condition, and their impacts will likely be exacerbated by climate change (Joyce et al. 2008).

For some nationwide aspects of climate change, there is a strong consensus on the types of changes to be expected.

- All of North America is very likely to warm during this century, and to warm more than the global average increase in most areas (Gray et al. 2008).
- Abnormally hot days and nights and heat waves are very likely to become more frequent, and cold days and cold nights are very likely to become less frequent over North America (Gray et al. 2008)
- It is likely that drought will continue to be exacerbated by earlier and possibly lower spring snowmelt runoff in the mountainous West, which results in less water available in late summer (Gray et al. 2008).
- Snow cover is projected to continue to decrease as the climate warms (Gray et al. 2008).
- Glaciers and terrestrial ice sheets are projected to continue to lose mass (Gray et al. 2008).
- The resilience of many ecosystems is likely to be exceeded this century by unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire, insects), and other global change drivers (e.g. pollution) (Gray et al. 2008).

- The interaction of climate change with other stressors, as well as direct stressors from climate change itself, may cause more complicated responses than have so far been observed (Backlund 2008).
- Warming has generally resulted in and is expected to continue to result in shifts of species ranges poleward and to higher altitudes (Gray et al. 2008).
- Because of the projected changes in temperature, precipitation, and CO_2 concentrations, river discharges are expected to change in many regions; the total volume of river runoff and the timing of peak flows and low flows are expected to shift significantly in some regions (Palmer 2008).

Climate change in the Greater Yellowstone Ecosystem

The Greater Yellowstone Ecosystem (GYE) has long been an area subject to climate variability. Hansen describes this climatic variability in the Yellowstone Bioregional Assessment (2006).

> While current climate strongly shapes the biota of the GYE, the legacy of past climate continues to influence modern ecological patterns. Climate here has fluctuated on the scale of millennia since glaciation and on the scale of decades in recent centuries. This change is expected to continue in the future under the influence of human induced global warming.
>
> Since the last glacial maximum some 20,000 years ago, solar radiation has varied due to the tilt of the earth and wobble on its axis (Whitlock 1993, Meagher and Houston 1998, Millspaugh et al. 2004). Temperatures were approximately 10-15^0 C colder than today and there was less precipitation. Conditions became warmer and moister during the period 12,000 – 14,000 years before present. By 9,500 years ago, solar radiation in summer had increased to about 8.5% greater than today and temperatures were 1-2^0 C (34-36^0 F) warmer. The summer dry regions of GYE became cooler and wetter starting about 5,000 years ago. The summer wet portions of the area became warmer and drier. Both regions warmed during the Medieval Warm Period, 1,000 to 650 years ago. The Little Ice Age followed (1650-1890), with coldest, wettest conditions occurring from about 1860-1890. Rapid warming and drying has occurred in the last century with about a 1^0 C (1.8^0 F) rise since 1900. Hence, the period of European settlement in the GYE was the coldest and wettest in about 14,000 years and the current period of management is within a rapid warming phase.
>
> Superimposed on this recent warming are 10-20 year cycles in temperature and moisture that result from changes in sea surface temperature in the Pacific. Yellowstone experienced cycles of high moisture during 1900-1950. Much of the time since 1950 has had below average moisture (Pederson et al. 2006). The effects of warming since 1900 and the decadal cycles of precipitation have not been well integrated into thinking about ecosystem dynamics and management in the region.
>
> Consensus among the scientific community is that humans have influenced global climate in recent decades and that this effect will intensify in the future (Houghton et al. 2001). Under the doubling of atmospheric CO_2 (expected in ca 100 years), the climate of Yellowstone is predicted to continue to warm. Both summer and winter temperatures are projected to increase by up to 10^0 C (18^0 F) (Bartlein et al. 1997). There is considerable uncertainty about future precipitation. Bartlein et al. (1997) project nearly a doubling of winter precipitation in the Yellowstone area. A more recent analysis by Schafer et al. (2001) suggested

drier than present conditions for higher elevations and moister conditions for lower elevations.

A major conclusion is the climatic conditions across the GYE for the past 100 years are not representative of many earlier periods nor indicative of likely future conditions. Climate here has varied on millennial, centennial, and decadal scales. Current vegetation patterns were likely heavily shaped by the colder and wetter conditions of the Little Ice Age. The system has been on a trajectory of warming for the past century and this is likely to intensify in the future. Embedded within this change is decadal variation in moisture. Management regimes should be designed to be robust to such changes in climate.

Climate change trends and strategies for the Shoshone National Forest

In this report, climate change trends and the management strategies to respond to them are centered on the ecological systems of the Shoshone National Forest—water, vegetation, wildlife, and disturbance processes. We understand that impacts to the Shoshone's ecological systems also produce impacts to local communities through changes in recreation, livestock grazing, and forest products—the social and economic values provided by the Forest. We did not attempt to address social and economic values separately because of the uncertainties about the direction and extent of climate change—especially at local levels—and how resources will respond.

For example, there may be changes to the location and timing of some winter outdoor recreation activities, like snowshoeing and snowmobiling. On the other hand, the seasons for hiking, backpacking, hunting, and camping may be longer. Fishing opportunities may change as fish species respond to changes in water temperature. Changes in the composition of forest stands, in the distribution of vegetation, and in the quality of forage, will affect wildlife, the production of timber, and when and where commercial livestock grazing may occur. Water will become even more important. Afforestation, the conversion of land into forest, could occur to provide the benefits of carbon sequestration and provide biofuels (Joyce et al. 2008). All these changes will affect how the Shoshone provides benefits to people.

The management direction and approaches in the forest plan are not static. As monitoring and evaluation provide information about the Forest's resources and how people are using them, and as Forest Service research provides better understanding about changing conditions, land managers will be able to determine appropriate plan direction for adaptation and mitigation.

As the climate changes, it will be more important than ever for agencies and private landowners to cooperate and collaborate to reduce stressors to the environment (especially air pollution, altered fire regimes, habitat fragmentation, invasive species, and demands on water resources). The forest plan identifies opportunities to establish baseline data, identify thresholds, and monitor ecosystems to identify ongoing changes. These data efforts can be coordinated with state and other federal agencies, Greater Yellowstone Area national forests, cooperators, and partners.

Water

Trends and expectations

The uncertainty in climate model projections of precipitation change make future projections of streamflow highly uncertain across most of the United States. One exception is watersheds that are dominated by spring and summer snowmelt, most of which are in the western United States. Temperate montane ecosystems are characterized by cooler temperatures and often increased precipitation compared to

surrounding lowlands. Consequently, much of that precipitation falls in the form of snow, which serves to insulate the ground from freezing air temperatures, stores water that is released as snowmelt during the following growing season, and triggers migration by animal species that cannot survive in deep snow.

In regions with winter snow, warming has shifted the magnitude and timing of hydrologic events. The fraction of annual precipitation falling as rain (rather than snow) increased at 74 percent of the weather stations studied in the western mountains of the United States from 1949 to 2004. Spring and summer snow cover has decreased in the West. April snow water equivalent has declined 15 to 30 percent since 1950 in the western mountains of North America, particularly at lower elevations, primarily due to warming rather than changes in precipitation (Gray 2008). In regions in which snowmelt occurs earlier due to warmer temperatures, flooding may be pronounced if high flows coincide with heavy rainfall events ("rain on snow events") (Palmer 2008). Though many models show increases in total precipitation, a pattern of decreasing precipitation trends appears in the lee of the Rocky Mountains in the northern Great Plains (National Assessment Synthesis Team 2001).

The Shoshone has a large number of glaciers, which contribute to summer stream flows. Glaciers and terrestrial ice sheets are projected to continue to lose mass as increases in summertime melting outweigh increases in wintertime precipitation (Gray 2008). The disappearance of glaciers in montane areas along with changes in patterns and abundance of meltwater from glaciers have significant implications for species that are dependent upon glaciers and melting snowpack for water supplies.

Climate change factors that may affect achievement of desired conditions

Changes in water quantity, timing, and quality are expected to become increasingly important issues under the changing patterns of precipitation projected for a warming environment. These changes will impact desired conditions for providing quality and quantity water resources and aquatic habitats, particularly for cold-water species.

How the forest plan addresses climate change adaptation

The forest plan includes direction that will

- Maintain high elevation, fully functional riparian wetlands that help store and regulate the release of water over longer periods. This may help mitigate the loss of flows from glaciers and snowpacks.
- Increase beaver colonization on streams and protection of fens; both will enhance water storage and regulate the release of water, thereby lengthening the duration of water flows, providing more water later in the year.
- Consider water storage proposals. Proposals will be addressed through site-specific analyses.
- Promote the maintenance of a mosaic of vegetation conditions across the Forest through a combination of disturbance processes, which include fire and mechanical treatments. This mosaic is the best means for reducing evapotranspiration and augmenting water yield while still meeting other desired conditions.
- Maintain water quality primarily through application of best management practices. The plan includes direction on following the Watershed Conservation Practices Handbook.
- Consider intense rain events that could generate debris flows when determining the size of need culverts at road crossings.

Ecosystem diversity

Trends and expectations

An emerging but growing body of literature indicates that over the past 3 decades, the changes in the climate system—including the anthropogenic component of warming—have caused physical and biological changes in a variety of ecosystems. These changes include shifts in genetics, species' ranges, phenological patterns, and life cycles. Most (85 percent) of these ecological responses have been in the expected direction (e.g., pole ward shifts in species distributions), and it is very unlikely that the observed responses are due to natural variability alone (Julius 2008).

Climate change affects biodiversity directly by altering the physical conditions to which many species are adapted. Although species with large geographic ranges have a wide range of physiological tolerance, species that are rare, threatened, endangered, narrowly distributed, and endemic, as well as those with limited dispersal ability, will be particularly at risk under climate change because they may not be able to adapt in situ or migrate rapidly enough to keep pace with changes in temperature. Changes in precipitation patterns may disrupt animal movements and influence recruitment and mortality rates. The projected changes in fish habitat associated with increases in temperature and changes in hydrology are likely to cause shifts in the distributions of fish and other aquatic species (Joyce et al. 2008).

Ecosystem diversity—vegetation

Trends and expectations

Simulations of future vegetation distribution in the interior West show a significant increase in woody vegetation because of enhanced water-use efficiency from elevated CO_2, moderate increases in precipitation, and a strengthening of the Arizona Monsoon, with the greatest expansion of woody vegetation projected in the northern parts of the interior West (Joyce et al. 2008). Ecosystems at high latitudes and elevations (including many coniferous forests), as well as savannas and other water-limited ecosystems, are expected to be particularly vulnerable to climate change. Temperature-induced droughts in these ecosystems are expected to contribute to forest diebacks. Which of these scenarios is most likely on the Shoshone is unknown. Though decreasing water may be the most likely, the geographic variation over the Shoshone that extends over 180 miles north to south could result in different scenarios on different portions of the Forest.

Alpine ecosystems are also projected to decrease in area as temperatures increase. Specifically, as treelines move upward in elevation, many species could be locally extirpated as they get "pushed" off the top of the mountains. Also, given the strong species-area relationship that has been shown for the "island" habitats on the tops of western mountains, species diversity could be significantly reduced as these habitats become smaller or even disappear (Joyce et al. 2008).

Climate change and associated changes in disturbance regimes will result in shifts in the distributions of tree species and the composition of forest stands. With warming, forests will extend further north and to higher elevations. Over currently dry regions, increased precipitation may allow forests to displace grasslands and savannas. Changes in forest composition in turn can alter the frequencies, intensities, and impacts of disturbances such as fire, insect outbreaks, and disease. The rates at which migration northward and to higher elevations occurs are uncertain and depend not only on climate change, but also on future land use patterns and habitat fragmentation, which can impede seed source and species migration. Despite

changing climatic conditions, long-lived plants (e.g., trees) may persist for some time in their current positions (Gray 2008).

Energy-limited ecosystems in general appear to be responding positively to warming temperatures over the past 100 years. In contrast, productivity in water-limited systems may decrease with warming temperatures, as negative water balances constrain photosynthesis, although this may be partially offset if CO_2 fertilization significantly increases water-use efficiency in plants. Littell (2006) found that most montane Douglas-fir (*Pseudotsuga menziesii*) forests across the northwestern United States appear to be water limited; under current climate projections these limits would increase in both area affected and magnitude (Joyce et al. 2008).

Ecosystem function and species composition of temperate grasslands and savannas are likely to respond to changes in precipitation patterns and warming temperatures. For example, a Canadian grassland fixed roughly five times as much carbon in a year with 30 percent higher rainfall, while a 15 percent rainfall reduction led to a net carbon loss (Gray 2008).

Carbon stocks are very likely to be strongly reduced under more frequent disturbance, especially by fire. On average, grasslands are likely to show reduced carbon sequestration (due to enhanced soil respiration losses through warming, fire regime changes, and increased rainfall variability). However, possible regional gains in woody cover (through CO_2 fertilization and increased plant carbon stocks) cannot be dismissed (Gray 2008). Forests and woody cover still sequester the largest fraction of terrestrial ecosystem carbon stock.

Climate change factors that may affect achievement of desired conditions

Species distributions will change in response to changes in precipitation, temperature, and disturbances. This is may make it more difficult to maintain species with limited distributions.

Changes in ecosystems between grasslands and forestlands will impact carbon sequestration. Carbon sequestration consideration may become a more prominent objective in the forest plan.

How the forest plan addresses climate change adaptation

The forest plan includes direction that will

- Reduce or remove the impacts from fire exclusion and conifer encroachment that could hinder an ecosystem's ability to withstand climatic events.
- Emphasize a mosaic of vegetation cover types and structures to lessen the impacts from insect epidemics and large wildland fire events.
- Manage for young, vigorous forest stands and forest and biomass products that will increase carbon sequestration as well as provide support to local economies.
- Increase the likelihood of maintaining alpine species and fen species by protecting them from stressors caused by management activities.
- Accelerate the sequestration of carbon through more aggressive reforestation of disturbed areas.
- Increase emphasis on gathering additional information on species locations.
- Increase the extent of four vegetation communities: aspen, willow (riparian), sagebrush, and grasslands. The first three are limited communities on the Forest that are highly desired. The fourth, grasslands, is extensive and may naturally expand as warming increases. The plan includes a management approach that considers climate change in selecting where to spend limited

dollars. Examples that will be considered are shifting dollars away from areas where warming temperatures and lower moisture will make it more difficult to restore aspen, and away from areas where warming temperatures and lower moisture may naturally lead to expansion of grasslands.

- Management approaches in the forest plan consider climate change when selecting species to plant and defining stocking rates in silvicultural prescriptions, helping mitigate species range changes, and decreasing precipitation. Examples include:
  - Reforesting with species tolerant to low soil moisture and high temperature.
  - Using a variety of genotypes in the nursery stock, and moving plant genotypes and species into disturbed areas from other seed zones.
  - Managing for a variety of species and genotypes with a range of tolerances to low soil moisture and higher temperatures.
  - Reforesting an area after a fire or windfall event with a type of tree species that is better adjusted to the new or unfolding regional climate. This may be difficult to achieve, because the climate that exists during the early years of tree growth will be different from those that will persist during the later stages of tree growth based on the available information.
  - Large-scale thinnings might be implemented to reduce stand densities in order to minimize drought effects, avoid large wildfire events in areas where these are not typical, and manage the potential for increased insect and disease outbreaks under a changing climate. Not all forest landscapes and stands are amenable to thinning, nor is it ecologically appropriate in some upper-elevation forest types. In these situations, shelterwood cutting that mitigates extreme temperatures at the soil surface can facilitate continued cover by forest tree species while mitigating risks of uncharacteristically severe fire, insects, and disease,
  - Proactively managing early successional stages that follow widespread mortality by deliberately reducing synchrony. Asynchrony can be achieved through a mix of activities that promotes diverse age classes, species mixes, stand diversities, genetic diversity, etc., at landscape scales. Early successional stages are likely the most successful (and practical) opportunities for resetting ecological trajectories that are adaptive to present rather than past climates, because this is the best chance for widespread replacement of plants. Such ecological resetting is evidenced in patterns of natural adaptation to historic climate shifts (Joyce et al. 2008).

Ecosystem diversity—wildlife

Trends and expectations

Climate change affects biodiversity directly by altering the physical conditions to which many species are adapted. Although species with large geographic ranges have a wide range of physiological tolerance, species that are rare, threatened, endangered, narrowly distributed, and endemic, as well as those with limited dispersal ability, will be particularly at risk under climate change because they may not be able to adapt in situ or migrate rapidly enough to keep pace with changes in temperature. Changes in precipitation patterns may disrupt animal movements and influence recruitment and mortality rates. The projected changes in fish habitat

associated with increases in temperature and changes in hydrology would cause shifts in the distributions of fish and other aquatic species (Joyce et al. 2008).

Changes in snowpack and snow accumulation will affect montane species. The disappearance of glaciers in most montane areas along with changes in patterns and abundance of meltwater from glaciers have significant implications for species that are dependent upon glaciers and melting snowpack for water. Species such as deer, bighorn sheep, and elk that cannot survive in deep snow and move to lower elevations for the winter may also be affected by changing temporal patterns of snowpack formation and disappearance (Gray 2008). These changes may result in shifting locations for big game winter ranges. Some of this shift may be positive if winter ranges shift from private lands to forest lands that are at higher elevations. Wolverine and Canada lynx, two species that depend upon deep snow cover, may be adversely affected.

Fisheries are sensitive to changes in water temperature and supply. Increased temperatures can lead to seasonal increases in fish growth but may also increase risks at the upper end of their thermal tolerance. Cold-water fisheries will likely be negatively affected by a warming climate, warm-water fisheries will generally benefit, and the consequences for cool-water fisheries will be mixed (Gray 2008). One estimate indicates that cold-water fish habitat may decrease by 30 percent nationally and by 50 percent in the Rocky Mountains by 2100 (Joyce et al. 2008).

Temperature and precipitation changes will impact freshwater animals, such as amphibians, where migration to breeding ponds and the production of eggs is intimately tied to temperature and moisture availability. Evidence is beginning to accumulate that links the spread of pathogens to a warming climate. For example, the chytrid fungus is a pathogen that is rapidly spreading worldwide and decimating amphibian populations (Gray 2008).

Elevated atmospheric CO_2 concentrations can affect forage quality. Elevated atmospheric CO_2 can increase the carbon to nitrogen ratio in forages, reducing their nutritional value (Gray 2008).

Climate change factors that may affect achievement of desired conditions

Shifts in big game winter ranges may impact where winter range direction is applied.

The ability to provide habitat for some species may be affected. Specifically 1) species that do not readily adapt to changes in habitat will be more at risk, 2) species that need deep snow cover will be more at risk, 3) changes in water temperature and flow will affect fish species, and 4) amphibians may be affected by changes in temperature and moisture availability and an increase in diseases.

Changes in forage quality could affect both big game species and commercial livestock grazing.

How the forest plan addresses climate change adaptation

The plan contains direction that will

- Focus management attention on decreasing stressors and monitoring species of concern and interest that are endemic or declining.
- Manage habitat that should help reduce stressors for species, including Canada lynx, grizzly bear, and wolverine.
- Expand the occupied range of Yellowstone cutthroat trout.
- Maintain habitat connectivity, which is crucial to provide the opportunity for species to shift ranges in response to climate change and resulting ecosystem changes.

- Maintain open space in connection with livestock operations. The loss of open space is of particular concern because it may impede species' migration during extreme climatic events, and possibly result in increased population extirpation (Joyce et al. 2008).
- Stress the need to work with the Wyoming Game and Fish Department to identify shifts in winter ranges that may require changes in where management direction for winter range is applied. Changes to forage and winter range may influence management needs for big game species and associated management of livestock. Winter ranges may expand to higher elevations or the timing of seasonal movements may change. These shifts, along with changes in forage nutritional value, may require a reassessment of management of forage resources on the Forest. These are long-term changes that will be addressed in future planning periods, but deserve watching as we move through the current planning period.
- Consider the effects of climate change when selecting areas to expand Yellowstone cutthroat trout
- Emphasize the need to coordinate with others on a long-term strategy to gather genetic material, to preserve the opportunity for reintroduction of species that may be locally extirpated.
- Increase the emphasis on managing riparian ecosystems to mitigate the effects of warming temperatures on water temperature and cold-water fisheries.

Invasive species

Trends and expectations

Some invasive plants are expected to respond with greater growth rates than non-invasive plants. Invasive plants in general may better tolerate a wider range of environmental conditions and may be more successful in a warming world because they can migrate and establish new sites more rapidly than native plants, and they are not usually limited by pollinators or seed dispersers.

The positive response to current (from pre-industrial) levels of atmospheric CO_2 by six invasive weeds—Canada thistle, field bindweed, leafy spurge, perennial sowthistle, spotted knapweed, and yellow star-thistle—suggests that 20th century increases in atmospheric CO_2 may have been a factor in the expansion of these invasives (Joyce et al. 2008).

The rate of cheatgrass invasion is related to temperature at higher elevations and soil water availability at lower elevations. Increased variability in soil moisture and reductions in perennial native herbaceous cover can increase susceptibility of low-elevation sites to cheatgrass invasion. Once established, non-native annual and perennial grasses can generate massive, high continuity fine-fuel loads that predispose arid lands to fires more frequent and intense than those with which they evolved (Gray 2008).

Climate change factors that may affect achievement of desired conditions

More rapid expansion of invasive plants, especially cheatgrass, may impact native species and natural ecosystem processes.

How the forest plan addresses climate change adaptation

The plan includes direction that will target the control of existing populations of invasives and the elimination of new populations. Direction is included specifically for cheatgrass.

Disturbances (insects, diseases, and fire)

Trends and expectations

Insects and diseases are a natural part of forested ecosystems; they are nearly always present at endemic levels within terrestrial ecosystems. However, when conditions are right, their populations can increase dramatically to epidemic levels with a corresponding increase in the damage they produce. Their effects vary from defoliation and retarded growth, to reduction in timber quality, to massive forest diebacks. Insect life cycles are sensitive to climate variables which can be important factors in determining when they increase to epidemic levels.

Warmer temperatures facilitate bark beetle outbreaks in two ways: 1) drought stress makes trees more vulnerable to attack, and 2) insect populations respond to increased temperatures by speeding up their reproductive cycles (e.g., to one-year life cycles). Warming temperatures would be expected to exacerbate these outbreaks and facilitate their spread northward and eastward across the continental divide. Warmer temperatures, in combination with beetle mortality, set up some ecosystems for shifts in species dominance that will be mediated by disturbances such as fire (Joyce et al. 2008). Research suggests that warming temperatures are resulting in an expansion of suitable range for mountain pine beetle and increase the probability of spruce beetle outbreak (Gray 2008).

While in some cases a changing climate may have positive impacts on the productivity of forest systems, changes in disturbance patterns are expected to have a substantial impact on overall gains or losses. Earlier spring snowmelt contributes to greater wildfire frequency and faster spreads by extending the period during which natural ignitions could potentially occur and by reducing water availability to ecosystems in midsummer, thus enhancing drying of vegetation and surface fuels. In the last 3 decades, the wildfire season in the western United States increased by 78 days, and burn durations of fires greater than 1,000 hectares (2,470 acres) have increased from 7.5 to 37.1 days, in response to a spring/summer warming of 0.87°C. Earlier spring snowmelt has led to longer growing seasons and drought, especially at higher elevations, where the increase in wildfire activity has been greatest. These trends in increased fire size correspond with the increased cost of fire suppression (Gray 2008).

Land use influences do not appear to have altered fire regimes in high elevation forests with long fire return intervals (Joyce et al. 2008). This finding is supported by findings for high elevation spruce/fir forests on the Shoshone (Meyer et al. in review). With warming temperatures, fire regimes for these high elevation forests may be altered. The potential for increased fire activity in high elevation forests could be exacerbated by the increased fuel loads expected to result from enhanced winter survival of mountain pine beetles and similar pests (Joyce et al. 2008).

Future climate change may offer opportunities to conduct prescribed fire outside traditional burn seasons, with increased accessibility in some areas in the winter (Joyce et al. 2008).

Climate change factors that may affect achievement of desired conditions

Increases in bark beetle outbreaks and wildland fire size and intensity, decreasing precipitation, and higher temperatures may make it difficult to meet desired conditions for some cover types.

How the forest plan addresses climate change adaptation

The plan includes direction that will

- Develop a mosaic of species and stand structures using a combination of natural fire, prescribed fire, and mechanical treatments. This approach reduces stand susceptibility to large fires and insect epidemics that cover large areas.
- Mitigate the impacts of wildland fire and insect epidemics by using variations of the silvicultural strategies discussed earlier. These may involve intensive treatments, such as those used in high-value agricultural situations: resistance breeding, novel pheromone applications (such as sprayable micro-encapsulated methods), complex pesticide treatments, and aggressive fuelbreaks. Additionally, resistance practices include thinning and fuels abatement treatments at the landscape scale to reduce crown fire potential and risk of insect epidemic, maintaining existing fuelbreaks, strategically placed area treatments that will reduce fuel continuity and drought susceptibility of forests, and creating defensible fuel profile zones around high-value areas (such as the wildland urban interface, critical habitat, or public water supplies).

References cited (in progress)