MOUNTAIN VIEWS

The Newsletter of the Consortium for Integrated Climate Research in Western Mountains

CIRMOUNT

Informing the Mountain Research Community

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Mountain Views

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The Mountain Views Newsletter

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Welcome to Mountain Views, the biannual newsletter of the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT). With our third volume (5th issue) of the *Mountain Views* Newsletter (MVN), we begin our third year of publication. CIRMOUNT provides a forum for the mountain science community in western North America to integrate and communicate research from diverse disciplines related to climate. CIRMOUNT also seeks to promote awareness and solutions to the serious societal issues arising from changing climates. Among other events in recent months, CIRMOUNT hosted its fifth session at the Fall 2008 meeting in San Francisco of the American Geophysical Union. The session focused on complex interactions of climate with ecosystems and options for adaptation and conservation. The schedule for the MTNCLIM Conferences, CIRMOUNT's flagship event, is now on alternating years with sister series, the PACLIM Workshops. PACLIM will meet this year on April 19–22, 2009 at Asilomar, Pacific Grove, California. Contact Scott Starrat (sstarrat at usgs.gov) for information. MTNCLIM will next convene in spring 2010—we are still evaluating locations, so please stay tuned. Archives for all CIRMOUNT meetings as well as prior issues of *Mountain Views* are on our website: www.fs.fed.us/psw/cirmount/.

Mountain Views is a clearinghouse for information on recent developments in our field, including summaries of new findings about the state of regional and larger-scale climate patterns and related environmental and ecological-science activities bearing on western society. CIRMOUNT is committed to delivering sound and useful science that serves policy, conservation, and resource management in light of climate change.

To this end, we are especially pleased to present this special issue of *Mountain Views* on "Adapting to Climate Change in Mountain Ecosystems". In the rush of recent interest to address climate concerns in mountain environments, a resounding urgency has come from resource managers for assistance to develop science-based planning and management strategies for western forest and rangelands, watershed, fuels and fire management, and biodiversity conservation. At MTNCLIM 2008, convened in Silverton, CO in June, the program featured a special session on adaptation.

We thank David L. Peterson, Research Biologist and Team Leader with the USFS PNW Research Station, for serving as guest editor of this special issue. Dave introduces the issue with background on the novel challenges facing resource managers as they attempt to integrate climate into their already overfilled job requirements.

Among the greatest challenges in Western forests are the historically unprecedented interactions of climate change with forest stressors such as fire, insects, and disease. Donald McKenzie and Jeremy Littell address options for adapting to the complex uncertainties of these situations. Water is an especially critical climate issue for the arid West, and Jim Prairie and Carly Jerla review interim climate guidelines for the Colorado River basin. Jill Baron and Linda Joyce summarize key findings from the federal Climate Change Science Program's Synthesis and Adaptation reports relevant to Western mountain adaptation. Success stories are especially valued at this early stage. David Spittlehouse outlines strategies that have been effectively developed for Canadian forested ecosystems, and Kathy O'Halloran offers suggestions from her experience with US Forest Service national forests. Participants to MTNCLIM 2008 learned firsthand of the active engagement of scientists and stakeholders in the San Juan Colorado regional climate partnership, summarized by Koren Nydick as the final contribution.

As we have noted previously, we welcome contributions from the readers on subject matters such as have been presented in this and previous issues of the Newsletter. These topics include scientific aspects of climatic variations and change, on past, emerging and potential future impacts of such changes on the management of water, forest, and ecosystem resources, and on studies of the ongoing demographic changes in the region as they interact with changes in climate.

Adapting to Climate Change in Mountain Ecosystems—A New Challenge for Resource Management

David L. Peterson

U.S. Forest Service, Pacific Northwest Research Station, Seattle, WA

Planning and management for the anticipated effects of climate change on natural resources is in its infancy in mountain ecosystems in North America. Despite the fact that over 20 years of data are available from federally funded research programs, most agencies have been slow to integrate climate change as a factor in projected future conditions of resources, planning strategies, and on-the-ground applications. This slow response is due to absence of a policy-driven mandate to respond to climate change, lack of local information on which to base decision-making, reticence to address a complex issue for which the magnitude and timing of anticipated changes are uncertain, and a division of values among stakeholders.

Awareness of the need to incorporate climate change into resource management and planning has increased in association with the Fourth Assessment by the Intergovernmental Panel on Climate Change and in western North America well-publicized reports on regional climate and hydrologic trends. Recent efforts on adaptation to climate change have focused primarily on conceptual issues addressed through general scientific discussion, social and economic adaptation, and proposed actions by governmental institutions.

Efforts to develop strategies that facilitate adaptation to documented (e.g., altered hydrologic systems) and expected (e.g., increased area burned by wildfire) responses to climate change are now beginning in earnest in North America. In the most substantive efforts to date, the Government of Canada (see article below by Spittlehouse) and U.S. Climate Change Science Program (see article below by Baron and Joyce) have developed summaries of adaptation options for resource managers. Recent discussions on adaptation emphasize the importance of implementing adaptive management (in a general sense, as opposed to adaptation to climate change), with resource monitoring as a critical feedback to evaluation of management strategies.

Federal agencies in the U.S. have been criticized for being slow to respond to mitigation and adaptation concerns on federal lands despite the huge volume of scientific literature documenting a warming climate and effects of climate change on natural resources. Nevertheless, in my experience, resource managers at local administrative units (e.g., national forests, national parks) have a strong interest in understanding the effects of climate change on resources, have demonstrated grass-roots leadership on this issue, and are anxious to undertake the job of adapting to those changes.

As part of the MtnClim conference in Silverton, Colorado in June 2008, a special session explored adaptation to climate change for a wide range of natural resources, and a workshop on adaptation was convened to connect local resource managers with scientists. This issue of Mountain Views focuses on information and ideas that emerged from MtnClim 2008, with articles written by speakers at the conference. With considerable uncertainty about the magnitude and timing of effects of climate change on natural resources, we are taking our first steps into the field of adaptation. Communication of ideas at an early stage in this important undertaking will ensure that we move forward quickly and thoughtfully.

Climate Change, Fire, Insects, and Disturbance Interactions: Adaptation Challenges in the West

Donald McKenzie
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Jeremy S. Littell
University of Washington, Center for the Study of Earth Sciences, Climate Impacts Group, Seattle, WA

Terrestrial ecosystems may experience widespread mortality of vegetation from the direct effects of changes in temperature and precipitation (Breshears et al. 2005, Lutz and Halpern 2006, van Mantgem and Stephenson 2007) and from increased extent, intensity, and frequency of disturbance (Overpeck et al. 2000, McKenzie et al. 2004, Gedalof et al. 2005, Littell et al. 2009a). New ecosystem types, comprising heretofore rare or non-existent combinations of species, may succeed those no longer adapted to new climates, changing landscape structure and spatial pattern across a range of scales. Anticipating these changes is challenging, but needed to support long-term planning by those in charge of managing natural resources and maintaining the myriad services that ecosystems provide.

Increasing moisture limitations are likely to change species composition and productivity across the West by locally favoring more xeric species, creating episodes of vegetation dieback, and altering mortality and turnover rates. Nevertheless, disturbances and their interactions, exacerbated by warming temperatures, will alter ecosystems more rapidly, and possibly abruptly, than the direct effects of changing climate (Figure 1 – McKenzie et al. 2008).

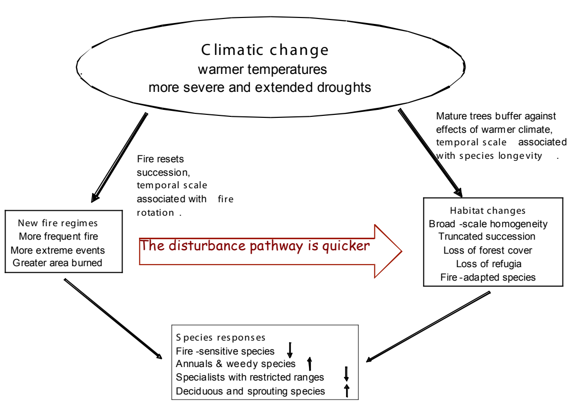

Figure 1. Relative time scales for fire vs. climate change alone to alter ecosystems: changing disturbance regimes produce more rapid change than climate alone.

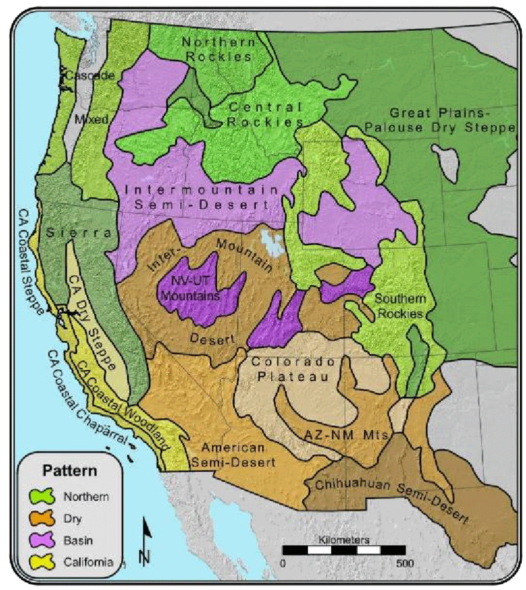

Figure 2. Four distinct geographic patterns across the West, each associated with different climate drivers of area burned. From Littell et al. (2009a).

Two important disturbances in forests of the West are wildfire and outbreaks of the mountain pine beetle (MPB – Dendroctonus ponderosae). Wildfire has been linked to climatic variability via studies of Holocene charcoal sediments, fire-scar and stand-age reconstructions of fire history, and statistical models using 20th-century instrumental records (McKenzie et al. 2004 and references therein). Of particular concern are increases in fire area in a warming climate and the effects of extreme wildfire events on ecosystems (Gillett et al. 2004, Gedalof et al. 2005). For example, in 2006, the Tripod Complex Fire in north-central Washington burned over 80,000 ha, much of it higher severity than expected from historical fires.

Climate drivers of synchronous fires differ regionally. Littell et al. (2009a) identify four distinct geographic patterns across the West, each associated with a unique set of climate drivers of annual area burned by wildfire (Figure 2). For example, in northern mountain ecosystems ("Northern" pattern, Figure 2), variables representing current year's climate were the best predictors of

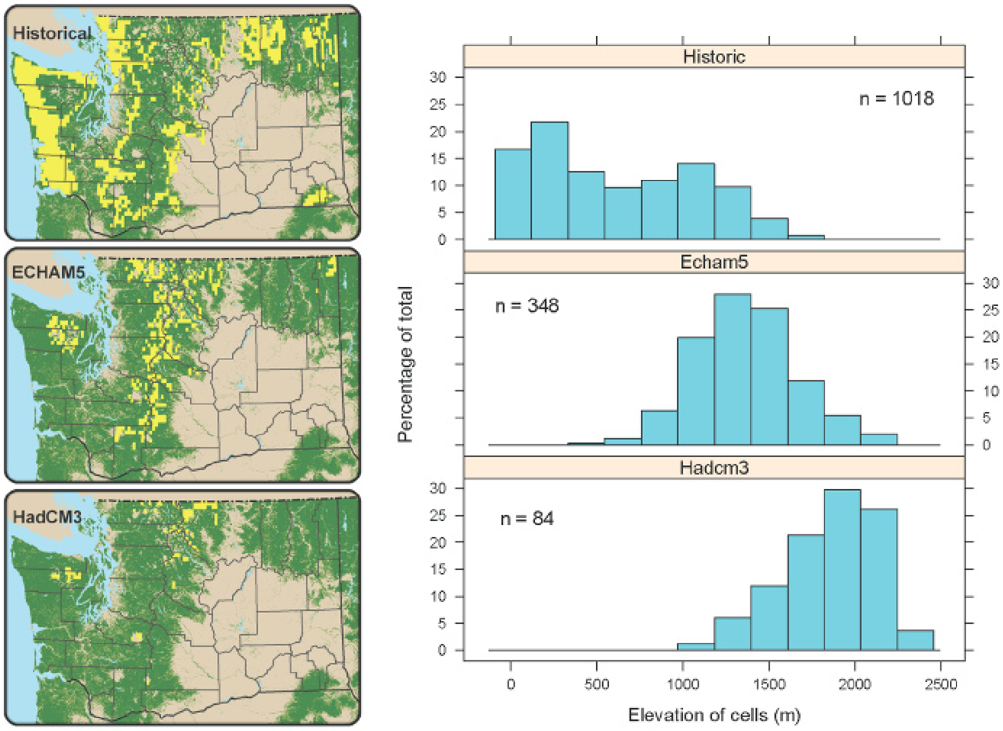

Figure 3. Adaptive seasonality of mountain pine beetle in Washington forests for historical (1970-1999), ECHAM5, and HadCM3 future scenarios for the 2080s (SRES scenario A1B). Yellow cells are suitable space for the beetle. Histograms show the change in elevation distribution across scenarios for suitable cells with n = total suitable cells. From Littell et al. (2009b).

large fire years, suggesting that fuel condition, that is dry vs. wet, was the key determinant of regionally synchronous fires. In contrast, in the Southwest ("Dry" pattern, Figure 2), the previous year's climate was highly significant, suggesting that fuel abundance and continuity determined large fire years.

Mountain pine beetle infestations have historically occurred frequently and extensively throughout the Pacific Northwest (Logan and Powell 2001). Climate change, in particular warming and drought, affects bark beetle life stage development rates, winter mortality, and host tree susceptibility (Logan and Powell 2001, Carroll et al. 2004, Oneil 2006). Across the West, future climate change is predicted to reduce the area of climate suitability for the MPB at low elevations, and increase climate suitability at higher elevations (Hicke et al. 2006).

Although the nature, timing, and impacts are only beginning to be understood, the potential exists for synergistic interactions between disturbances to produce larger effects than would occur from either disturbance independently (McKenzie et al. 2008). For example, MPB outbreaks have been linked to the increased likelihood of stand-replacing fire and changes in fire behavior depending on the time since infestation (Lynch et al. 2006, Jenkins et al. 2008). Simultaneous climatically driven shifts in the locations of species' optima, ecosystem productivity, disturbance regimes, and the interactions between them could reset forest succession over large areas and short time frames compared to changes observed during the 20th century.

There is still substantial uncertainty, however, surrounding both future climate (IPCC 2007a,b) and ecosystem responses and disturbance interactions driven by climate, particularly at regional and sub-regional scales. Each ecosystem type presents unique uncertainties, but there are also intrinsic limits to our ability to project future conditions. On the one hand, accelerated global warming makes ecosystems more sensitive to abrupt, possibly irreversible, changes, which are difficult to forecast even with state-of-the-art "mechanistic" models. On the other hand, there are negative feedbacks associated with geographic limitations; increasing disturbance, in particular, can "run out" of area to be converted. In the simplest case, if fire area burned were to increase year by year, as predicted by models, the vulnerable area within a region would decrease at an accelerating rate. Combining the stochastic nature of fire with its decreasing "land base" produces a negative forcing on area burned, which has not yet been considered in predictive models.

Another, more complex, negative feedback is more easily quantified. As stated earlier, MPB attacks have increased partly because rising temperatures have created more favorable environmental conditions for beetle populations (Hicke et al. 2006). Littell et al. (2009b) identified areas within Washington State where environmental conditions would be most suitable under future climate scenarios, and found a drastically reduced vulnerable area by the late 21st century (Figure 3). This suggests that because beetle population dynamics are so sensitive to temperature, the largest outbreaks may have already passed, at least for this species.

The combination of rapid change and substantial uncertainty of outcomes provides a formidable challenge to long-term planning and adaptation. Millar et al. (2007) identify three stages through which adaptation must evolve as climate and disturbance regimes depart further from their historical conditions. Each is temporarily functional but will become dysfunctional or even counter-productive as change continues.

- **Resist Change:** A key to this is anticipating extreme events, but these are nearly always short-term solutions that may increase the inertia in a system (e.g., building higher levees).
- **Promote Resilience to Change:** Anticipate landscape structure and composition associated with future climate and disturbance regimes, but accept that there is probably no historical analogue to optimal conditions for resilience, especially with invasive species present.
- **Enable Forests to Respond to Change.** Continue to anticipate rapid change, and rather than holding onto "desired future conditions," develop goals for managing uncertainty. Assisting migrations and increasing redundancy in systems may be of use, but maintaining process and function rather than pattern will be more productive.

Marshaling the talent and resources to adapt to climate change and disturbance in mountain ecosystems will require active collaborations among constituencies who may think very differently. On the scientific side, empirical or observational work, combined with modeling, will be needed, but a two-way process of information transfer with management is critical (Figure 4). Individual

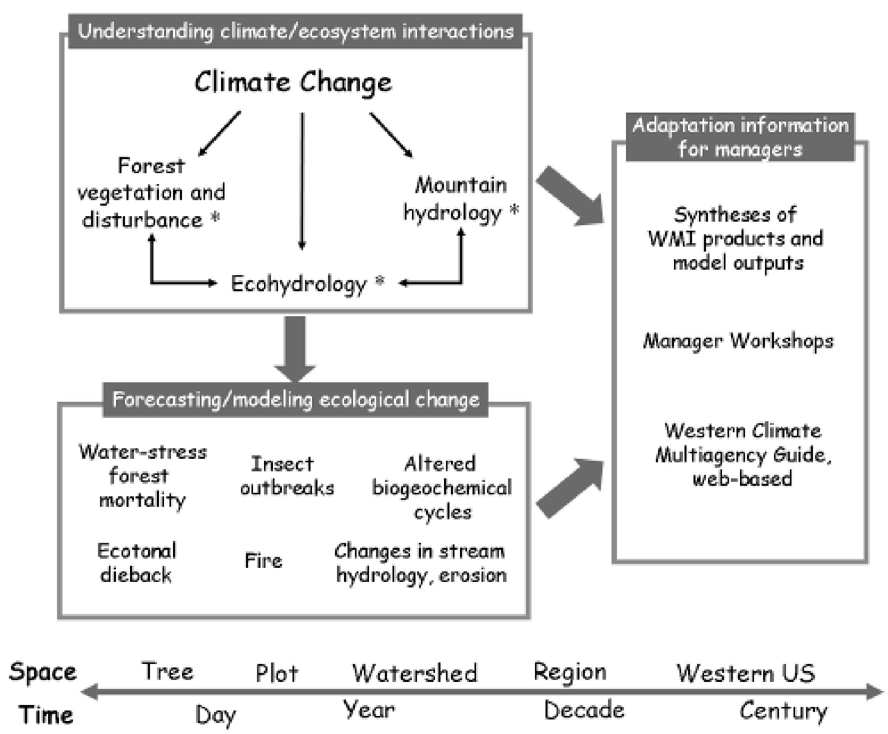

Figure 4. Empirical work, synthesis, and modeling to inform adaptation—the research program of the Western Mountain Initiative (2008-2013). Understanding disturbance and disturbance interactions is central to forecasting the effects of climate change on ecosystems.

researchers and consortia (e.g., Western Mountain Initiative) within CIRMOUNT are increasing their efforts to develop cogent adaptation strategies, both with local land managers and decision makers at all levels.

References

Breshears DD, Cobb NS, Rich PM, Price KP, Allen CD, Balice RG, Romme WH, Kastens JH, Floyd ML, Belnap J, Anderson JJ, Myers OB, Meyer CW (2005) Regional vegetation die-off in response to global-change type drought. Proc Natl Acad Sci, USA 102:15144-15148.

Carroll AL, Taylor SW, Regniere J, Safranyik L (2004) Effects of climate change on range expansion by the mountain pine beetle in British Columbia. In: Mountain Pine Beetle Symposium: Challenges and Solutions. Nat Resour Can, Can For Serv, Pacific Forestry Centre, Kelowna, BC, pp 223-232.

Gedalof Z, Peterson DL, Mantua NJ (2005) Atmospheric, climatic, and ecological controls on extreme wildfire years in the Northwestern United States. Ecol Appl 15:154-174.

Gillett NP, Weaver AJ, Zwiers FW, Flannigan MD (2004) Detecting the effect of climate change on Canadian forest fires. Geophys Res Lett 31, L18211, doi:10.1029/2004GL020876.

Hicke JA, Logan JA, Powell J, Ojima DS (2006) Changing temperatures influence suitability for modeled mountain pine beetle (Dendroctonus ponderosae) outbreaks in the western United States, J Geophys Res B, 111, G02019, doi: 02010.01029/02005JG000101.

IPCC (Intergovernmental Panel on Climate Change) (2007a) Climate Change 2007: the Physical Science Basis. Summary for policymakers. http://www.ipcc.ch

IPCC (Intergovernmental Panel on Climate Change) (2007b) Working Group II Report "Impacts, Adaptation and Vulnerability." http://www.ipcc.ch/ipccreports/ar4-wg2.htm

Jenkins MJ, Hebertson E, Page W, Jorgensen CA (2008) Bark beetles, fuels, fires and implications for forest management in the Intermountain West. For Ecol Manage 254:16-34.

Littell JS, McKenzie D, Peterson DL, Westerling AL (2009a) Climate and wildfire area burned in western U.S. ecoprovinces, 1916-2003. Ecol Appl (in press).

Littell JS, Oneil EE, McKenzie D, Hicke JA, Lutz JA, Norheim RA, McGuire-Elsner M (2009b) Forest ecosystems, disturbance, and climatic change in Washington State, USA. Washington Climate Change Impacts Assessment: evaluating Washington's future in a changing climate. In press.

Logan JA, Powell JA (2001) Ghost forests, global warming and the mountain pine beetle (Coleoptera: Scolytidae). Am Entomol 47:160-173.

Lutz JA and Halpern CB (2006) Tree mortality during early forest development: a long-term study of rates, causes, and consequences. Ecol Monogr 76:257-275.

Lynch HJ, Renkin RA, Crabtree RL, Moorcroft PR (2006) The influence of previous mountain pine beetle (Dendroctonus ponderosae) activity on the 1988 Yellowstone fires. Ecosystems 9:1318–1327.

McKenzie D, Gedalof Z, Peterson DL, Mote PW (2004) Climatic change, wildfire, and conservation. Conserv Biol 18:890-902.

McKenzie D, Peterson DL, Littell JS (2008) Global warming and stress complexes in forests of western North America. In S. V. Krupa (ed.), Developments in Environmental Science, Vol. 8, Wild Land Fires and Air Pollution, A. Bytnerowicz, M. Arbaugh, A. Riebau, and C. Anderson (eds.). Amsterdam, The Netherlands: Elsevier Science, Ltd. pp. 319-337.

Millar CI, Stephenson NL, Stephens SL (2007) Climate change and forests of the future: managing in the face of uncertainty. Ecol Appl 17:2145-2151.

Oneil EE (2006) Developing stand density thresholds to address mountain pine beetle susceptibility in eastern Washington forests. PhD Dissertation, University of Washington, Seattle, 99 pp.

Overpeck JT, Rind D, Goldberg R (1990) Climate-induced changes in forest disturbance and vegetation. Nature 343:51-53.

van Mantgem PJ, Stephenson NL (2007) Apparent climatically induced increase of tree mortality rates in a temperate forest. Ecol Lett 10:909-916.

Guidelines for Helping Natural Resources Adapt to Climate Change

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The changes occurring in mountain regions are an epitome of climate change. The shrinkage of major glaciers over the past century—and especially in the last 30 years—is one of several iconic images that have come to symbolize climate change. Climate creates the context for ecosystems, and climate variables strongly influence the structure, composition, and processes that characterize distinct ecosystems. Climate change, therefore, is having direct and indirect effects on species attributes, ecological interactions, and ecosystem processes. Because changes in the climate system will continue regardless of emissions mitigation, management strategies to enhance the resilience of ecosystems will become increasingly important. It is essential that management responses to climate change proceed using the best available science despite uncertainties associated with the future path of climate change, the response of ecosystems to climate effects, and the effects of management. Given these uncertainties, management adaptation will require flexibility to reflect our growing understanding of climate change impacts and management effectiveness (West et al., in preparation).

A recently released report by the U.S. Climate Change Science Program, *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources*, identifies adaptation strategies for U.S. national forests, national parks, wildlife refuges, wild and scenic rivers, estuaries and marine sanctuaries (CCSP 2008). Fully one third of the world's legally protected

Spring and fall views of North Klawatti Glacier, North Cascades National Park, Washington. (Courtesy National Park Service)

Map: Location of case studies used to develop adaptation options on U.S. federal lands.

areas, including many U.S. national parks and forests, are in mountains (Körner et al. 2005). Elevation and climatic gradients make mountains especially vulnerable to climate change, thus management approaches that encourage natural processes and populations to adapt to changing climates will become increasingly important.

Starting with the management goals of each of these systems, scientists identified approaches that could increase the short-term resilience (over several decades) of ecosystems, with resilience defined as the amount of change or disturbance an ecosystem can absorb before it enters a fundamentally different state. As climate continues to change, however, resilience thresholds may be exceeded. Thus, longer-term adaptation approaches will require flexibility, managing for changing conditions instead of fixed goals, and management approaches that acknowledge uncertainty (Box 1). Case studies, although certainly not definitive, were used to begin to apply principles of adaptation to specific US public lands (Box 2, Map).

Successful adaptation of natural resource management to climate change begins by identifying resources and processes at risk from climate change, defining thresholds and reference conditions, establishing monitoring and assessment programs, and engaging in management actions that increase the resilience of these resources. Adaptation strategies include scenario planning; adaptive management, increased capacity to learn from management successes and failures; and identification and response to the multiple scales at which species and processes function. The latter point will require regional to international partnerships and a shared vision among multiple organizations. Science-based management principles will become more critical because past experience may not serve as a guide for novel future conditions. Preparing for and adapting to climate change is as much a cultural and intellectual challenge as an ecological challenge (Baron et al., in review).

BOX 1
Steps to Implementing Adaptations to Climate Change for Park and Reserve Managers

- Identify resources and processes at risk from climate change
- Establish reference conditions, identify thresholds, and monitor for change
- Assess, plan, and manage at multiple scales, letting the issues define the appropriate scales of time and space
- Form partnerships with other resource management entities
- Increase reliance on adaptive management and scenario-based planning
- Use best management practices to reduce other human-caused stresses to ecosystems
- Reward managers who adopt approaches that increase understanding and accelerate the pace of learning

Identifying Resources and Processes at risk from Climate Change

Systematic characterization of potential climate changes on resources can be accomplished through summaries of the literature, guided research, gatherings of experts, and workshops in which scientists, managers, and the public discuss risks to resources. We caution against the tendency to insist on high-resolution climate forecasts before undertaking this exercise. While detailed and site-specific climate forecasts may be helpful for specific applications, general projections may be sufficient for the initial stages of risk assessment. Subsequent iterations of the exercise can explore resource risk in more detail. It may be useful to rank susceptibility of resources and processes based on the speed of expected response, the role that species or processes play in the ecosystem, the importance of the species or resources to meeting management goals, and the ecological and socioeconomic potential for adaptation. Assessment of risk requires explicit consideration of how crossing thresholds will affect valued species, communities, ecosystem processes, and their interactions. Climate change provides the impetus to identify not only acceptable versus unacceptable change, but controllable versus uncontrollable change.

Establishing Reference Conditions, Identifying Thresholds, and Monitoring for Change

Climate changes may cause ecological thresholds to be exceeded, leading to abrupt shifts in the structure of ecosystems. Threshold changes in ecosystems have profound implications for management because such changes may be unexpected, large, and difficult to reverse. Understanding where thresholds have been exceeded in the past and where (and how likely) they may be exceeded in the future allows managers to plan accordingly and avoid tipping points where possible. Activities taken to prevent threshold changes include establishing reference conditions, modeling a range of possible climate changes and system responses, monitoring to identify relevant ecological changes, and responding by implementing adaptation actions at appropriate scales and times.

Reference conditions determined partly by observations and data from the past, including paleoenvironmental records, help managers and scientists identify ecological states or regimes, and hence guide management activities. But reference conditions are also value statements; what a set of individuals identify as important. With uncertain future climates, managing towards a reference condition may no longer be an appropriate goal (Milly et al. 2008). Knowledge of the ecological and physical setting that produced the reference condition is still useful, however. If the reference condition would incur greater resilience to human-caused disturbance, including climate change, than current conditions, it provides a goal for protection or restoration. Alternatively, if the reference condition is highly dependent on past climate conditions, it identifies the need for adaptation to new conditions. Scientific evidence that past and highly valued conditions are no longer attainable may provide the incentive to plan for ecosystems that are sustainable under future conditions (Choi 2007).

Wildfire caused minimal damage to overstory trees following thinning and prescribed burning, Okanogan-Wenatchee National Forest. (Photo by S. Prichard).

Managing at Multiple Scales

Complex ecological systems operate and change at multiple spatial and temporal scales. The scales at which ecological processes operate often will dictate the appropriate scales at which management institutions should be developed. Migratory bird management, for instance, requires international collaboration; ungulates and carnivores with large home ranges call for regional collaboration; marine preserves require cooperation among many stakeholders; all are examples in which managers cannot be effective working solely within park or reserve boundaries. Similarly, preparation for rapid events such as floods will be managed quite differently than responses to climate impacts that occur over decades. Species may be able to move to favorable climates and habitats over time if there is appropriate and connected habitat.

Increasing Reliance on Adaptive Management and Scenario Planning

Ecosystems that provide societal goods and services are complex systems within a complex landscape. Doak et al. (2008) suggest complexity and surprises reinforce the need for management plans that are highly precautionary, rather than plans that assume specific management actions will have specific outcomes. The two major factors that influence selection of strategies for managing complex systems are the degree (and type) of uncertainty and the extent to which key ecological processes can be controlled. Most current approaches toward resource management are appropriate when uncertainty is low and specific activities are likely to achieve a clear outcome. But the changes to ecosystems that will result from interactions of natural dynamics, anthropogenic change, and novel climates will increasingly negate the ability to manage for specific outcomes.

Adaptive management, which is a process that integrates learning with management actions, is applicable to circumstances where there is ability to influence an ecological process, but uncertainty as to the best methods (Holling 1978, Walters 1986, Lee 1993). By treating management activities as hypotheses, adjustments are made in decisions as outcomes from management actions and other events are better understood. This method supports managers in taking action today using the best available information while also providing the possibility of ongoing future refinements

BOX 2
Case Study Summary

The authors of SAP 4.4 explored opportunities to adapt to climate change in 13 case studies encompassing the range of ecosystems and types of federally managed systems covered in the report (see Map). In general, these ecosystems will face warmer temperatures, more frequent and prolonged droughts, and more precipitation falling in intense storms. Moreover, many of the cases examined will face limits in water availability due to a combination of decreased snowpack, earlier spring snowmelt, and increased evaporation and runoff. Mountain ecosystems will likely suffer more severe insect and disease outbreaks, longer fire seasons and more severe fires, and shifts in biotic communities (e.g., cold-water dependent fishes) due to warmer air and water temperatures.

Although specific adaptation options varied by management context, some common themes emerged from across the case studies. For example, many case studies emphasized the need to capitalize on the flexibility in current planning processes and to explicitly incorporate climate change considerations in management plans. Another key theme was the importance of implementing better monitoring systems to provide salient information for improved decisions for climate change adaptations. Similarly, most of the case studies emphasized the need for education (of management staff and the public) about the science of climate change and its implications. Engaging landowners to manage vegetation near buildings and dwellings, for example, would help the US Forest Service minimize risks to property and lives from the expected increase in wildfires within the landscape mosaic of National Forests. Finally, several case studies highlighted the need for a strong science-management partnership to develop and implement adaptations. The Olympic National Forest case study, for example, noted that collaboration with other agencies and organizations helped develop innovative climate change adaptations for the benefit of multiple stakeholders (Joyce et al. 2008).

through an iterative learning process. Scenario-based planning provides a way of envisioning a range of quantitative or qualitative plausible futures (Peterson et al. 2003). Adaptation responses can then be developed for the range of plausible futures; this approach is more robust to uncertainties than managing for any single projection of the future.

Adaptation Approaches

The report identified seven resource management approaches that might confer short-term resilience to ecosystems and highly valued species:

- *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.
- *Maintaining 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.
- *Replicating* 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.
- *Restoring* is the practice of rehabilitating ecosystems that have been lost or compromised.
- *Identifying refugia* refers to taking advantage of areas that are less affected by climate change than other areas and as sources of "seed" for recovery or as destinations for climate-sensitive migrants.
- *Relocating* refers to human-facilitated transplantation of organisms from one location to another in order to bypass a barrier (e.g., urban area) (West et al., in preparation; CCSP 2008).

We estimated confidence in the ability of each of the seven approaches to provide resilience by quantifying the amount of available evidence to support the determination that the effectiveness of a given adaptation approach is well-studied, understood, and agreed upon throughout the scientific community. The resulting confidence estimates varied both across approaches and across management systems. Reducing anthropogenic stresses was the one approach for which there was considerable scientific confidence in its ability to promote resilience for virtually any situation. Confidence in the other approaches—including protecting key ecosystem features, representation, replication, restoration, identifying refuges, and especially relocation—was much more variable.

Cheatgrass in ponderosa pine forest. (Courtesy U.S. Forest Service)

Many Existing Management Practices can be Applied to Protect Ecosystems from Some Aspects of Climate Change

Changes in temperature, precipitation, sea level, storm intensity and other climate-related factors can exacerbate problems that are already of concern to managers. Fortunately, many existing management practices also can address these climate change interactions. For example, reducing the delivery of pollutants to estuaries may enhance physiological resistance of many estuarine species to elevated water temperature. Use of riparian buffer strips is effective at limiting nutrient and sediment loadings from agricultural lands into rivers under a wide range of current climates, suggesting that it will be effective under future climates as well. However, this does not mean that managers should only continue or intensify existing practices; they also need to explore key adjustments in the timing, spatial extent, and location of their practices to ensure greatest effectiveness given climate change.

The Importance of Communication, Trust, and Scientist-Manager-Public Partnerships

Even highly reasoned actions have some potential to go awry, especially as climate changes. Although clearly not desired, failures provide opportunities for learning. Continued and expanded public education about the complexity of resource management, transparency in the decision-making process, frequent public updates on progress or setbacks, and internal agency efforts that promote trust and respect for professionals within the agency are all important methods for promoting more nuanced management efforts. Partnerships among managers, scientists, educators, and the public can go a long way towards efficiently closing information gaps. With good communication and coordination, scientists can target their research to better inform management challenges, resource managers can share data and better design monitoring to test scientific hypotheses, and outreach specialists can better engage the public in understanding and supporting adaptation activities.

Managing for Change

Adapting to climate change may require more than simply changing management practices—it could require changing management goals. In other words, when climate change has such strong impacts that original management goals are untenable, the prudent course may be to alter the goals. At such a point, it will be necessary to manage for and embrace change. Climate change requires new patterns of thinking and greater agility in management planning and activities in order to respond to the inherent uncertainty of the challenge. There are no clear answers yet for how exactly to proceed, but a critical dialog among engaged stakeholders including scientists, managers, and the public may help chart the way forward.

References

Baron JS, Gunderson L, Allen CD, Fleishman E, McKenzie DH, Meyerson LA, Oropeza J, Stephenson N. Options for national parks and reserves for adapting to climate change. Environmental Management in review

CCSP 2008: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Julius, S.H., J.M. West (eds.), J.S. Baron, L.A. Joyce, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA, 873 pp.

Choi YD (2007) Restoration ecology to the future: a call for a new paradigm. Restoration Ecology 15:351-353

Doak DF, Estes JA, Halpern BS, Jacob U, Lindberg DR, Lovvorn J, Monson DH, Tinker MT, Williams TM, Wootton JT, Carroll I, Emmerson M, Micheli F, Novak M (2008) Understanding and predicting ecological dynamics: are major surprises inevitable? Ecology 89:952-961

Holling CS (1978) Adaptive Environmental Assessment and Management. Blackburn Press, Caldwell, NJ

Joyce, L.A., G.M. Blate, J.S. Littell, S.G. McNulty, C.I. Millar, S.C. Moser, R.P. Neilson, K. O'Halloran, D.L. Peterson. 2008. Adaptation options for climate-sensitive ecosystems and resources: National Forests.

Körner C, Ohsawa M, et al., 2005: Mountain Systems. Chapter 24 in: Millennium Ecosystem Assessment. Current State and Trends: Findings of the Condition and Trends Working Group. Ecosystems and Human Well-being, vol.1, Island Press, Washington DC.

Lee KN (1993) Compass and Gyroscope: Integrating Science and Politics for the Environment. Island Press, Washington, DC

Milly PCD, Betancourt J, Falkenmark M, Hirsch RM, Kundzewicz ZW, Lettenmaier DP, Stouffer RJ (2008) Stationarity is Dead: Whither Water Management? Science 319:573-574

Peterson GD, Cumming GS, Carpenter SR (2003) Scenario planning: a tool for conservation in an uncertain world. Conservation Biology 17:358-366

Walters, C (1986) Adaptive Management of Renewable Resources. McGraw Hill, New York

West JM, Julius SH, Baron JS, Griffith B, Joyce LA, Kareiva P, Keller BD, Palmer M, Peterson CH, JM Scott. Flexibility is the key to resource management under climate change. In preparation for Conservation Letters.

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Adapting to Climate Change in Forest Management—A Management Agency Response

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Forest and rangelands occupy about 65% of British Columbia's 95 million hectares. Vegetation zones range from cool, moist coastal forests, to warm, dry interior forests and semi-arid grasslands, to cold boreal and sub-alpine forests and alpine ecosystems. Managing these lands to meet society's needs under current climatic conditions is a challenge, and this task is expected to become even more of a challenge under global warming. British Columbia has seen warming of air temperature and changes in precipitation regimes over the last 100 years (Rodenhuis et al. 2007). Under global warming, British Columbia will see an increase in annual temperature of 2 to 5°C with greater warming in the north. Southern and central British Columbia are expected to get drier in the summer and wetter in the winter, while northern British Columbia is likely to be wetter (IPCC WGI 2007). Climate change will act in concert with global competition, changing consumer demands for forest products, and social values.

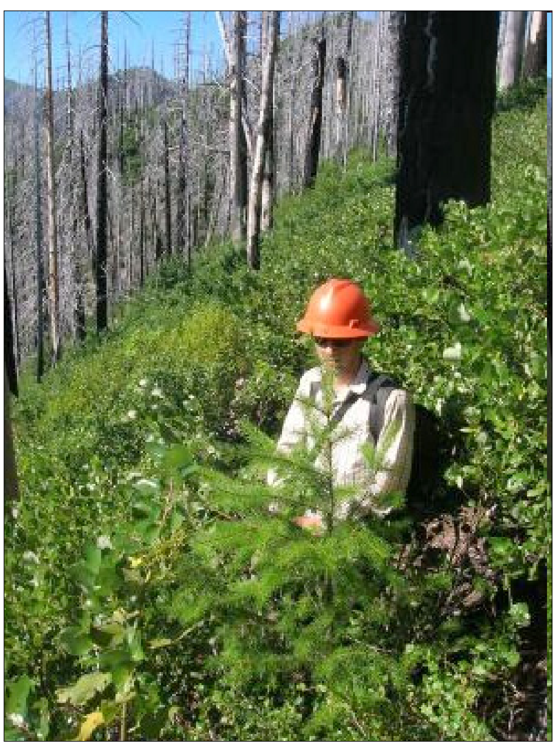
The recent extensive mountain pine beetle infestations in British Columbia (Carroll et al. 2004), and consideration of forest carbon as a commodity have highlighted the need for the forestry community to become fully engaged in the climate change issue. The Future Forest Ecosystems Initiative (FFEI – http://www.for.gov.bc.ca/hts/Future_Forests/) was established by the British Columbia Ministry of Forests and Range to help adapt the forest and range management framework to a changing climate. It has two desired outcomes: (1) ecosystems remain resilient to stress caused by climate change, human activity, and other agents of change, and (2) ecosystems continue to provide the services, products, and benefits on which society depends. Initial objectives are: to establish baseline information for forecasting and monitoring ecosystem changes, and to forecast how climate change might affect key species and ecological processes over time.

FFEI is overseen by a team of researchers, technical advisors and managers. Funding for research is allocated through a competitive process. Current FEI activities include development of background papers and topic overviews (e.g., Spittlehouse 2008, Pike et al. 2008), providing access to high spatial resolution climate data (Wang et al. 2006), and extension activities such as seminars. Work is underway to conduct vulnerability assessments for forest and range values, develop adaptation options and develop policies to address climate change. The approach follows that laid out in the Forest Futures Project (Sustainable Forest Management Network 2008). Background papers are being used to develop a set of future forest scenarios for 2050 under two climate regimes. Policy advisors will attend a workshop where by looking back from 2050 they will evaluate which adaptation policies would be needed to respond to and mitigate changes. Independent of this process, the Ministry of Forests and Range has recently taken a step in adapting seed transfer guidelines to past and future climate change. Following recommendations in O'Neill et al. (2008), upper elevation limits to seed transfer were raised by 100 to 200 m.

Mortality in lodgepole pine forest caused by mountain pine beetle. (Courtesy British Columbia Ministry of Forests)

Adapting to climate change reduces vulnerability by reducing risks and capitalising on benefits through maintaining social and ecological resilience (Nelson et al. 2007, Millar et al. 2007). Vulnerability of an entity (e.g., organism, ecosystem, company, community, or province) depends on exposure and sensitivity to climate change, and to its adaptive capacity. Entities have different vulnerabilities, and changes that may be detrimental to one entity could be beneficial to another. Consequently, management will require juggling a range of vulnerabilities and values. Determining adaptive actions requires a framework for analysis (Spittlehouse and Stewart 2003, Johnson and Williamson 2007, Millar et al. 2007): (1) define the issue (impacts and risks), (2) evaluate vulnerability to risks, (3) determine how to reduce vulnerability (i.e., adaptation); and (4) implement an adaptation strategy. Recently completed Canadian (Lemon et al. 2008) and U.S. (Julius et al. 2008) national adaptation studies provide some examples of climate change impacts and adaptation options. A major challenge in taking adaptive actions is the uncertainty in the magnitude and timing of future climate change. When will we know enough to respond, for example, which climate scenario should we plan for and what are the vulnerabilities of species and forest operations? We need to decide who "owns the risk" of failure when asking managers to respond to an uncertain future.

The size of the forested land base in British Columbia means that much of the forest will need to adjust without human intervention. Of the approximately 62 million ha of forest in British Columbia there are about 38 million ha in the non-timber harvest land base (including parks, wilderness areas, and areas with operational constraints) where forest management consists mainly of fire protection and conservation. The 24 million ha timber harvest land base is harvested at about 0.2 million ha per year. Most of the timber supply for the next 50 to 100 years will depend on how existing trees will respond in situ to changing climate and disturbance regime. Adaptation through facilitated migration on harvested areas will focus on the major commercial tree species and perhaps a few animal species, while most plants and animals will need to adapt as best they can. In some areas, adaptation to reduce the vulnerability of resources such as water quality and quantity and biological conservation will be the highest priority. Adaptive actions for forest and range management (Spittlehouse and Stewart 2003, Millar et al. 2007) can be classified as biological or societal adaptation. The former involves deliberately adapting the ecosystems to a changing climate; the latter is adaptation of management and societal objectives in response to the effects of a changing climate on forest and range resources. Biological adaptation includes species selection, facilitated migration of species and provenances, stand management, creating fire-smart landscapes and forest carbon management. Societal adaptation includes developing policies to encourage adaptation, using more salvage wood, modifying wood processing technology, revising expectations on resource use, and revising conservation objectives. It may be a number of years before extensive adaptive actions will be implemented "on the ground, in the forest." In the meantime, raising awareness, capacity building and vulnerability assessments constitute important initial steps in the adaptation process.



Douglas-fir regeneration after fire. (Courtesy Oregon State University)

References

Carroll A.L., S.W. Taylor, J. Régnière, and L. Safranyik. 2004. Effects of climate change on range expansion by the mountain pine beetle in British Columbia. In Mountain Pine Beetle Symposium: Challenges and Solutions. T.L. Shore, J.E. Brooks, and J.E. Stone (editors). Natural Resources Canada, Can. For. Serv., Pacific Forestry Centre, Victoria, B.C., Information Report BC-X-399, pp. 223–232.

IPCC WG I. 2007. Climate change 2007: The physical science basis: Summary for policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland. http://www.ipcc.ch (Last accessed Mar. 3, 2008.)

Johnson, M. and T. Williamson. 2007. A framework for assessing climate change vulnerability of the Canadian forest sector. The Forestry Chronicle 83:358–361.

Julius, S.H. J.M. West, J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.C. Palmer, C.H. Peterson and J.M. Scot. 2008. Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources. A report by U.S. Climate Change Science Program And the Subcommittee on Global Change Research, US Environmental Protection Agency, Washington, DC.

Lemmen, D.S., F.J.Warren, J. Lacroix and E. Bush (editors). 2008. From Impacts to Adaptation: Canada in a Changing Climate 2007, Gov. Canada, Ottawa, ON.

Millar, C.I., N.L. Stephenson and S.L. Stephens. 2007. Climate change and forests of the future: Managing in the face of uncertainty. Ecological Applications, 17:2145–2151.

Nelson, D.R., W.N. Adger, and K. Brown. 2007. Adaptation to environmental change: Contributions of a resilience framework. Ann. Rev. Environ. Resources 32:395–419.

O'Neill, G.A., N.K. Ukrainetz, M.R. Carlson, C.V. Cartwright, B.C. Jaquish, J.N. King, J. Krakowski, J.H. Russell, M.U. Stoehr, C. Xie, and A.D. Yanchuk. 2008. Assisted migration to address climate change in British Columbia: recommendations for interim seed transfer standards. B.C. Min. For. Range, Res. Br., Victoria, BC. Technical Rep. 048. http://www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr048.htm

Pike, R.G., D.L. Spittlehouse, K.E. Bennett, V.N. Egginton, P.J. Tschaplinski, T.Q. Murdock, and A.T. Werner. 2008. A summary of climate change effects on Watershed hydrology. Extension Note EN87, Research Branch, B.C. Min. Forests and Range, Victoria, BC. http://www.for.gov.bc.ca/hfd/pubs/Docs/En/En87.htm

Rodenhuis, D., K.E. Bennett, A. Werner, T.Q. Murdock, and D. Bronaugh. 2007. Hydro-climatology and future climate impacts in British Columbia. Pacific Climate Impacts Consortium, Univ. Victoria, Victoria, B.C. http://www.pacificclimate.org/resources/publications/ (Last accessed 3 March 2008.)

Spittlehouse, D.L. 2005. Integrating climate change adaptation into forest management. The Forestry Chronicle 81:91–95.

Spittlehouse, D.L. 2008. Climate change, impacts, and adaptation scenarios: climate change and forest and range management in British Columbia. B.C. Min. Forests and Range, Victoria, BC, Technical Rep. 045. http://www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr045.htm

Spittlehouse, D.L. and R.B. Stewart. 2003. Adapting to climate change in forest management. www.forrex.org/jem/2003/vol4/no1/art1.pdf. Printed version, J. Ecosystems Manage 4:7–17.

Sustainable Forest Management Network. 2008. Forest Futures Project. http://www.sfmnetwork.ca/html/forest_futures_e.html (Last accessed 27 November 2008).

Wang, T., A. Hamann, D.L. Spittlehouse, and S.N. Aitken. 2006. Development of scale-free climate data for western Canada for use in resource management. International J. Climatology 26:383–397.

Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead: Efforts to Address Climate Change and Variability

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During the period from 2000 to 2005, the Colorado River experienced the worst drought conditions in approximately 100 years of recorded history. During this period, storage in the two major Colorado River reservoirs (Lake Powell and Lake Mead) dropped from nearly full to approximately 46 percent of capacity. At that time, there were no specific operational guidelines in place to address the operations of Lakes Powell and Mead during drought and low reservoir conditions. In addition, due to changing hydrologic conditions and anticipated future demands, lower reservoir conditions could occur with more frequency. These factors, along with increasing tensions among the seven Colorado River Basin States (Basin States) led the Department of Interior to conclude that additional management guidelines were necessary and desirable for the efficient management of the Colorado River.

In May of 2005, the Secretary of the Department of the Interior (Secretary) tasked the Basin States to develop a consensus plan to mitigate drought in the Colorado River Basin (Basin). With or without the States' consensus, the Secretary directed the Bureau of Reclamation (Reclamation), to engage in a process to develop guidelines for Lower Basin shortages and the operation of Lakes Powell and Mead, particularly under drought and low reservoir conditions. This action was proposed in order to provide a greater degree of certainty to Colorado River water users and managers by providing detailed and objective guidelines for the operations of Lakes Powell and Mead. Later that year, Reclamation announced the intent to initiate a National Environmental Policy Act (NEPA) process to develop such guidelines.

A broad range of reasonable alternatives were analyzed in the Final Environmental Impact Statement (Final EIS). This document is available on U.S. Bureau of Reclamation's website at: http://www.usbr.gov/lc/region/programs/strategies.html. These alternatives were developed in coordination with a diverse body of stakeholders, including the Basin States, a consortium of environmental non-governmental organizations (NGOs), Native American tribes, federal agencies and the general public. The Basin States submitted a consensus alternative signifying a historical agreement on issues of this magnitude.

The current level of Lake Mead is far below capacity. (Courtesy of Ken Dewey, University of Nebraska)

The Preferred Alternative (PA), based on the Basin States and Conservation Before Shortage (an alternative submitted by the environmental NGOs) alternatives, was comprised of four key operational elements. The first element is a shortage strategy for Lake Mead and the Lower Division states. The PA proposed discrete levels of shortage volumes associated with Lake Mead elevations to conserve reservoir storage and provide water users and managers in the Lower Basin with greater certainty to know when, and by how much, water deliveries will be reduced during low reservoir conditions. The second element required coordinated operation of Lakes Powell and Mead. The PA proposed a fully coordinated operation of Lakes Powell and Mead to minimize shortages in the Lower Basin and avoid risk of curtailments of use in the Upper Basin.

The third element required a mechanism for the storage and delivery of conserved system and non-system water in Lake Mead. The PA proposed the Intentionally Created Surplus (ICS) mechanism to provide for the creation, accounting and delivery of conserved system and non-system water thereby promoting water conservation in the Lower Basin. The fourth element required modifying and extending elements of the existing Interim Surplus Guidelines (ISG). The PA extended the term of the ISG and modified those guidelines by eliminating the most liberal surplus conditions thereby leaving more water in storage to reduce the severity of future shortages.

A Record of Decision (ROD) was issued in December 2007 officially adopting the guidelines (Guidelines) set forth in the Preferred Alternative. The ROD implements a robust solution to the unique challenges facing Reclamation in managing the Colorado River. The Guidelines are interim in duration, extending through 2026, providing the opportunity to gain valuable operating experience for the management of Lakes Powell and Mead, and improve the basis for making additional future operational decisions, whether during the interim period of thereafter. The coordinated operation element allows for the adjustment of Lake Powell release to respond to low reservoir storage conditions in either Lakes Powell or Mead.

The Guidelines also encourage efficient use and management of Colorado River water and enhance conservation opportunities in the Lower Basin and the retention of water in Lake Mead through adoption of the ICS mechanism. The shortage strategy for Lake Mead includes a provision for additional shortages to be considered, after appropriate consultation. Finally, the Basin States have agreed to address future controversies on the Colorado River through consultation and negotiation before resorting to litigation. This and the operational elements included in the Guidelines preserve and provide Reclamation the flexibility to deal with and adapt to further challenges such as climate change and deepening drought.

Glen Canyon Dam below Lake Powell. (Courtesy Colorado River Commission of Nevada)

Acknowledging and responding to the potential impacts of climate change and increased hydrologic variability during the process to develop the Guidelines, Reclamation empanelled a group of leading climate experts (Climate Technical Work Group) to assess the state of knowledge regarding climate change in the Basin and to prioritize future research and development needs. Their findings and recommendations were published as an appendix to the Final EIS (Appendix U). A recommendation of the Work Group was to include a qualitative discussion of climate change and variability accompanied by a quantitative sensitivity analysis using paleoclimatic data (Appendix N).

Appendix N analyzed the sensitivity of hydrologic resources (including reservoir storage, reservoir releases, and river flows) to hydrologic scenarios derived from alternative methodologies (including stochastic hydrology and tree-ring based paleo reconstructions). For example, Figure 1 (denoted Figure N-4 in Appendix N) compares the results of two alternative hydrologic scenarios with the resampled historical record (Direct Natural Flow) for the No Action Alternative and the Preferred Alternative in terms of the risk of going below the minimum power pool at Lake Powell. The Direct Paleo scenario directly resamples the recent Lees Ferry reconstruction completed by Meko et al. (2007) that extends back to the year 762. The Nonparametric Paleo Conditioned scenario blends the hydrologic state (e.g., wet or dry) from the paleo reconstruction with the flow magnitudes from the historical record. It is evident that the alternative hydrologies increase the range of variability seen in key decision variables.

In addition to the qualitative discussion of climate change included in the Final EIS, the Climate Technical Work Group recommended future research and development critical to the continued incorporation of climate change information in Reclamation's long-term planning. These recommendations include:

- Improve availability and temporal resolution of regional climate projection
- Improve ability to model runoff under climate change
- Investigate paradigm for Colorado River Basin precipitation response
- Diagnose and improve existing climate models before adding additional features

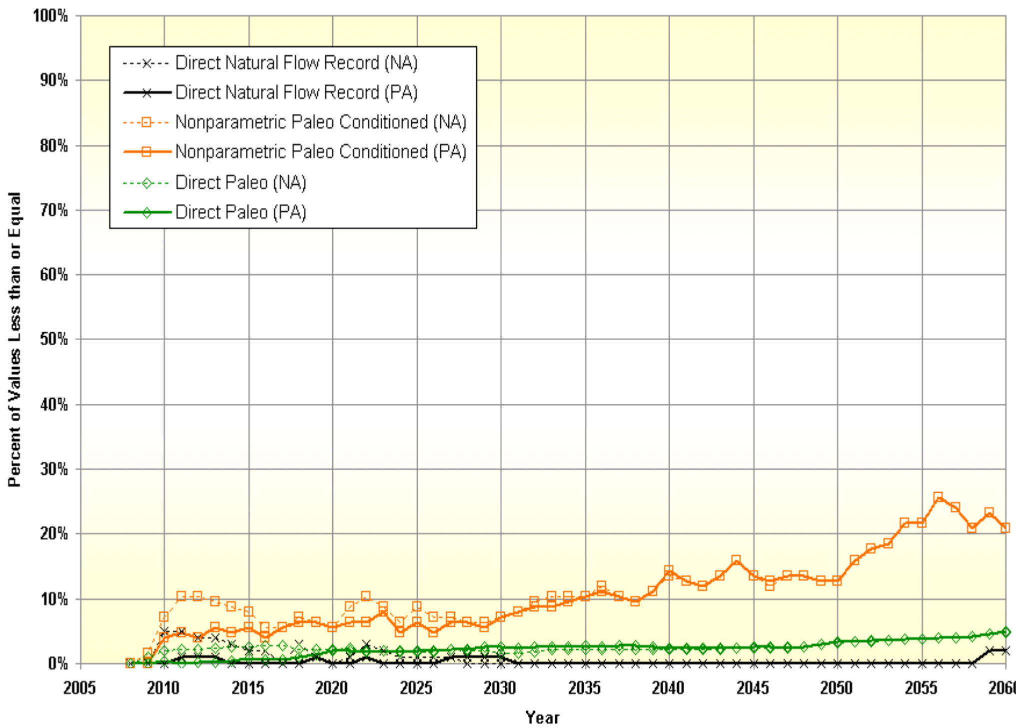

Figure 1. Lake Powell end-of-July water elevations. Percent of values < elevation 3,490 feet. Comparison of Direct Natural Flow Record to Meko et al. reconstruction for No Action Alternative (NA) and Preferred Alternative (PA).

- Investigate changes in modeled climate variability at multiple time scales
- Improve understanding of surface water, ground water and land cover interaction
- Improve prediction of interdecadal oscillations
- Investigate use of paleo record to inform modeled streamflow variability
- Interact with U.S. Climate Change Science Program and other climate change research initiatives

References

Meko, D. M., C. A. Woodhouse, C. A. Baisan, R. Knight, J. L. Lukas, M. K. Hughes, and M. W. Salzer, 2007: Medieval drought in the upper Colorado River Basin. Geophysical Research Letters, 34, L10705, doi:10.1029/2007GL029988.

More information relating to the Guidelines, including technical details, development process and environmental effects can be found in either the ROD or Final EIS. Both are available on Reclamation's website (http://www.usbr.gov/lc/region/programs/strategies.html).

Adaptation Considerations for National Forests in the Face of Climate Change

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The Olympic National Forest was selected as a location at which National Forest management practices would be examined in the face of climate change. This effort is a partnership among Olympic National Forest (ONF), the U.S. Forest Service Pacific Northwest Research Station (PNW), and the University of Washington Climate Impacts Group (CIG).

This partnership began in November 2006 at a time when the topic of climate change had not yet been discussed to any degree within the management branch of the Forest Service, and articles about climate change were not yet appearing in daily newspapers. Dave Peterson (PNW) and Jeremy Littell (CIG) presented information on the basic science of climate change to ONF natural resources staff, which served to raise the awareness of the managers to potential climate change impacts to resources that they manage. The discussions were summarized and published as a part of the "Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources" (National Forests, pages 3-1 to 3-127; Synthesis and Assessment Product 4.4, U.S. Climate Change Science Program).

With carefully designed questions, the scientists were able to elicit the concerns of managers and focus the discussion on which adaptation strategies are most likely to be successful. The ONF considers itself a restoration forest with the majority of its management directed at restoring ecological functions to forest lands that have been affected by past practices of intensive management. The ONF staff identified road issues, fish and wildlife concerns, and recreation management as resource areas that need to be considered. These resource managers have many years of experience in managing the ONF land base, and through interactive discussions with the scientists, were able to develop adaptation strategies that will help reshape future management activities in the context of anticipated effects of a warmer climate. The scientists synthesized and documented these discussions, thus providing a structure and framework for adaptation strategies.

Road repair on Olympic National Forest following damage caused by storms in 2006. (Courtesy U.S. Forest Service)

Treeline, eastern Olympic Mountains. (Photo by J. Littell)

Key overarching adaptation strategies identified through this process were:

- Manage for biodiversity at multiple scales and through a variety of specific actions.
- Manage for the future, recognizing that historical information is only a part of the picture.
- Integrate climate change into laws, regulations, and policy.
- Collaborate among different agencies and stakeholders.

Additional detail on these strategies has been summarized following additional discussions with ONF resource staff:

Manage for Biodiversity

Managers have long been managing for biodiversity, so many of the necessary tools already exist, but may have to be used in new ways. For example, managers know how to relocate species from one area to another such as has been done for reintroducing extirpated species, but mangers may consider moving species as habitat shifts occur related to a warmer climate. Managers are comfortable with managing for biodiversity, but will need to work closely with geneticists and other plant biologists if actions such as assisted migration are considered.

Manage for the Future

Conservation theory is predicated on the basis of a steady state—restoration implies that we will bring back a system to a condition that existed previously. Yet with the climate changing, we can no longer rely on our historical perspectives to provide the insights for management. New tools and a strong partnership between science and management are needed to create these tools rapidly. Managers and scientists need to create bridges to bring the most current thinking to bear on management issues. Modeling and scenario planning are tools that can provide insights into likely futures of the resources for which national forests are responsible. Although this may involve considerable uncertainty, which is an uncomfortable situation for management, working closely with scientists will facilitate a better understanding of uncertainty and provide a firm foundation on which to base decision-making.

Integrate climate change in laws, regulations, and policy

U.S. conservation laws of the 1970's, such as the Endangered Species Act, National Environmental Policy Act, and Clean Water Act, were built on basic conservation theory, as are the implementing regulations and policies. Yet these ideas may need to be viewed in a new light as climate change modifies our perspectives on managing natural resources. For example on the Olympic Peninsula, the barred owl has expanded its range into the spotted owl's range, which poses a great deal of uncertainty for the recovery of the spotted owl. This situation challenges beliefs and perspectives about invasive species and how goals of species recovery can be met under altered environmental conditions including a warmer climate. Managers and policy makers need to discuss and rethink how to best meet the goals of existing conservation laws.

Collaborate with Others

Working across traditional lines of government, administration, and management will be needed to effectively implement adaptation to climate change at large spatial scales. Many of our natural resources—water, air, fish, wildlife—transcend political boundaries on maps and could be imperiled without strong cooperation among those responsible for managing them. A rapid transfer of knowledge about climate-change science from research to management will be critical. It will also be important to engage the public more effectively in order to generate support for adaptation.

Variable density thinning reduces competition among trees and increases resilience to stress. (Courtesy of U.S. Forest Service)

Next Steps

Some aspects of these strategies are being applied in current resource management, while others require new approaches. In order to encourage discussion of new approaches and new thinking, we have shared the results of our management-science partnership—known as the Olympic Case Study—with other national forests in the Pacific Northwest and beyond. Reactions to the Case Study have varied, depending on the degree to which adaptation strategies were perceived to challenge traditionally held perspectives.

We have observed that as these ideas and new strategies are presented to a wide range of audiences, managers and scientists have begun to work more closely together and form new working relationships. These ties are critical to the success of national forest management. Information sharing is a key to success as we strive to have a rapid transfer of scientific information into the management realm. The ONF and PNW are continuing to work on integrating climate information into the program management of the Forest, applying adaptive strategies at large spatial scales, and implementing science-based management on the ground. In addition, during 2009 we will be working with Olympic National Park resource managers to jointly develop adaptation strategies that will facilitate adaptation to climate change on the Olympic Peninsula.

The San Juan Climate Initiative: A Scientist-Stakeholder Partnership for Understanding and Adapting to Climate Change

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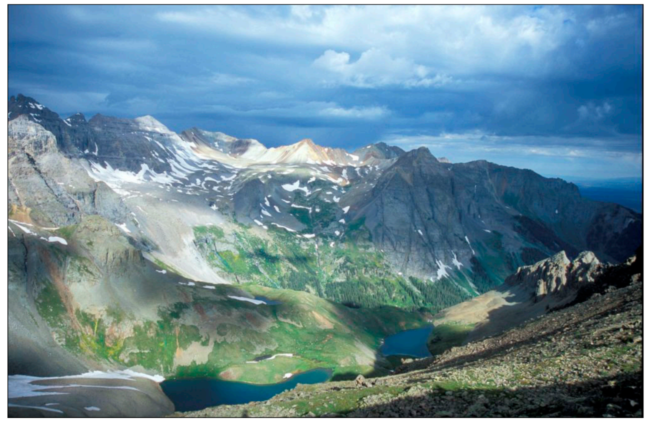
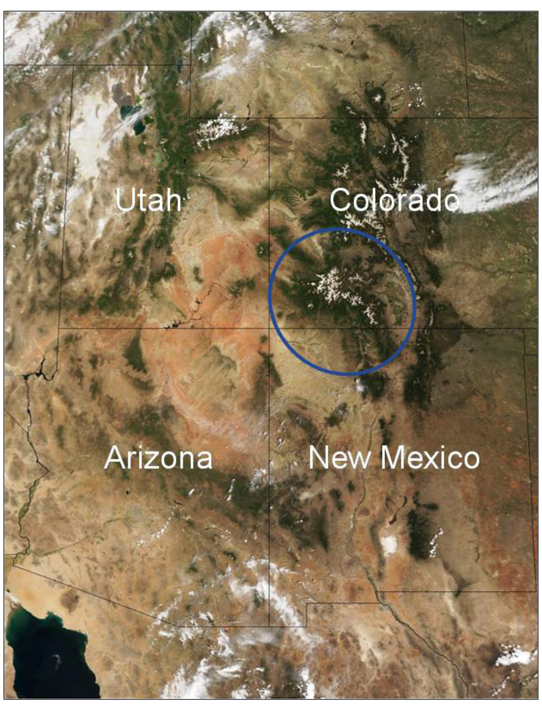
The San Juan Climate Initiative (SJCI) is a grassroots stakeholder- and scientist-driven effort to: (1) assess existing and potential threats caused by climate change, and (2) develop strategies to plan for, adapt to, and reduce the effects of climate change on ecosystems and society. We focus on the San Juan Mountain region, southwestern Colorado extending into northwestern New Mexico, an area that combines complex natural landscapes with a rapidly changing human footprint.



Blue Lakes and Upper Dallas Creek. (Photo by K. Nydick)

Understanding the Context: Environment & Socioeconomics

From the headwaters of the San Juan, Rio Grande and Uncompahgre Rivers to the arid rangelands below, the varied topography of the San Juan Mountains provides biodiversity, wildlife habitat, critical water resources, recreational amenities, and homes and livelihoods for the region's occupants. This region straddles the southern edge of the Southern Rockies and northeastern tip of the American Southwest. It encompasses diverse landscapes ranging from alpine to sagebrush, a climatic regime that fits neither the Western Slope nor the Four Corners completely, a critical high-elevation snowpack, and growing human communities, coalbed methane development, and tourism. It is a place where northern species meet their southern extent and southern species hit their most northern coverage. It is where aspen is both inching upward to higher altitudes but dying in its lowest reaches. The San Juans are where lynx have been reintroduced and mountain pine beetle has yet to decimate. It is a place with incredible scenic vistas and Wilderness Areas, but also deteriorating air quality.



San Juan Mountain region. (Courtesy Mountain Studies Institute)

All of these resources are interconnected with the region's climate. For example, melting of mountain snow packs provides water at critical times when plants begin their annual life cycles, wildlife depend on abundant forage, water managers expect reservoirs to fill up, and boaters take to white water adventures. The severe drought experienced in 2002–03 demonstrated the detrimental effects of reduced snowpack and early snowmelt: water shortages, dried landscapes leading to increased wildfire and forest dieback, and reduced economic activity from recreation and tourism. In the San Juan future, this type of drought is expected to occur more frequently, and average temperatures are projected to increase by 2.5 ºF to 5.5 ºF by 2050.

What does this mean for water, wildlife, forest and freshwater resources, agriculture, human economies, and public health? Furthermore, how can information on current and projected climate change be integrated into important management and planning elements, such as National Forest land management plans, city and county development plans and land use codes, water and flood infrastructure, storm water permitting, fisheries management, endangered species protection and reintroductions, reservoir operations and re-licensing, watershed restoration, air quality permitting, and recreation regulations?

Rural areas like the San Juan Mountain region have minimal resources to assess climate change threats and plan for adaptation. The majority of support to study climate change rests in the hands of large research universities and government agencies. Regions outside of major metropolitan areas or key national parks do not receive the same amount or quality of information, access to training, and other needed resources. Rural communities, like those in the San Juan Mountain region, often have below average incomes and educational levels, and do not have the tax base to fund special studies or planning processes. At the same time, natural resources and the amenities that they provide can be more important for rural residents than city dwellers. Water quality/quantity, air quality, wildlife habitat, and scenic/visual quality rank among the most important issues for residents of southwestern Colorado (The Social and Economic Effects of Second Homes in Southwest Colorado, Phase 2 – Homeowners Survey. Region 9 Economic Development District of Southwest Colorado Inc., July 10, 2006).

Convening the Process—Partnerships, Stakeholders, Education, and Dialogue

In order to bring needed resources to this rural area, the Mountain Studies Institute (MSI) has partnered with the University of Colorado at Boulder, the San Juan Public Lands Center (U.S. Forest Service, Bureau of Land Management) and Fort Lewis College in the *San Juan Collaboratory*. This partnership brings together the regional stakeholder focus of a rural non-profit institute with the expertise of a major university, the management directives of a public lands center, and teaching opportunities of an undergraduate-serving college.

The SJCI began based on stakeholder and scientist concerns about the recent drought and what future climate might have in store for a region already stressed by the legacy of mineral extraction, protracted water battles, oil and gas development, expansive wildfires, land use change and population growth. We convened the process with events that educated stakeholders, gathered stakeholder input, and brought in experts to add to our knowledge base. A Conference, *Climate Change and Variability in the San Juan Mountains: a Stakeholder–Scientist Dialogue*, kicked off the effort in October 2006 (http:// www.mountainstudies.org/Research/sjClimateInitiative.htm). Scientists and stakeholders shared and discussed what is known about climate change and variability for the San Juan Mountain region, what we do not know but should, and what information stakeholders need in order to adapt to or prepare for the effects of climate change. Stakeholders include those involved with water, land and community planning, biodiversity, wildlife, forestry, recreation and tourism, agriculture and ranching, and energy.

A second event in 2008, *Climate Adaptation Workshop for Natural Resource Management* (part of the MTNCLIM Conference held in Silverton, Colorado, http://www.fs.fed.us/psw/mtnclim/talks/managers.shtml), brought in the expertise of CIRMOUNT climate change adaptation scientists and then continued the stakeholder-scientist discussion. Further dialogue has been generated by a recently initiated effort by La Plata County, Colorado to develop a Climate and Energy Action Plan, which includes a section on climate preparedness. Examples of information gained from these events are summarized in Box 1.

Integral to almost every discussion about planning for climate change and conducting climate vulnerability assessments was the need to agree on the extent of climate change for which to prepare. The topic of uncertainty often then emerges. “What do we know?” is a question heard frequently in stakeholder discussions. This is why climate change education—for elected officials and local government staff, public lands managers, water managers, and others—is so critical. Stakeholder education is not necessarily like educating a graduate student. For example, stakeholders want to know what a 1ºF change means to people, communities and resources. What does it look like? Discussion of the data and the uncertainty levels is similarly important, because not only do we want stakeholders to understand the latest and greatest science, but we want them to have enough confidence in it and in themselves to use the information and participate in the planning process. With the help of this education we can develop climate change scenarios of plausible future conditions that the majority of stakeholders and scientists can agree upon for planning.

Sometimes a second question is asked, “Well, what CAN we do to prepare for climate change?” It is not like we can stop extreme events from happening, for instance. Therefore, a discussion of what is meant by “adaptation” (or “preparedness”) strategies can be essential. Often specific examples are the most important tool. We have learned that educating stakeholders, agreeing to and “buying into” future scenarios, and understanding adaptation are not a quick process that can be accomplished in one meeting. We will be producing an outreach booklet, “Climate Change in the San Juan Mountain Region” to aid in these efforts.

BOX 1
Stakeholder Input: How are resources vulnerable to climate change?

Water, Land, Community Planning

- Earlier timing of snowmelt has far-reaching effects, including water-rights holders who are tied to specific dates (including agriculture), wildlife needs, reservoir operations, and recreation/tourism, including snow sports, white water boating, and fishing. Reduction in total annual discharge has further implications, such as approval of new water rights for development and the amount of water left in the river for wildlife and recreation. Higher water temperatures and lower flow could reduce water quality and aquatic habitat.
- Pressures for new higher-elevation reservoirs on public lands are increasing, not necessarily due to a reduction in precipitation, but more as a result of earlier spring runoff, and less spring/summer storage in high elevation snowpack.
- Increasing temperatures could drive people to move to higher elevations to live and/or recreate, therefore shifting resource demand away from existing population centers into the wilderness fringe. Location of wildlife corridors and highway crossing areas could change, wildlife-human conflict could increase, and more people could want to build homes in ponderosa pine and mixed conifer forest prone to wildfire.
- Increasing flooding, landslides, fires, and resulting sedimentation in aquatic habitat could affect recreation/tourism. Is the public prepared for catastrophic events? Is infrastructure adequate to protect the public?
- Increased heat waves, air pollution (ozone, smoke from fires), and spread of disease could affect public health.

Recreation, Tourism

- Climate change could create business opportunities. Scenic beauty and visual quality are essential. Distinct seasons—recreation currently utilizes two seasons, could market and operate in all four.
- "We are the first stop on the way out of hell"—Texas, Arizona, New Mexico will be very hot in summer, we won't be as hot. Sell the fact that we're less affected and keep it that way.
- Season-specific recreation (e.g., rafting) will be at risk if we lose a season or the length of season is reduced. May need a "portfolio" of recreation offerings to reduce risk to one type of activity decline. Small specialized businesses will suffer if the season on which they depend is negatively affected.

Energy

- There will be changes in energy peak demands, from winter draw (heating) to summer draw (air conditioning). Net result will be affected by population growth in the area.
- Fuel crops for biodiesel may do better/worse depending on how temperature affects water supply.
- Hydroelectric capacity may decline due to less water storage.
- Higher temperatures may change wind regime for wind power. Increased aridity will increase our solar index (ability to use solar for energy). There may be greater number of solar energy (cloud-free) days.
- There may be increased pressure on local coal, gas, and energy resources, with harmful effects on air, soil, and water. Warmer temperatures could mean more ozone pollution.

Agriculture

- Insects, disease and weeds may increase. New pests and exotics may migrate from the South or lower elevations.
- Climate change could alter the timing of pollinator life cycles relative to plants.
- Soil moisture will decrease. More irrigation will be required, but water supply may decline or an earlier snowmelt could reduce late summer water availability. Major shifts in agricultural practices will be needed to reduce water use and increase soil water storage.
- Local agricultural products may increase in demand as people try to reduce their carbon footprint.
- Ability to cultivate may shift to higher elevations and to new crops that require warmer temperatures, longer growing season, and are drought resistant. Some existing crops or areas under cultivation may become less successful.

Forests, Timber, Wildfire

- Drought combined with higher temperatures will cause mortality or reduced vigor of certain species, such as pinyon pine and aspen, as witnessed in the recent drought.
- Minimum temperatures could increase enough to allow new insect pests because they can complete a full life cycle in most years.
- Legacy of wet years and fire suppression has created forests that are challenged going into climate change. Together this will cause increased rates of mortality due to disease, insects, competition, and large-scale wildfires.
- Forest may not return to the same composition and stand structures after disturbance. We may see forest species changing, moving uphill. High-elevation forests could burn more than in the past.
- Regeneration may be slower if soils are too dry. Some areas may be barren for longer time periods after fire or erosion events.
- There may be a shorter time window for prescribed fire and increased regulations regarding smoke.
- Carbon sequestration on forest land may become an income source (carbon credits) if managed well.

Biodiversity, Wildlife

- Warmer springs and earlier snowmelt will alter the timing of phenological events, but at different rates. Coupling of plant-herbivore, plant-pollinator, and prey-predator relationships may change as timing of one shifts differently than the other.
- The composition and relative abundances of species in an ecosystem may change. Certain species may shift in elevation, and some more than others. Some species may be locally extirpated. Some ecosystems, like fen wetlands, may decline in extent.
- Changes in snow depth could affect wildlife movement and activity patterns, timing of green-up and food availability. This could affect wildlife populations, timing of wildflower blooming, and recreation dependant on these events.
- Warmer water temperatures could reduce cold water fish habitat regionally.
- Habitat and food resource shifts may decrease the success of reintroduction efforts (e.g., lynx, cutthroat trout).

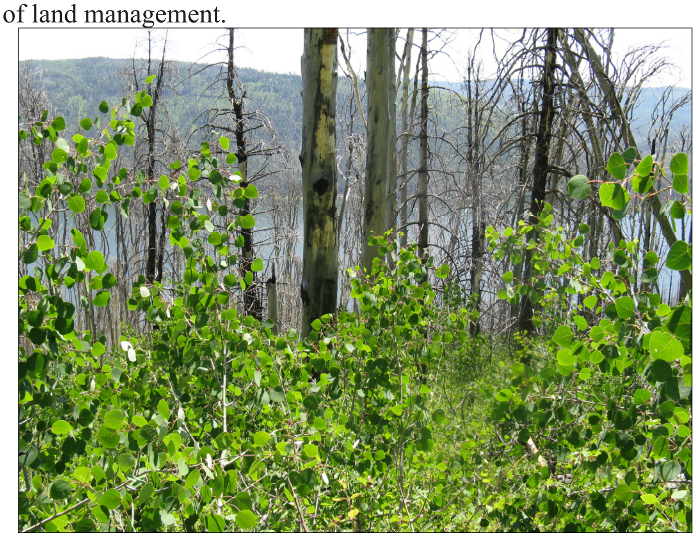
Riparian ecosystem. (Photo by K. Nydick)

The SJCI is continuing to pursue education while at the same time moving ahead with vulnerability and risk assessment. It became apparent that these assessments can follow two main pathways – a lower-cost method, or a higher-cost, data-rich method. The first relies on published research and expert opinion and produces a more general understanding of vulnerabilities and risks. The second uses tools like high-resolution climate projections coupled with additional spatial data like species distributions or watershed modeling to quantitatively identify geographic areas, ecosystems, or species that are more or less vulnerable. We think that a combination of these two methods is more feasible and can be adapted to a budget that is slowly growing, one grant and contract at a time. Stakeholders are integral to the vulnerability/risk assessment process because they are the experts dealing with natural resource management and community planning. Furthermore, it is the stakeholders who will actually implement the adaptation practices on the ground once they are developed.

Getting Started—Adaptation and Carbon Cycle Management on Federal Lands

San Juan Collaboratory partners MSI, University of Colorado, and San Juan Public Lands Center are beginning a climate change adaptation and carbon cycle management project on the San Juan Public Lands. It specifically addresses the need to include climate change in long-term Forest Service and BLM Planning, the likelihood that assessment of climate change impacts becomes part of the National Environmental Planning Act (NEPA), and potential future mandates for carbon management. The effort will start with a brief climate change "state of science" report and initial vulnerability/risk assessment to be included in the Forest Plan Revision. The report will be accompanied by general management strategies to prepare for and mitigate harmful effects of climate change.

A series of more intensive, data-rich vulnerability assessments also will be conducted over time. Jason Neff at the University of Colorado will be using high-resolution climate projections developed by the National Center for Atmospheric Research (NCAR), assessing their capability for SW Colorado, and then conducting a vulnerability assessment for changes in soil moisture deficit. Additional vulnerability assessments, including changes in wildfire risk, stream flow, vegetation communities, and wildlife habitat will be developed from the high-resolution climate projections as funding becomes available. The project will also develop a baseline carbon inventory and management/monitoring plan. This part of the project will address the increasing need to understand the amount of carbon stored and released from land management activities. Future markets for carbon offsets include consideration of land management.



Aspen regeneration after fire. (Photo by K. Nydick)

Filling Data Gaps

The process of convening scientists and stakeholders also identified many data gaps for which we do not have observations or process understanding to make assessments with high (or even moderate) certainty. A partial list of recommended studies is included in Box 2. While much information is currently lacking,

BOX 2
Stakeholder questions: What do we need to know?

- How will geography of human populations, home buying, recreation, and tourism be affected?
- Will snow recreation season be as long? As much snow? Longer than others? What elevations and locations are more at risk for losing snow?
- What is the impact of "green business" on clients' willingness to buy?
- Is it possible to do selective thinning to increase snow yield and water storage at ski areas?
- How long will growing season be in 2-4 decades?
- How will changing temperatures affect energy use and seasonal demand? How will solar and wind potential change for energy sources?
- How do different ecosystems respond to climate change, and how does their location or elevation correlate with the change that we are seeing? How will altitudinal shifts of various components of systems change the mix of species, and possibly extirpate some species? What species and ecosystems are most vulnerable? Which are most valuable? Which can we conserve by management actions?
- Which climate variables are important to species? Water, extreme heat, life cycles, etc? Can we develop scenarios and models to understand which direction the landscapes might head with changes in climate and management practices?
- How do we work with communities and residents to explain that ecosystems change and not expect them to be held stable as they have been? Education tools to tell the story of changes climate change would bring. Need to translate what +1ºF means to people, communities, and resources. What will biodiversity changes mean to people?
- Can we get better local information about weather and forecasting for site-specific controlled burns? Planning of agricultural crops?
- What is the expected rate of change – gradual versus catastrophic? What are the thresholds?
- What new pests or exotic species will migrate north? What new controls can help with pest issues? How do we increase resilience of ecosystems?
- How will climate shifts affect pollinators?
- Can we increase water storage in the soil for agriculture?
- How do we encourage adaptability in farming and ranching? How do we increase the local market to support local agriculture? Market studies to identify the needs? How do we gain support or subsidize?
- Which crops are better suited for "resiliency" in the face of climate change? Are there ways to increase "real time" response to climate change to be able to change which crops are planted in response to real-time weather patterns?
- Can we shift farming to other lands or crops that are more supportive of farming practices as climate changes?
- How can we mitigate increasing credit risk, as climate variability and extreme events increase?
- How will wildfire cycles change over space and time? How will different forest types and elevations be affected? Change in duration and intensity? Could large fires effectively alter or prevent the monsoon season? How should we manage fires in the wildland-urban interface? How much will fire mitigation and firefighting costs increase?
- If forests are changing, what are we restoring if the landscape is on a trajectory of change?
- How will changes to species affect recreation?
- How will changes in magnitude and timing of flooding affect ecosystems, species, and people?

the SJCI is moving ahead with the planning effort while at the same time being opportunistic about starting or supporting needed research and promoting the efforts of partner organizations. For example, MSI has provided seed funding to projects via its mini-grant program. Climate change-related investigations in the San Juans include:

- Analysis of 100 years of climate records for the San Juan Mountains – Imtiaz Rangwala, Rutgers University, MSI mini-grant
- Small mammal monitoring along elevational gradient – Christy McCain, Univ. Colorado, MSI mini-grant
- Pika distribution and climate – Liesel Peterson, Univ. Colorado, MSI mini-grant
- "GLORIA" alpine vegetation and soil temperature monitoring – Koren Nydick, MSI
- Mountain system climate monitoring on Red Mountain Pass – Center for Snow and Avalanche Studies (CSAS)
- Dust on snow research: earlier snowmelt – Tom Painter, Univ. Utah; Chris Landry, CSAS; Jason Neff, Univ. Colorado
- Effects of early snowmelt on alpine plant phenology – Heidi Steltzer, Colorado State Univ.
- Long-term monitoring of fen hydro-ecology and response to annual and seasonal climate variability – David Cooper, Colorado State Univ.; Rod Chimner, Michigan Tech Univ.

Where to Go From Here

The SJCI started as an idea without funding and is now on a trajectory to provide needed information on likely future conditions and vulnerability, which will allow informed strategies and practices to be developed and implemented. Working with partners—including both scientists and stakeholders—will continue to be the only way to meet our goals. Funding remains a challenge, but our partnerships have opened up new sources of support. We encourage new collaborators.

2008 AGU Cryosphere Young Investigator Award: Jessica Lundquist

Anne Nolin
Department of Geosciences, Oregon State University, Corvallis, Oregon

Dr. Jessica Lundquist was selected for the 2008 Cryosphere Young Investigator Award based on her innovative contributions to cryospheric research. Jessica has demonstrated the ability to independently address critical questions in cryosphere science and link the results of her research both within and beyond the broader cryosphere community.

Jessica graduated from the Scripps Institution of Oceanography, University of California-San Diego in 2004 and has already generated an impressive list of journal articles published in several of the highest impact journals in snow science and hydroclimatology. She has demonstrated excellence in field techniques, introducing the snow hydrology community to the value of small temperature sensors for characterizing snow processes in mountain regions. In addition to her creativity, independence, and excellence in research, Jessica demonstrates maturity and collegiality making her a highly valued colleague in mountain research. Notable contributions by Dr. Lundquist include:

1. Identifying the importance of snowpack spatial heterogeneity to streamflow patterns in the California Sierra Nevada;
2. Developing new field techniques for monitoring snow cover and temperature in topographically complex environments;
3. Demonstrating how earlier snowmelt due to climate warming will result in very different patterns of snowmelt because of differences in sun angle;
4. Developing a spatial model to explicitly account for cold air pooling, and;
5. Engaging in important cross-disciplinary research that promotes the important role of the mountain snowpacks in climate, hydrology, atmospheric science, and ecology.

Jessica was nominated by Jeff Dozier (University of California, Santa Barbara), with supporting letters from Connie Millar (USFS Sierra Nevada Research Center) and Steve Burges (University of Washington). Jeff presented the award to Jessica prior to the delivery of the Nye Lecture on Cryosphere at the Fall 2008 American Geophysical Science Meeting in San Francisco.

A Sample of Jessica's Publications

Lundquist, J. D. and J. Roche, Climate change and water supply in western national parks. Park Science, invited paper for special issue, accepted March 2008, in press.

Lundquist, J. D., P. J. Neiman, B. Martner, A. B. White, D. J. Gottas, and F. M. Ralph, 2008. Rain versus snow in the Sierra Nevada, California: Comparing radar and surface observations of melting level. J. Hydrometeorology, 9, 194-211.

Neiman, P. J., F. M. Ralph, G. A. Wick, J. D. Lundquist, and M. D. Dettinger, 2008. Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the west coast of North America based on eight years of SSM/I satellite observations. J. Hydrometeorology, 9, 22-47.

Lundquist, J. D. and D. R. Cayan, 2007. Surface temperature patterns in complex terrain: daily variations and long-term change in the central Sierra Nevada, California. J. Geophys. Res., 112, D11124, doi:10.1029/2006JD007561.

Lundquist, J. and A. Flint, 2006. Onset of snowmelt and streamflow in 2004 in the Western United States: How shading may affect spring streamflow timing in a warmer world. J. Hydrometeorology, 7, 1199-1217.

Lundquist, J., M. Dettinger, and D. Cayan, 2005. Snow-fed streamflow timing at different basin scales: Case study of the Tuolumne River above Hetch Hetchy, Yosemite, California. Water Resour. Res., 41, W07005, doi:10.1029/2004WR003933.

Lundquist, J. and M. Dettinger, 2005. How snowpack heterogeneity affects diurnal streamflow timing. Water Resour. Res., 41, W05007, doi:10.1029/2004WR0003649.

Lundquist, J., D. Cayan, and M. Dettinger, 2004. Spring onset in the Sierra Nevada: When is snowmelt independent of elevation? J. Hydrometeorology, 5, 325-340. **Paper selected to receive Wagner Memorial Award for Women in Atmospheric Sciences, 2003.

Lundquist, J.D., D.R. Cayan and M.D. Dettinger, 2003. Meteorology and hydrology in Yosemite National Park: A sensor network application. In Information Processing in Sensor Networks, F. Zhao and L. Guibas (eds.): IPSN 2003, LNCS 2634, 518-528.

Lundquist, J. and D. Cayan, 2002. Seasonal and spatial patterns in diurnal cycles in streamflow in the Western United States. J. Hydromet., 3, 591-603. **Featured as Paper of Note in Bulletin of the American Meteorological Society, January 2003.

An Interview with Jessica Lundquist on October 21, 2008
by Connie Millar

Connie: Let's start with an easy one: What are your current science interests?

Jessica: *Mountains! Mountains have always been my passion—they were when I was a child, they are now, and I'm sure will be in my future. Temperate mountains. Snow, ice, and water. Climate is the great integrator—the umbrella that holds mountain processes together. I am interested more in process than climate per se, and am obsessed with spatial and temporal patterns. For example, it is not average temperature that is meaningful for ecosystems but the ranges, extremes, and variation over space and time. I'm interested in dynamics that have a fractal nature, for instance CAP (cold-air pooling), snowmelt, and snow depth. I'm especially interested in studying these micro- and meso-processes because this is where management and conservation actions can have effect. But to understand processes at that level, we have to realize you can't just downscale from the macroscopic and understand the local.*

Connie: What do you consider your most important research contribution?

Jessica: *Getting people to hang [climate] sensors in trees! It is so easy and inexpensive, and we have learned so much from this opportunistically. I try to model to my students that you can make important discoveries using cheap and simple equipment if you use high-powered and sophisticated analyses. With simple and cheap instruments, you can afford to be wrong and you can afford to risk testing hypotheses that might not be popular but might actually be right.*

I am proud of the research I have done with colleagues on snowmelt synchrony, as I believe it is an example of a process that was not expected from our knowledge of broader landscape scales.

Connie: Where would you like to steer your career in coming years?

Jessica: *I'm excited to embark on research studying spatial patterns of precipitation at local scales. This is much, much harder to do than temperature because of the challenge of accurately measuring precipitation. With my student Mark Raleigh, I am having fun figuring methods to use inexpensive mini-temperature sensors (e.g., iButtons) in combinations of air and ground locations and to develop a proxy for snowpack level. I'm currently verifying my first trial of this against snowpillow records and generally these are within about 10% accuracy. I will present this work at AGU in Dec 2008 [invited presentation in CIRMOUNT session, now past], and this will be the focus of Mark's Master's thesis.*

Connie: How did you get interested in being a research scientist and in studying snow and ice (and mountains)?

Jessica: *I didn't mean to be a scientist at all. I wanted to grow up and be like John Muir and write natural-history stories. I wanted to be a park ranger, live in Yosemite National Park, and write stories. My family camped in Tuolumne every summer since I was seven years old. While still in high school I started work-*

ing in Tuolumne as a park interpretation intern. Then I got very sick and for years I was not able to be at high-elevation at all. What was I to do? I went back to school in oceanography—and through that took all the hard-core math and physics classes. I found that I was really good with numbers, and by then I was really interested in science! And, I was slowly able to return to the mountains. I saw a picture of Dan [Cayan] and Mike [Dettinger] working in Yosemite in a Scripps magazine, and said to myself, "I want to work for them!" What happened after that was history and I came full circle back to my beloved Tuolumne Meadows. Those four years when I was sick taught me to be very careful, and to count each day as a blessing.

Connie: What advice do you give aspiring cryosphere graduate students?

Jessica: *Find your passion and stay with it. You have to be excited about your work because there will be many days when things are painful. What keeps me going at those times? I look at numbers on my screen and see waterfalls or meadows.*

I tell my graduate students not to be afraid of hypotheses that are outside the box. I was very lucky to have had considerable freedom during my own graduate career. I was supported by colleagues and advisors who recognized the importance of creative experimentation. I tell my students to collect data—lots of data—to measure, measure, measure, and to be willing to use simple, quick & dirty approaches. Also, don't hold onto your original ideas too dearly—I found that all my initial hypotheses were totally wrong.

News from the Mountain Research Initiative (MRI)

MRI invited the MIREN collaborators to introduce their organization in the first Newsletter of the Mountain Research Initiative, which has appeared in September 2008. Like the Mountain Research Initiative, MIREN is a research network, which aims at supporting mountain ecosystem managers through problem-oriented research. This summary for the Mountain Views Newsletter was updated by Christoph Kueffer and coauthors in December 2008.

The Mountain Invasion Research Network (MIREN)—a boundary organization bridging research and management for addressing plant invasions in mountains

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Introduction

As a result of global change invasive non-native plants increasingly may threaten mountain areas. The Mountain Invasion Research Network (MIREN, www.miren.ethz.ch), launched in 2005, initiates and integrates surveys, monitoring, experimental research, and management of plant invasions into mountains at a global scale (Dietz et al. 2006). MIREN is associated with the Mountain Research Initiative (MRI), the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT, http://www.fs.fed.us/psw/cirmount/), and the Global Mountain Biodiversity Assessment (GMBA, http://www.gmba.unibas.ch/index/index.htm), one of the 4 transversal networks of DIVERSITAS. The MIREN core research program includes 6 mountain regions (Pacific Northwest [USA], Swiss Alps, Chilean Andes, Australian Alps, Hawaii, and the Canary Islands [Spain]), covering the major climatic zones and including island and continental systems. All core areas participate in standardized monitoring of non-native plant distributions and demography, and comparative experiments. Beyond the core program, MIREN networks researchers and managers in an extensive set of mountain regions and thereby functions as a boundary organization bridging research and management for addressing plant invasions in mountains (compare Kueffer & Hirsch Hadorn 2008).

MIREN reviews, integrates and advances knowledge on plant invasions, uses elevational gradients in mountains as a model system for global change ecology, and promotes proactive approaches to managing potential future risks of plant invasions into mountains. The following sections briefly illustrate each of the three pillars of MIREN and give some current developments.

1. *Towards a conceptual framework for understanding and predicting plant invasions into mountain ecosystems*

In 2005, a special issue of Perspectives in Plant Ecology, Evolution and Systematics on plant invasions into mountains (Vol 7 No 3) brought together 6 articles showing that non-native plants are present in mountain ecosystems around the world, but that the distribution patterns and impacts along elevation gradients differ between regions. In an upcoming article of the journal Frontiers in Ecology and the Environment (Pauchard et al. in press), we present a conceptual framework for understanding these differences and more generally plant invasion into mountains. Although factors determining plant invasions into high elevations are the same as in other ecosystems, the manner by which they influence the outcome of invasions changes in mountains because of the extreme conditions. Harsh climatic conditions, isolation and limited human pressure have made mountain ecosystems relatively resistant to plant invasions. However, this situation may start changing as species adapt to colder and harsher environments, as the climate changes, and as human pressures expand into mountainous environments, making mountain ecosystems as susceptible to invasions as other historically invaded areas.

2. *Mountains as model system for global change ecology*

MIREN believes that due to steep environmental gradients over small spatial scales, mountainous regions provide particularly useful model systems for understanding ecological and evolutionary processes associated with plant inva-

Figure 1: Hieracium aurantiacum infestation (in flower) in Kosciuszko National Park, Australia. This species has the capacity to invade undisturbed vegetation and quickly attain dominance. The site shown was searched two years prior to the photograph and no Hieracium was detected (photo by Keith McDougall).

sions. As most non-native plant species reach their distribution limit at some point along these gradients, mountains provide the opportunity to study processes at the invasion front. This can help to disentangle the relative contributions of propagule pressure (i.e. input of seeds or other types of propagules to a site), biotic interactions, phenotypic plasticity and local adaptation as limiting factors of invasions. At the Ecology and Management of Alien Plant Invasions (EMAPi) 10 meeting in August 2009 in Stellenbosch, South Africa Aníbal Pauchard and José Ramon Arevalo (MIREN) will chair a session where the value of mountains as a model system for invasion biology will be discussed with a broader audience of researchers.

A particularly promising approach is to make reciprocal comparisons of mountain regions, using species native to one region but invasive in the other, and vice versa. In a recent study, Alexander et al. (accepted) compared patterns of trait variation in natural populations of eight Asteraceae species along altitudinal gradients in the Wallowa Mountains, Oregon (USA) and the southern Swiss Alps. Four of the species were native to North America and four to Eurasia, and all were present in both study areas. Despite having been introduced to these regions only within the last 200 years, all species had similar altitudinal ranges and showed parallel clines in plant height, capitulum (flower head) number and seed size. These results indicate that the need to respond to altitudinal gradients, possibly by local adaptation, has not limited the ability of these species to invade mountain regions. However, the authors also found differences in patterns of resource allocation to capitula among species in the native and the introduced areas. These suggest that the mechanisms underlying trait variation, for example increasing seed size with altitude, might differ between ranges.

3. *A proactive approach for managing potential future risks of plant invasions into mountains*

At the recent annual meeting of MIREN, held in Australia at Kosciuszko National Park, a Mountain Biosphere Reserve, priorities for control of invasive species in mountains were discussed with park managers. The meeting was timely because Australian park managers face a significant threat to mountain biodiversity in the form of a recent invasion and rapid spread of two Hawkweed species (Hieracium aurantiacum and H. prealtum; see Figure 1). Dr. Peter Espie gave a graphic account of the New Zealand experience with Hawkweeds, which now cover several million ha of grazing land and natural vegetation in montane areas. Land managers in Australia are now working with researchers to understand the invasion process for hawkweeds and respond quickly to eradicate these threats in the Australian Alps.

The emergence of the Hawkweeds as a threat in Australia is typical of a global change in invasion patterns in mountains. A review of mountain invasions by MIREN (McDougall et al., in prep.) has identified almost 1500 plant taxa worldwide that are naturalized or invasive in mountain areas.

Figure 2: Globally, the most widespread mountain plant invaders to date are species typical of European pastures (e.g. grasses, Trifolium spp., Verbascum thapsus), which were probably introduced during an early phase of livestock grazing in many mountain regions. The picture shows a pasture in the native range of these species in the Swiss Alps (photo by Tim Seipel).

Far from being resistant to invasion as commonly thought, mountains are home to a large number of non-native plant species. More than half the taxa are confined to a single mountain region suggesting that all regions can expect further invasions. The most widespread mountain plant invaders are species typical of European pastures (e.g. Holcus lanatus, Rumex acetosella, Trifolium repens, compare Figure 2), which were probably introduced during the past few hundreds years for livestock grazing in many mountain regions. These species appear to have had relatively little impact on local biodiversity. Some invaders (e.g. Hieracium spp., Cytisus spp., Salix spp.), however, have appeared recently, as mountain land use has shifted in many regions from agriculture to tourism. These species have often been selected for the cold adaptation and now pose an important threat to biodiversity. This threat is likely to grow as tourism expands and global warming allows invaders to reach higher altitudes.

Prevention is widely considered the most cost-efficient management strategy against the threat posed by invasive non-native species. Mountains are one of very few ecosystems not yet badly affected by plant invasions. In mountains, therefore, invasive species researchers and managers have the unique opportunity to respond in time to the threat by preventing invasions before they are actually happening. MIREN is therefore researching and promoting efficient implementation of proactive measures, such as restricting the transport of likely invasive species into mountain areas and early detection searches, to prevent invasions before they become another major threat of vulnerable mountain ecosystems.

References

Alexander, J.M., Edwards, P.J., Poll, M., Parks, C.G., & Dietz, H., accepted.

Establishment of parallel altitudinal clines in traits of native and introduced forbs. Ecology.

Dietz, H., Kueffer, C., & Parks, C.G., 2006. MIREN: A new research network concerned with plant invasion into mountain areas. Mountain Research and Development 26: 80-81.

Kueffer, C., & Hirsch Hadorn, G., 2008. How to achieve effectiveness in problem-oriented landscape research: The example of research on biotic invasions. Living Reviews in Landscape Research 2: 2. http://www.livingreviews.org/lrlr-2008-2

Pauchard, A., Kueffer, C., Dietz, H., Daehler, C.C., Alexander, J., Edwards, P.J., Arévalo, J.R., Cavieres, L., Guisan, A., Haider, S., Jakobs, G., McDougall, K., Millar, C.I., Naylor, B.J., Parks, C.G., Rew, L.J., & Seipel, T. (2009) Ain't no mountain high enough: Plant invasions reaching new elevations. Frontiers in Ecology and the Environment, in press, doi:10.1890/080072.

Meeting Summary

Mountain Climate Conference Co-Sponsored by CIRMOUNT in Bishop, California "Climate, Ecosystems, and Resources of Eastern California"

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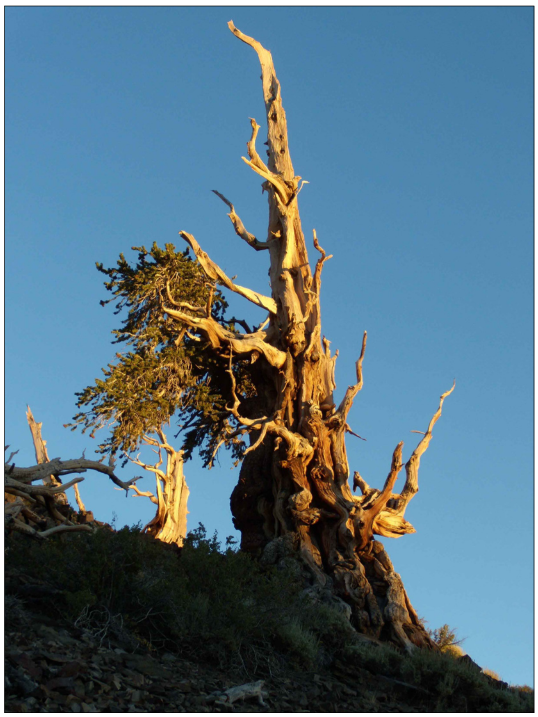

CIRMOUNT joined with the White Mountain Research Station as primary sponsors of the "Climate, Ecosystems, and Resources of Eastern California" Conference (CEREC) held at the Tri-County Fairgrounds in Bishop, California, November 5-8, 2008. Focused on the eastern Sierra Nevada, White Mountains and adjacent ecoregions, the meeting addressed basic science issues of complex climatic changes, effects on ecosystems, and options for resource conservation and management in light of changing climates. Environments and resources of the eastern Sierra Nevada region support key ecosystem services that fuel local economies and also provide critical resources to distant metropolitan areas. Effects of climate change already have influenced water management, ski-industry, biodiversity conservation, agriculture and ranching, and forest health and wildfire, creating strong incentives for greater knowledge about future effects. The region is unusual for its abundance of scientific activity and has for decades been the focus of many research studies relating to climate.

The conference offered an opportunity for these scientists to network among each other and with resource managers and conservationists. CEREC talks and posters addressed questions of broad interest to this audience, including: What form is climate change taking in this region? What is and will be the nature of ecosystem responses to climate change? How are particular plant and animal species responding? How are ecosystem changes affecting services on which local and distant economies depends? How can resource managers and local governments proactively address these changes and develop effective adaptation strategies?

Participation at this conference was record-breaking, and scientists, managers, and policy makers came away bolstered in new understanding and awed at the depth and breadth of ongoing research activity in the region. Over 200 participants presented nearly100 talks during the three-day-conference. Overview plenary sessions with distinguished invited speakers began each day. These sessions focused on physical changes, including climate, addressed by Dan Cayan (UC Scripps Institution), water, by Jessica Lundquist (University of Washington), and glaciers, by Doug Clark (Western Washington University); ecosystem responses to climate change, with review of the Grinnell mammal resurveys by Steven Beissinger (University of California Berkeley), subalpine forests by Malcolm Hughes (University of Arizona), and plant physiology and snowpack by Michael Loik (University of California Santa Cruz); and management responses, including a paleohistoric perspective from Robin Tausch (USFS, Rocky Mtn Research Stn), adaptive management challenges from Peter Stine (USFS, Sierra Nevada Research Center), and strategic approaches of the National Park Service by Leigh Welling (NPS). A sampler of conclusions from these talks is in Box 1.

David Nahai, CEO and General Director of the Los Angeles Department of Water and Power (DWP), delivered a public keynote lecture in which he addressed key energy conservation commitments and strategies that DWP is adopting to reduce carbon footprints. Scott Stine, Professor of Geography, California

BOX 1
Highlights from the CEREC Plenary Sessions

- "Recent IPCC model projections for western precipitation are scattered, but several show moderate drying as tends to be characteristic of Mediterranean regions globally. A reduction in precipitation is amplified into even greater reduction in soil moisture and runoff in the more arid basins of the West" (Dan Cayan).
- "Ecological shifts are likely sensitive to the end of the growing season, when water runs out; correctly modeling late season water supplies depends on correctly simulating snow heterogeneity in a watershed" (Jessica Lundquist).
- "The Little Ice Age (~700 to 100 years before present) was the coldest period of the past ~10,000 years in the Sierra Nevada; greater advances (coldest temperatures) were ~15-200 years ago; no glaciers existed in the Sierra Nevada from ~ 10,000 to 3,200 years ago" (Doug Clark).
- "For 28 mammal species resurveyed from the Grinnell studies of the early 20th century, closely related and ecologically similar species responded idiosyncratically; Life Zone was the best indicator of shifts in lower elevation limits; Life Zone, Longevity, and Litter Size were the best indicators of shifts in upper elevation limits" (Steve Beissinger).
- "Bristlecone pine (*Pinus longaeva*) trees within 150 vertical meters of their upper limit showed ring growth in the second half of the 20th century greater than for any 50 years in at least the last 3700 years. Rising temperatures at these elevations played a major role in this" (Malcolm Hughes).
- "Soil moisture varies as a function of year, time since snow melt, and snow depth; snow depth affects species composition, soil properties, and tree growth; interactions between species may feedback on responses to snow climate change. Climate models need to more realistically capture local and regional climate patterns to generate better scenarios for planning and management" (Mike Loik).
- "The patterns and rates of change in Great Basin piñon-juniper woodlands over the last 150 years provide an example of the speed and landscape scales at which climate and human driven changes in environmental conditions can drive landscape scale ecosystem changes. The major challenge for management is that, combined with the increasing presence of exotics, these climate and environmentally driven changes can result in permanent alteration of the affected ecosystems" (Robin Tausch)
- "Examples of silvicultural practices for maintaining resiliency include: thinning to avoid overstocked stands susceptible to increased mortality from drought, insects, disease and wildlife; underplant thinned stands with adapted species or genotypes when advanced regeneration is unacceptable for future conditions; provide structural diversity at stand and landscape scales; promote development of mixed-species and mulit-provenance forests" (Peter Stine).
- "An adaptation framework for climate best identifies opportunities for partnerships among decision makers, scientists, and topic experts, and includes the following steps: Frame the problem (all); identify key drivers (scientists); identify internal dynamics (scientists); develop scenarios (all); test and refine the scenarios (scientists); develop policy and plans (decision makers); and track progress (all)" (Leigh Welling).

State University, East Bay, presented a second keynote lecture in which he elaborated new insights on climate relations involved in formation of tufa in the playa lakes of the Great Basin.

A total of eighteen concurrent sessions with invited and contributed talks followed the morning plenary sessions and focused on research updates and new insights into climatic variability; hydroclimatic challenges; glacial and periglacial processes; alpine plant community and subalpine forest implications of changing climate; amphibian and aquatic ecosystem responses; terrestrial wildlife responses; climate & ecosystem feedbacks and National Park, Wilderness, and NGO management for climate. Poster presentations addressed many of these themes as well.

The catalytic effect of the CEREC conference is being felt in new research projects and management actions initiated in the region. The General Management Plan under development for Devils Postpile National Monument, for instance, is centered on climate issues, and proposes the Monument to serve as a biodiversity refugium park as climates change. As another example, an agreement was made following the CEREC conference for the Inyo National Forest to become a formal climate case study in the USFS-USGS Westwide Climate Toolkit Project. New alpine plant monitoring for climate change under the North American GLORIA (Global Observation Research Initiative in Alpine Regions) project has been proposed as a result of networking at CEREC. A telling sign of the success of CEREC was the unanimous request at its conclusion for a repeat conference to be held in the region within a few years. An article about this meeting was published in *Moonshine Ink* by Terray Sylvester, which can be found at: http://www.moonshineink.com/articles.php/58/1062.

In addition to CIRMOUNT and the White Mountain Research Station, sponsors for CEREC included the USFS Pacific Southwest Research Station, University of California Sierra Nevada Aquatic Research Lab, National Park Service Pacific Region and Great Basin Cooperative Ecosystem Studies Unit, USGS Western Ecological Research Center, and Mammoth Mountain Ski Area. CEREC was co-convened as the Fifth White Mountain Research Station Symposium. For more information about CEREC, visit the CEREC website, where archives of abstracts and presentations may be found. Questions may also be directed to John Smiley (UC WMRS), jsmiley at ucsd.edu or Connie Millar (USFS), cmillar at fs.fed.us.

CEREC Information, List of Attendees, and Archive of Abstracts and Presentations at: http://www.wmrs.edu/projects/CEREC/

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