Changing Climates: Past, Present, and Future

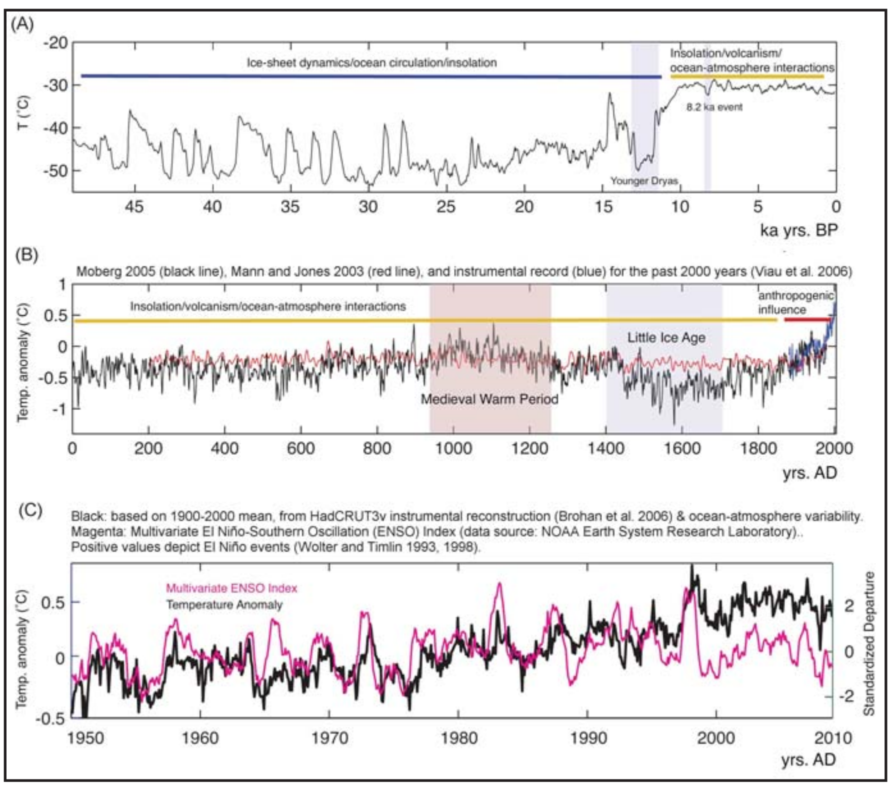
Middle Teton Glacier, Grand Teton National Park

Climate is the collection of long-term average meteorological conditions that are characteristic of a region. These conditions include patterns of temperature variation, precipitation, humidity, atmospheric pressure, wind speeds and direction, and many other elements that are the primary forces shaping the structure and distribution of ecosystems, natural processes, and the species that depend on them. Throughout the history of earth, climate change at many scales has dramatically altered ecosystem dynamics by shifting plant communities, creating opportunities for recruitment of new species, and restructuring land surface processes and nutrient cycles. Management planning must address the consequences of on-going change.

Climate patterns and processes

Unlike weather, which can be highly variable from day to day and month to month, climates are relatively stable over large areas, with patterns of variation that are evident on scales from decades to centuries to thousands of years. Climate variations on time scales of 10,000-100,000 years are attributed to slow fluctuations in the earth's orbit that lead to changes in global average temperatures, driving numerous glacial and interglacial cycles over the past several million years. Over periods of thousands of years, the presence or absence of large North American ice sheets has been a major influence on ocean ice-atmosphere interactions driving changes in atmospheric circulation patterns. On shorter time scales, climate variation at the scale of tens to hundreds of years is related to changes in solar activity, volcanism, sea surface temperature and pressure anomalies in both the Atlantic and Pacific Oceans, as well as more recent changes driven by human activities and arising from rapidly increasing atmospheric greenhouse gas and aerosol concentrations.

Knowledge of natural variations in climate provides a context for understanding how communities and individual species might respond to both current and predicted future rates of change. For instance, climate change may lead to widespread bark beetle outbreaks, increased forest fire activity and stress related tree mortality, and rapid changes in glacier mass balance, snowpack and streamflow.



Primary drivers of climate and resulting climate variations at millennial, centennial, and interannual scales. (A) Temperature reconstruction from the central Greenland (GISP2) ice core record (B) Temperature anomalies for the Northern Hemisphere based on multiple proxy data (e.g., ice core, ice borehole, lake sediment, pollen, diatom, stalagmite, foraminifera, and tree-ring records) for the past 2000 years. (C) Recent global temperature anomalies from HadCRUT3v instrumental reconstruction and ocean-atmosphere variability (El Niño/La Niña Southern Oscillation - ENSO).

How do we know about past climates?

Reconstructions of past climatic conditions and the associated ecological response use a number of direct and indirect measurements of past change. Direct measurements include ground temperature variations, gas content in ice core air bubbles, ocean sediment pore-water change and glacier extent changes. Indirect measurements typically come from organisms (e.g., trees, corals, plankton, diatoms, chironomids and other life forms, both living and fossil) that are sensitive to changes in climate, and show climate-related changes in growth rates, abundance, or distribution. Lake sediments, tree-ring cores, and packrat middens are three of the primary indirect sources used for reconstructing past conditions for the western United States.

Photo courtesy P. Higuera.

Obtaining lake sediment core, Rocky Mountain National Park.

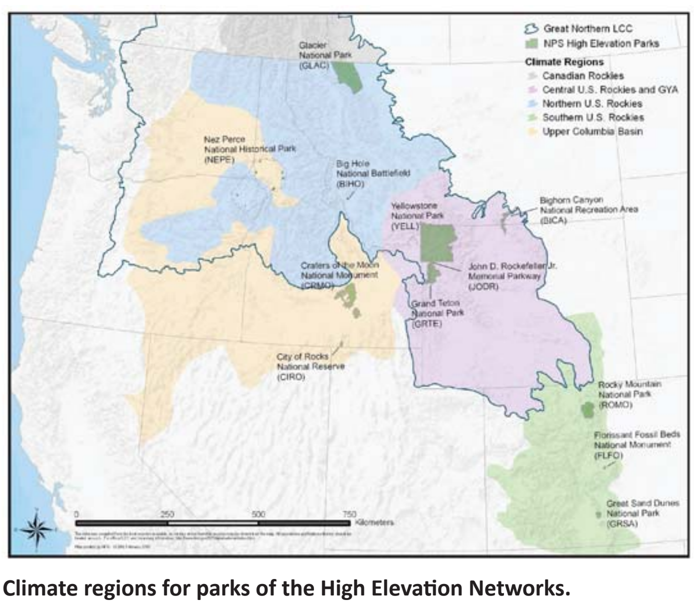
Photo D. McWethy

Obtaining tree-ring core, Crazy Mountains, Montana.

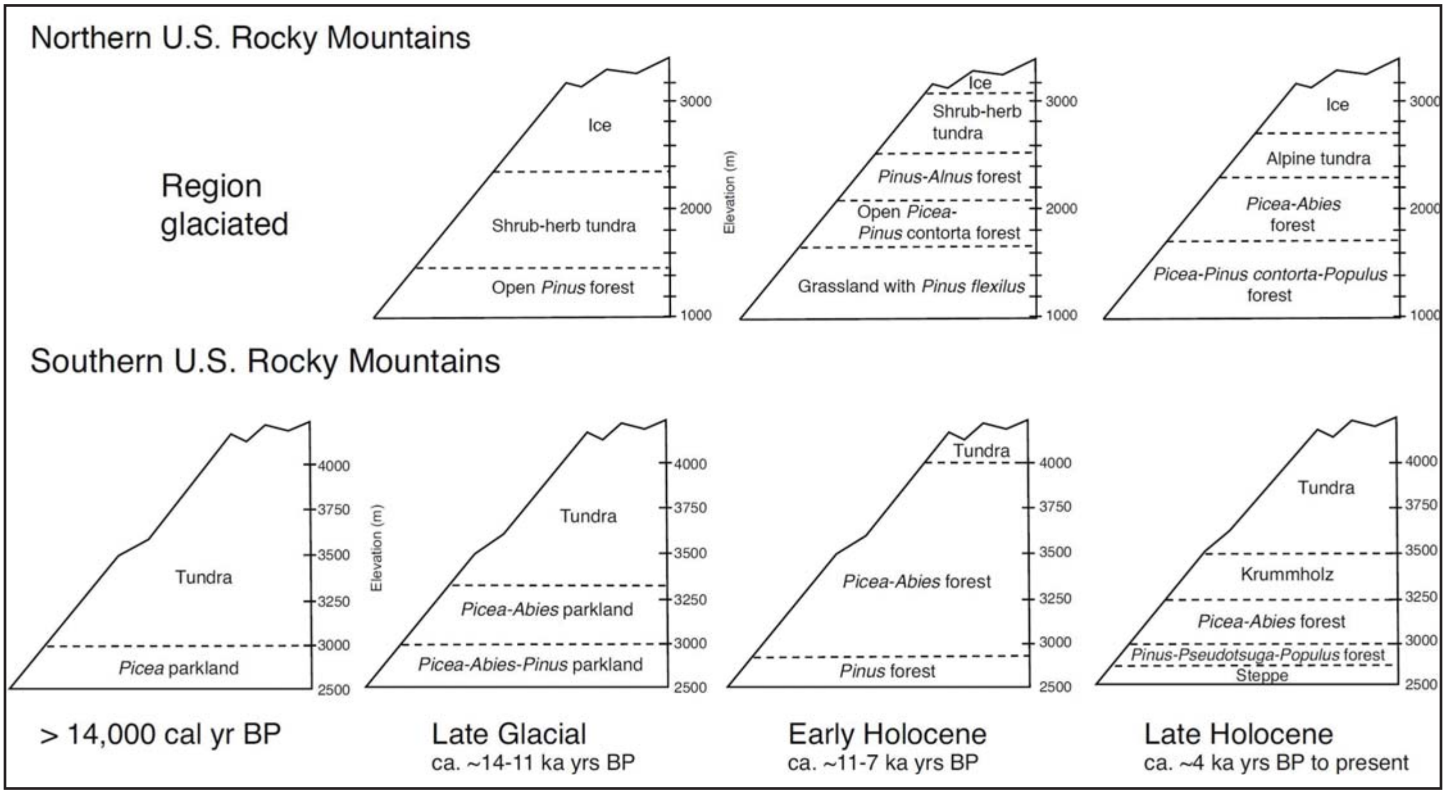
Climates of the past

Information about past conditions suggests that future changes in precipitation patterns will also be regionally variable, and that boundaries between precipitation regimes are likely to be quite sharp in mountainous regions. The western United States is influenced by two precipitation regimes: a summer-dry area under the influence of the northeastern Pacific subtropical high-pressure system (the Northwest) and a summer-wet region strongly influenced by summer monsoon circulation (the Southwest). These two regimes were enhanced during the early Holocene, when summer solar radiation was higher than at present. As a result, summer-wet areas became wetter and experienced fewer fires than at present, and summer-dry areas became drier with more fires and drought-tolerant vegetation than at present. In most regions, the modern vegetation and climate were established during the late Holocene (the last 4000 years).

In general, climate-driven vegetation changes have resulted in similar plant communities appearing at lower elevations with increasing latitude. Prior to 14,000 years ago, much of the Northern Rocky Mountains were glaciated. The Upper Columbia Basin was ice covered in higher elevations, while lower elevations were characterized by tundra above open pine woodlands. Further south, the Central Rocky Mountains and Greater Yellowstone Area were dominated by tundra, and the Southern Rocky Mountains experienced cooler and wetter conditions that supported tundra vegetation at high elevations (~300-700 m below present treeline), with spruce parkland at low elevations.



Climate regions for parks of the High Elevation Networks.



Examples of ecological response to changing climatic conditions following glacial retreat in the western U.S.
Northern U.S. Rocky Mtns. derived from MacDonald 1989 and Reasoner and Hickman 1989 (Whitlock unpublished). Southern U.S. Rocky Mtns. derived from Fall 1997.

Lessons from the paleoenvironmental record

Overlapping climate changes occurring on multiple time scales means that no period in the last 20,000 years is an exact analogue for the future.

Key Lessons:

- Natural variations in climate and the accompanying ecological responses occur at multiple temporal and spatial scales, all of which must be understood to explain modern plant communities and their distributions. Paleoecological data provide evidence of a range of responses that are not adequately represented in the last two centuries. A baseline of natural variability for restoration efforts must therefore consider a longer time scale.
- Many terrestrial ecosystems in the study region were established during the last 3,000 to 4,000 years in response to gradual cooling and increased effective moisture in the late Holocene. More subtle changes occurred during the Medieval Climate Anomaly and Little Ice Age. The sequence of events that led to present vegetation is not likely to be repeated in the future, which argues against strategies to restore to a reference condition. Instead, we need process-based approaches and flexible management responses.
- Key ecosystem processes such as fire are driven by climate at large spatio-temporal scales. Patterns of fire in the 20th century poorly represent the potential range of fire regimes that have occurred in the past and may occur in the future.

Colorado Natural Heritage Program Photo

Treeline, Great Sand Dunes National Park & Preserve

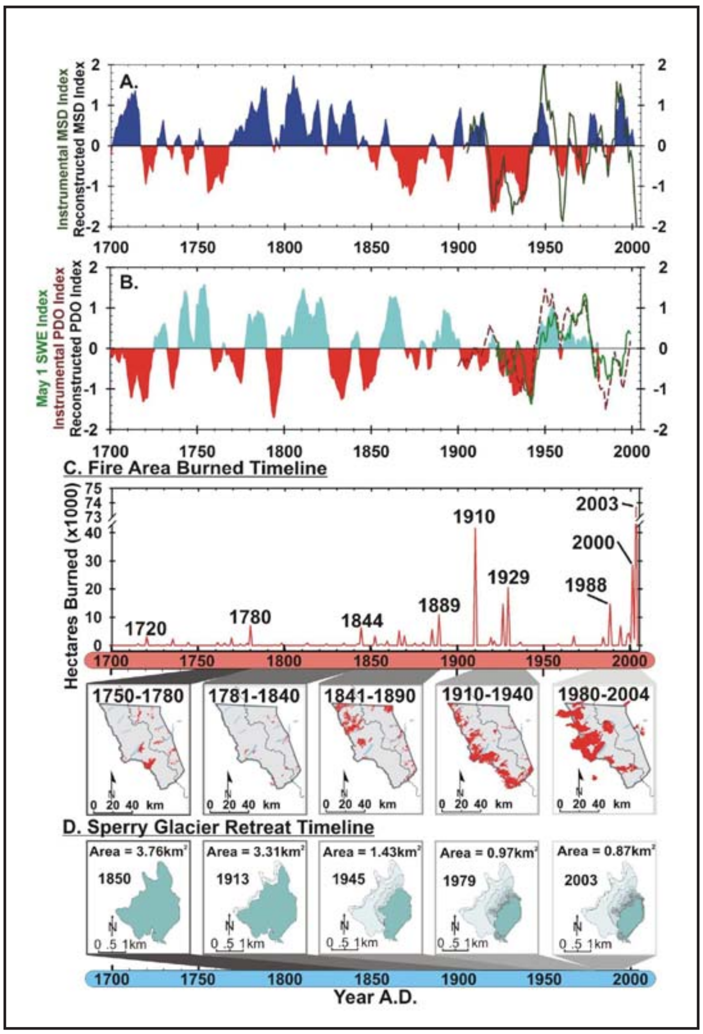
Climate change in the recent past

Over the course of the 20th century, average annual temperatures have increased by 1-2°C in the Northern Rocky Mountains. Seasonal and annual minimum temperatures are generally increasing at a rate greater than that of the maximum temperatures. Because summer and winter seasonal average minimum temperatures are increasing at a significantly faster rate than average maximum temperatures, daily temperature ranges are becoming narrower.

Although few statistically significant long-term trends can be derived from regional 20th century precipitation time series data, rising temperatures throughout the western U.S. have led to an increasing proportion of precipitation falling as rain instead of snow. Over the second half of the 20th century, studies have demonstrated a statistically significant decrease in the amount of water present in winter snowpack across the region. Additionally, earlier onsets of springtime snowmelt and streamflow have been documented.


NPS Photo

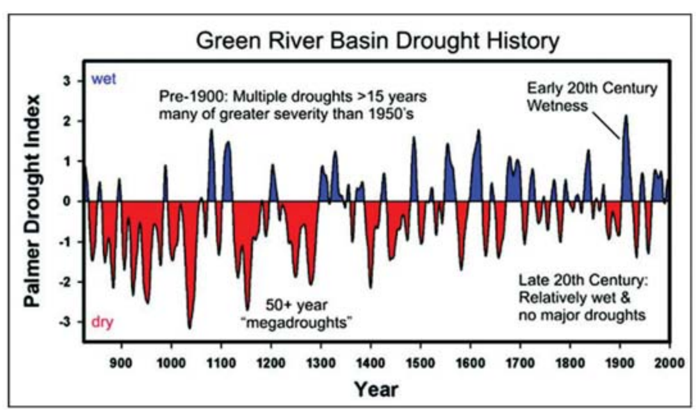
Flooding in Glacier National Park.



Relationship between Glacier National Park summer drought (a), inferred winter snowpack (b), fire area burned (c), and glacial recession 1700 to present (d). Source: Pederson et al. 2006, American Meteorological Society; reprinted with permission.

In comparison with the Northern Rockies, the Southern Rockies have experience a smaller increase in average annual temperature of 0.5-1°C. Warming is evident at almost all locations, but temperatures have increased the most in the north central mountains and the least in the San Juan Mountains of southwestern Colorado. Only the Arkansas River Valley in southeastern Colorado shows a slight cooling trend during the 20th century; no trend is evident in this area for the second half of the century.

Precipitation records for the Southern Rocky Mountains for the last century indicate highly variable annual amounts and no long-term trends. As elsewhere in the interior West, a greater proportion of precipitation is falling as rain rather than snow than in the past, but these changes are less pronounced than in the northern Rockies.



Drought history in the Green River Basin of southwest Wyoming (reconstructed from tree rings, Cook et al. 2004). Positive values (blue) indicate wet conditions and negative values (red) drought. Each point represents mean conditions over a 25-year period.
Source: Gray and Andersen 2010.

Lessons from the 20th century record

Small changes can have large impacts. Evidence from a number of studies suggests that even small temperature increases can have dramatic impacts on water availability for much of the western United States. Along with changes in snowpack and earlier spring runoff, the predicted temperature increases will likely contribute to increased drought severity, duration, and frequency. While ecosystems are adapted to natural variations in water availability, a shift in drought frequency and magnitude, or even the occurrence of an especially severe and prolonged dry event, could result in regional ecosystems reaching a tipping point whereby a major redistribution of vegetative communities ensues.

Key findings:

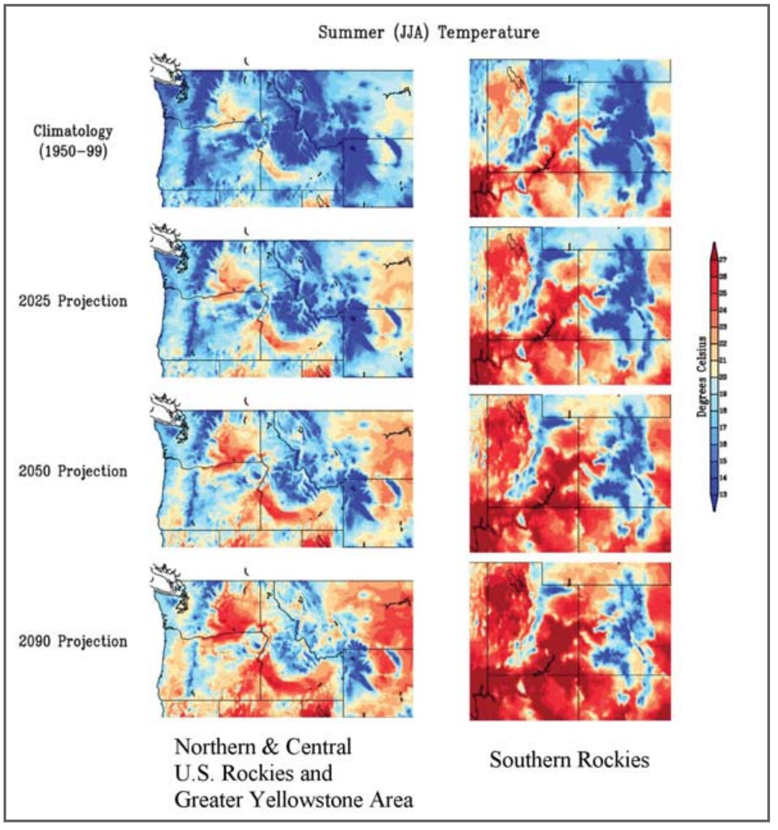
- Climate changes are variable between regions, and at different elevations.
- Temperature changes have been documented, but changes in precipitation are more difficult to quantify.
- Using the last century as a baseline for climate conditions does not capture important scales of natural climate variability and is often an inadequate reference for considering future climate change.
- Even large-scale climatic changes can have spatially variable impacts due to interactions among a number of controlling factors. For example, cooling during the Little Ice Age, evident at the scale of the Northern Hemisphere, occurred asynchronously or may not have registered at some locations.
- Rapid climate changes and associated ecosystem responses have occurred in the past and will likely occur in the future.

What can we expect in the future?

Many of the climate trends evident in the past century are expected to continue in the future. The influence of human activities in the climate system, primarily changes in greenhouse gases and aerosol concentrations, will be superimposed on natural drivers of climatic change. Past variability tells us that future conditions are also likely to be highly variable, and that our predictions are correspondingly uncertain. There is, however, widespread agreement that extreme climate conditions will increase in the future.

Temperatures are predicted to show a general increase across the landscape in the coming decades, but potential changes in precipitation are less well understood. Increasing temperatures in the near future mean that much of the western United States will be vulnerable to increased frequency and duration of drought conditions.

Models generally predict increased but highly variable precipitation for parts of the Upper Columbia Basin and the northern and central Rockies. Potential decreases in precipitation are predicted for parts of the central and southern Rockies.



Summer observed average temperatures and statistically downscaled projections for the Southern Rockies.
Observed average June-August temperature for 1950-1999 (top panel). Projections were calculated by adding the multi-model average temperature changes to the 4-km PRISM climatology. Observed climatological averages are from PRISM (DiLuzio et al. 2008), projected changes from the IPCC (CMIP3) 22-model average for the A1B emissions scenario.
Source: Ray et al. 2010; used with permission.

Changes in precipitation patterns may include a greater proportion of winter precipitation falling as rain than snow, decreased snow season length at most elevations, decreased spring snowpack, earlier snowmelt runoff and peak streamflows, increased frequency of droughts and low summer flows, and amplified dry conditions due to increased evapotranspiration even in places where precipitation increases. Underground recharge may decline with decreases in snowpack, and variability in mid-latitude precipitation is expected to increase.


NPS Photo

Fire at Craters of the Moon National Monument & Preserve.

As temperature and precipitation patterns change, the incidence of extreme conditions is predicted to increase, resulting in more episodes of extreme temperatures, increased frequency of extreme precipitation (storm) events, rain on snow and consequent winter/spring floods in mountains, and more frequent droughts. Increasing temperatures are likely to continue the recently observed trend for earlier blooming dates for many plant species, and a lengthened growing season and increased productivity where moisture/soil fertility and other factors are not limiting. Finally, changes in magnitude and frequency of disturbances linked to drought stress are likely to result in a higher frequency of large fires, a longer fire season and an increased area of western U.S. burned by fire, Greater drought stress will likely result in more insect infestations and disease affecting forests.

Planning for future climates

Planning for highly uncertain future conditions presents a significant challenge for land managers. However, techniques developed for business, finance and military applications can provide tools for planning in the face of large uncertainties. “Scenario planning” is one such approach that uses a combination of scientific input, expert opinion, and forecast data to develop alternative scenarios for the future. In scenario planning, a suite of alternative scenarios can be used as a starting point for exploring species or ecosystem vulnerabilities under a wide range of future conditions, and as a means for examining how management strategies might play out in the face of multiple drivers of change.

High levels of uncertainty about how ecosystems will respond to changing conditions should not paralyze managers planning for the future. Paleoenvironmental records from the past suggest that many ecosystems are resilient to climatic change across a variety of time scales, but that we should expect novel vegetation assemblages to occur in the future. Managers should anticipate dynamic and variable redistribution of vegetation across landscapes in the western U.S. and, as a result, might best plan for the future by supporting this dynamic redistribution by continuing to employ sound resource management and conservation practices. Management of areas surrounding protected areas in ways that work in concert with management objectives might include increasing connectivity, providing buffer habitat around protected areas and mediating human impacts both within and around public lands. Management actions that work to accommodate dynamic and unpredictable redistributions of vegetation will help protect our most valued resources.

For more information:

Natural Resource Reports:
http://www.nature.nps.gov/publications/NRPM/nrr.cfm

2010/260 Climate and Terrestrial Ecosystem Change in the U.S. Rocky Mountains and Upper Columbia Basin: Historical and Future Perspectives for Natural Resource Management

2010/220 Observed and projected ecological response to climate change in the Rocky Mountains and Upper Columbia Basin: A synthesis of current scientific literature.

Greater Yellowstone Inventory and Monitoring Network
http://science.nature.nps.gov/im/units/gryn/

Rocky Mountain Inventory and Monitoring Network
http://science.nature.nps.gov/im/units/romn/

Upper Columbia Basin Inventory and Monitoring Network
http://science.nature.nps.gov/im/units/ucbn/